Ownership of intellectual property and corporate taxation

Rachel Griffith [a,b,*], Helen Miller [a,*], Martin O'Connell [a,c,*]

[a] Institute for Fiscal Studies, United Kingdom
[b] University of Manchester, United Kingdom
[c] University College London, United Kingdom

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ABSTRACT

Intellectual property accounts for a growing share of firms' assets. It is more mobile than other forms of capital, and could be used by firms to shift income offshore and to reduce their corporate income tax liability. We consider how influential corporate income taxes are in determining where firms choose to legally own intellectual property. We estimate a mixed (or random coefficients) logit model that incorporates important observed and unobserved heterogeneity in firms' location choices. We obtain estimates of the full set of location specific tax elasticities and conduct ex ante analysis of how the location of ownership of intellectual property will respond to changes in tax policy. We find that recent reforms that give preferential tax treatment to income arising from patents are likely to have significant effects on the location of ownership of new intellectual property, and could lead to substantial reductions in tax revenue.

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1. Introduction

The growing importance of intellectual property as a factor in production,[1] and concern that it is easier for firms to shift income from this source than it is from others, presents challenges for tax design. Firms can and do position their intellectual property with a view to reducing tax liabilities. However, despite these concerns, firms do not by and large locate the legal ownership of intellectual property in the lowest tax countries, and corporate income taxes still raise considerable amounts of revenue in most developed countries. In this paper we address the question of how influential corporate income taxes are in determining where firms choose to legally register ownership of an important form of intangible assets, patents.

Our contribution is to extend the empirical literature on public policy and firm location choice by introducing new methods to this area of public economics. We estimate a mixed (or random coefficients) logit model that incorporates both observed and unobserved

heterogeneity in firms' location choices (see inter alia, Berry et al. (1995, 2004), Nevo (2001) and Train (2003)). A key strength of this approach is that it allows us to compute own and cross tax elasticities across locations that reflect patterns of correlation in observed choices in the data, and therefore to capture more realistic substitution patterns than standard logit models. Our estimates allow us to conduct ex ante analysis of how the location of ownership of intellectual property will respond to changes in policy. We use our estimates to simulate responses to recent policy reforms that provide preferential tax treatment to income arising from patents. We find that these reforms are likely to have significant effects on the location of ownership of new intellectual property, and could lead to substantial reductions in tax revenue. Our estimates could be used to simulate a wide range of other counterfactual situations.

We use comprehensive panel data on all patent applications made to the European Patent Office (EPO) by a large number of innovative European firms over 1985–2005. A patent is a legal document that grants a firm the exclusive rights to use or licence a novel technology for a specified period of time. A firm can register legal ownership of a patent in a subsidiary that is located in a country different to the firm's headquarters, different to the location where the underlying technology was created and different to the location where the intellectual property will be applied. Lipsey (2010) notes that, in multinational firms, intangible assets "*have no clear geographical location, but only a nominal location determined by the parent company's tax or legal strategies.*" For example,
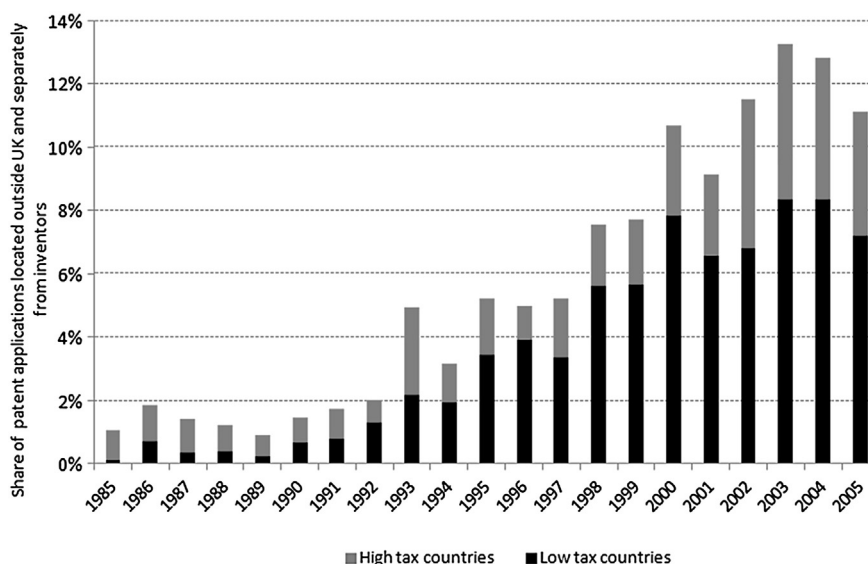
Fig. 1. Share of patent applications made by subsidiaries of UK parent firms that are located offshore and separately from innovative activity. Notes: The bars show the share of total patent applications made by subsidiaries of UK parent firms where the subsidiary is located outside of the UK, and is not in a country where associated innovative activity was carried out. Low (high) tax countries are defined as those locations that have a statutory tax rate less (greater) than the UK.

Fig. 1 shows the share of patent applications made by UK parent firms where the legal ownership is registered outside of the UK and in a separate place to where the underlying innovative activity occurred. This share has increased six-fold over the past two decades. The largest proportion has gone to countries that have a lower tax rate than the UK, but the amount going to countries with a higher tax rate has also increased.

We model the impact of tax on where firms choose to locate the legal ownership of patents. Tax could influence this decision because the legal ownership of the patent will be one of the determinants of where the income derived from the patent is taxed. The profits earned from the exploitation of intellectual property will be the result of a number of activities, including the research and development (R&D) investment undertaken to create the new idea, the financing of this investment and the subsequent commercialisation. When these activities take place in multiple countries, as is often the case for multinational firms, the returns must be allocated to individual jurisdictions for tax purposes.

Firms have an incentive to arrange their activities in such a way that, all else equal, profits accrue in the country in which they would pay the lowest tax. There are a number of strategies that can be used to achieve this. Such strategies commonly require that the income earned from exploiting intellectual property accrues outside of the country in which the underlying R&D took place. One way to achieve this is through contract R&D. For example, a subsidiary in a relatively low tax country may finance (and bear the risk for) R&D activities that are contracted to a related subsidiary in a higher tax country (possibly with the benefit of R&D tax incentives and access to high skills levels). The contract will specify the payment to be made for the R&D activities (commonly equal to the costs incurred plus an arm's length mark-up). Returns above this payment, either from using the technology directly or from licensing it, will accrue to the subsidiary that bore the financial risk. There is a tax advantage to this strategy if the true value of the R&D activities is less than the price paid for the contract R&D. A similar result may be achieved through the use of a cost sharing agreement that specifies how subsidiaries will share the costs, risks and returns associated with an R&D project. Such agreements may be designed such that the right to exploit and capture the returns from a technology accrues to a subsidiary in a low tax country. The strategies available to a firm depend on how the firm is organised and on the precise tax rules they are subject to (Finnerty et al. (2007)).

Tax rules limit a firm's ability to manipulate where income arises for tax purposes. Shifting income typically requires that payments made to compensate the company that conducts the R&D, or royalties made for the use of a technology, are at preferential prices. There are transfer pricing rules that aim to enforce the principle that the prices of intra-firm transactions are set as if they had occurred between unrelated parties — this is the arm's length principle. However, these transactions often do not have market counterparts, which means that firms may have opportunities to set the prices of related transactions in such a way as to reduce tax liability.[2] Tax rules, including those that dictate how a firm can allocate the returns to innovative activities, differ across European countries and are different to those faced by US multinationals. For example, countries differ on the acceptable methods used to calculate payments for contracted R&D services, and where there are cost sharing agreements, countries differ in the requirements over whether all subsidiaries involved in the agreement need be engaged in R&D (in contrast to the US, not all European countries allow holding companies in low tax locations to be part of cost sharing agreements).

The corporate tax rate is likely to be an important determinant of the location in which a firm chooses to hold legal ownership of intellectual property. However, it is unlikely to be the only factor; we would not expect all intellectual property to be legally registered in the lowest tax countries. Indeed, legal ownership of patents is rarely in the set of small countries that are often considered to be tax havens. The patents that are legally owned in such countries accounted for fewer than 0.5% of all patent applications made to the European Patent Office over the period 2001–2005, and many of those are unrelated to European firms.[3] This could be due, at least in part, to the operation of Controlled Foreign Company (CFC) regimes, which effectively seeks to tax income at the higher home country tax rate if it is deemed to be located in a low tax country for tax purposes. More generally, there may be characteristics of a location over and above its corporate tax rate that firms value. For example, the strength of intellectual property rights protection and market size might play a role, and, all else equal, firms may

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[2] When determining the correct transfer price there are both conceptual difficulties — it can be hard to separately determine the value that arises from integrated activities that take place across countries, and practical difficulties — firms have more information than tax authorities and an incentive to minimise their tax liability.

[3] Figure based on patent applications made by applicants located in Bahamas, Barbados, Bermuda, Cayman Islands, Gibraltar, Hong Kong, Liechtenstein, Malta, Monaco, Netherlands Antilles, Panama or Singapore.

be more likely to co-locate ownership of intellectual property with associated real innovative activity due to externalities from co-location.

There is likely to be a large degree of heterogeneity in how responsive firms are to tax when deciding where to locate the legal ownership of their intellectual property; a number of papers have emphasised the importance of incorporating heterogeneity in firms' decisions (Melitz (2003), Bernard et al. (2007a, 2007b), Krautheim and Schmidt-Eisenlohr (2011)). This heterogeneity will arise for a number of reasons, some of which relate to observable factors, and others that relate to factors unobserved by the econometrician. For example, firms are likely to be more sensitive to tax when choosing the location in which to legally own patents with a relatively high expected value (Becker and Fuest (2007), Bohm et al. (2012)). Firms are also likely to be differentially responsive to tax due to differences in their organisational structures. Their existing network of subsidiaries, the proficiency of their tax department and the tax strategies they are able to employ for managing income from intellectual property will play a role. Firms with headquarters in different countries might respond differently if countries differ in the stringency of their tax rules and in the effectiveness with which they are applied. Firms operating in some markets or using certain technologies might respond differently, because, for example, transfer pricing rules may be easier to circumvent for firms operating in markets where a high share of transactions are intra-firm meaning it is difficult for tax authorities to accurately assess what is a fair market price. Both firm size and industry have been highlighted as important in the context of firm decision making over how to organise offshore activities (Graham and Tucker (2006) and Desai et al. (2006)). Indeed, the value of a patent, the relative attractiveness of a location and a firm's strategies and organisational structures are likely to vary across industries and, within industries, across firms.

Our work relates to several papers in the literature. Most closely related, Dischinger and Riedel (2011) and Karkinsky and Riedel (2012) estimate the relationship between corporate tax and, respectively, the quantity of intangible assets and the number of patent applications made by subsidiaries located in each of a number of European countries. Also related is Ernst and Spengel (2011) who estimate the impact of R&D tax incentives and corporate tax on patenting. In common with these papers, we are interested in the relationship between corporate tax and where firms choose to locate intellectual property. We extend this literature by estimating a choice model that allows us to compute the full set of own tax and cross tax elasticities and which allows us to carry out ex ante analysis of how location decisions will respond to potential policy changes. Our work is also related to Cohen (2012), which uses a discrete choice framework to study how the design of US state tax rules influence US firms' decisions over in which state to incorporate.

There is a considerable literature in the Hall and Jorgenson (1967) tradition that considers the impact of taxes on production activity and on the location of R&D. Hines (1996, 1999) and Devereux (2006) provide surveys of the empirical literature. This literature finds that, despite the many factors that will influence a firm's location decision, tax exerts a significant effect on location choices. Hines and Jaffe (2001) show that tax affects the location of firms' innovative activities within US multinational groups. Most relevant for our analysis, previous work has highlighted the role that intangible assets play in allowing firms to organise their activities with a view to reducing their tax burden (Altshuler and Grubert (2006)). Empirical studies provide indirect evidence of tax avoidance by, for example showing that firms have relatively high profitability in low tax countries (Grubert and Mutti (1991), Hines and Rice (1994)) and that the share of royalty payments associated with low tax countries is higher than expected (Grubert and Mutti (2009)). Grubert (2003) formalises how intangible assets can be used to shift income and finds that about half of the income shifted from high-tax to low-tax countries by US manufacturing firms can be accounted for by income from R&D linked intangibles.

The structure of the paper is as follows. In Section 2 we outline a model of a firm's decision over where to locate the legal ownership of a patent. In Section 3 we describe the data we use to estimate the model. Section 4 presents the estimated coefficients and the tax elasticities between locations. An example of how the model can be used to conduct policy simulations is given in Section 5, where we consider the impact of recent reforms that reduce the tax rate for income derived from patents. A final section summarises and concludes.

2. Firm behaviour

When a firm generates a new idea, it expects to earn a stream of income on the application of that idea in the future. Ideas will vary both in their expected values and in the number of patents they give rise to (some will lead to one patent and some will lead to many). A firm faces the decision over where to initially locate the legal ownership of each patent. It will make this decision based, in part, on the rate of tax that it expects to face on income generated by the use of the patent in the future. Unobserved attributes of ideas are likely to be crucial, and potentially could generate correlations in patent location decisions. The firm will also take account of other characteristics of locations that it may value, for example, whether the real innovative activity associated with that intellectual property is also located there, the potential size of the market (if it also expects to commercialise the idea in that location), intellectual property rights' protection, technological condition, and many other location specific factors, at least some of which are likely to be unobserved by the econometrician. The importance of these location characteristic are likely to vary across ideas. For example, high value ideas may be more tax sensitive and the importance of intellectual property protection may differ across industries.

We develop a tractable empirical model that captures these determinants of location choice.

2.1. Firm payoffs

We specify a model in which a parent firm decides where to locate the legal ownership of each of its patents. Firms, indexed $f = 1,...,F$, realise ideas, indexed $i = 1,...,I$. Ideas are assumed to arise exogenously over time, indexed t. Each idea can yield a single patent or a group of related patents; patents are indexed $p = 1,...,P$. We model the country, indexed $j = 1,...,J$, in which the parent firm decides to locate the legal ownership of each patent, allowing for correlation in decisions between related patents (those that are part of the same idea). We consider all patents taken out by a parent firm that are technologically related in a quarter as part of the same idea; the precise definition of an idea is given in Section 1.

For each patent, the parent firm chooses the location that yields the highest payoff. The payoff the parent firm gets from choosing a location depends on the tax rate it expects to face, τ_{fjt}, the quality of the idea, q_i, whether any research activity that gave rise to the idea is located there, a_{ijt}, the strength of the country's intellectual property rights protection, the size of the local market (measured as GDP), and the level of technological innovativeness (measured as total annual business R&D expenditure as a share of GDP), captured in the vector x_{jt}. Crucially, we also allow location choice to depend on unobserved characteristics of both the idea and the location. We allow the impact of all observed and unobserved factors to vary across medium and large firms and for technologies in different industries; the subscript $r = 1,...,R$ denotes the industry–firm size category an idea belongs to.

We assume the payoff that firm f obtains from placing legal ownership of patent p (belonging to idea i) in location j takes the form,

$$\pi_{pjt} = \alpha_i \tau_{fjt} + \beta_i a_{ijt} + \gamma_r x_{jt} + \xi_{rj} + \epsilon_{pjt}. \tag{1}$$

The parameters α_i and β_i vary across ideas and are functions of both observable and unobservable idea characteristics,

$$\alpha_i = \overline{\alpha}_r + \alpha_r q_i + \sigma_r^\tau \eta_i; \quad \eta_i \sim \mathcal{N}(0,1), \tag{2}$$

$$\beta_i = \overline{\beta}_r + \sigma_r^a \nu_i; \quad \nu_i \sim \mathcal{N}(0,1). \tag{3}$$

We assume that η_i and ν_i are uncorrelated with each other and with the other covariates, and that the additive shock ϵ_{pjt} is distributed iid type I extreme value. ξ_{rj} is a location–industry–firm size fixed effect. The firm chooses option j^* if,

$$\pi_{pj^*t} > \pi_{pjt} \quad \forall \ j \neq j^*. \tag{4}$$

The resulting choice model is a mixed logit with unknown parameters $\left(\overline{\alpha}_r, \alpha_r, \sigma_r^\tau, \overline{\beta}_r, \sigma_r^a, \gamma_r, \xi_{rj}\right)$.

The tax rate τ_{fjt} varies across firms, because the tax system in a firm's residence jurisdiction may interact with the rules of the countries in which it is considering locating ownership of a patent through the operation of Controlled Foreign Company (CFC) rules. We use the tax rate dated t, making the assumption that when a firm chooses the location of a patent it expects that the current tax regime will apply in the future.

The tax parameter, α_i, is at the idea level. We allow it to vary with an observed measure of idea quality, q_i. Patents that are part of a high quality idea are likely to have a higher expected value, and thus their location may be more sensitive to tax. We also allow the idea level tax parameter to include a random term η_i. This captures all components of ideas that determine the responsiveness of location choice to tax and are observed by the parent firm but not by the econometrician. For instance, the quality variable is likely to be an imperfect measure of the expected value of the idea. There could be other factors that are correlated with the idea's expected values, unobserved by us, but available to firms, which will be captured by η_i.

The parameter $\overline{\alpha}_r$ captures the mean marginal effect of tax on the payoff, α_r tells us how this varies with the observed quality of the idea, and σ_r^τ tells us the standard deviation in the effect of tax on the payoff. These parameters all have an r subscript, indicating that we allow both the mean impact of tax on the payoff, and how this varies with both observed quality and unobservables, to vary across industries and across firm size.

Similarly, we model the parameter on real innovative activity, β_i, as an idea level random coefficient; the impact of real innovative activity on the payoff function varies across patents with the random term ν_i. Firms may value locating the legal ownership of intellectual property in the same country as it was created, and the strength of this motive is likely to vary across ideas.

A central assumption of the standard multinomial logit model is that the stochastic error term associated with the payoff from a particular option (in our case the decision to locate ownership of a patent in a particular location) has an iid type I extreme value distribution. This rules out correlation in latent payoffs. This assumption leads to a closed form solution for the location choice probabilities, which is empirically convenient. However, it is restrictive, leading the multinomial logit model to imply restrictive substitution patterns. In particular, the lack of correlation in payoffs endows the model with the independence of irrelevant alternatives (IIA) property.

Random coefficients allow us to relax the assumption of zero correlation in payoffs inherent in the standard multinomial logit model. In particular, we group patents into ideas and allow some of the parameters in the payoff function (those on tax and on real innovative activity) to be idea specific. We model these idea specific preference parameters as random coefficients — which leads to the mixed logit model. An implication of including random coefficients at the level of an idea is that it allows for correlation in the payoffs both

across location options for a given patent, and across patent locating decisions for all patents in a given idea (Train, 2003); the covariance between the payoff of locating patent p in location j and locating another patent p' associated with the same idea in location k is given by: $\text{Cov}(\pi_{pjt}, \pi_{p'kt}) = \sigma_r^\tau \tau_{fjt} \tau_{fkt} + \sigma_r^a a_{ijt} a_{ikt}$. Therefore, although the model still includes an iid type I extreme value term, it also contains other unobservable components that allow for rich correlations, the nature of which is in large part determined by the data (along with the distributional assumptions we make). An important consequence of allowing for such correlations is that the IIA property is not present in the mixed logit model, allowing the model to capture much more flexible substitution patterns (see Berry et al. (1995, 2004), Nevo (2001) and Train (2003)).

We include in x_{jt} a number of time varying location characteristics that firms are likely to value when choosing where to locate the legal ownership of intellectual property. However, there are likely to be other location characteristics that firms value that we do not observe. To capture these we include location–industry–firm size fixed effects, ξ_{rj}. These will control for location specific costs, such as the legal costs associated with setting up a subsidiary, or location specific benefits, such as government provided public goods, the relevance of which might differ for firms of different size or industry.

Note that there may be many other patent, idea or firm specific factors that do not vary across location but that do influence the costs or benefits of a location. However, because these do not vary across location they will not enter the location choice decision, and therefore are not explicitly entered into Eq. (1); including them would lead to an observationally equivalent choice model, because they would drop out when payoff comparisons are made across locations.

2.2. Choice probabilities

The choice model described above implies that the probability that legal ownership of patent p is located in location j, conditional on realisations of the idea specific variables η_i and ν_i, takes the form,

$$\rho_{pjt}(\eta_i, \nu_i) = \frac{e^{(\overline{\alpha}_r + \alpha_r q_i + \sigma_r^\tau \eta_i)\tau_{fjt} + (\overline{\beta}_r + \sigma_r^a \nu_i)a_{ijt} + \gamma_r x_{jt} + \xi_{rj}}}{\sum_k e^{(\overline{\alpha}_r + \alpha_r q_i + \sigma_r^\tau \eta_i)\tau_{fkt} + (\overline{\beta}_r + \sigma_r^a \nu_i)a_{ikt} + \gamma_r x_{kt} + \xi_{rk}}}. \tag{5}$$

The unconditional probability is obtained by integrating out the unobservable idea specific random terms,

$$P_{pjt} = \int \rho_{pjt}(\eta_i, \nu_i)dF(\eta_i, \nu_i). \tag{6}$$

Eq. (6) can be used to compute the impact of marginal changes in tax on location choice probabilities. For instance, the elasticity of the probability that legal ownership of patent p is in location j with respect to a marginal change in the tax rate in location k is given by,

$$e_{pjkt} = \frac{\partial P_{pjt}}{\partial \tau_{ikt}} \frac{\tau_{ikt}}{P_{pjt}} = \int \frac{\partial \rho_{pjt}(\eta_i, \nu_i)}{\partial \tau_{ikt}} dF(\eta_i, \nu_i) \frac{\tau_{ikt}}{\int \rho_{pjt}(\eta_i, \nu_i)dF(\eta_i, \nu_i)}. \tag{7}$$

We compute the elasticity of the share of patents with legal ownership in location j with respect to the statutory tax rate in location k in year t (τ_{kt}), by aggregating across Eq. (7) for all the patents that arose in year t (denote this set of patents Υ_t). We explicitly account for the operation of CFC regimes (see Section 2 for a description of how CFC regimes work). For a patent owned by a firm resident in a country that has a CFC regime, and that deems country k as a low tax jurisdiction, changes in the statutory tax rate of location k should have no bearing on their location probabilities. Define an indicator variable D_{pjt}, where $D_{pjt} = 0$ if patent p at time t is subject to CFC rules which bind in location j, and $D_{pjt} = 1$ otherwise. We can

then write the elasticity of the share of patents located in country j with respect to tax in location k in year t as,

$$E_{jkt} = \int \sum_{p \in T_t} D_{pkt} \frac{\partial \rho_{pjt}(\eta_i, \nu_i)}{\partial \tau_{ikt}} dF(\eta_i, \nu_i) \frac{\tau_{kt}}{\int \sum_{p \in T_t} \rho_{pjt}(\eta_i, \nu_i) dF(\eta_i, \nu_i)}. \qquad (8)$$

2.3. Identification

Our primary interest lies in pinning down the ceteris paribus impact of a change in the corporate tax rate set by any one country on the shares of patent applications made by subsidiaries in both that and in alternative locations. To do this we must consistently estimate the parameters of the payoff function outlined in Eqs. (1)–(4), and in particular the parameters governing the marginal impact of tax on the payoff associated with selecting a location, which are modelled as random coefficients. Train (2003) shows that the random coefficient model has a duel interpretation as an error component model. Under this representation, the mean of the random coefficient can be interpreted as a fixed coefficient — it is pinned down by variation in location choices in response to variation in taxes faced by firms, conditional on other observables included in the model. The standard deviation of the random coefficient is interpreted as a component in the error term — it is pinned down by correlation in payoffs across locations (both in a given choice set and across location decisions within a given idea).

Berry and Haile (2010) have established that in random utility multinomial logit models the distribution of unobserved preference parameters is non-parametrically identified given sufficiently rich micro data. However, non-parametric estimation of this model is computationally burdensome, and we therefore follow most papers in the literature by assuming payoffs are linear with independent additive shocks and that the distribution of unobserved parameters is normally distributed. These assumptions give us a convenient approximation.

The standard identification concerns still apply here; to consistently estimate the parameters we require that the additive shock (ϵ_{pjt}) and the idea specific random terms (η_i and ν_i) are independent from each other and from the other explanatory variables. Specifically, if there are factors which influence location choice, and that are not captured by the observed and unobserved controls that we include, this would lead to inconsistent estimates. To mitigate this concern, we include a number of controls in the model. We include location–industry–firm size fixed effects; these control for all country characteristics that affect a firm's payoff and that do not vary through time, but that potentially do vary across firms in different industries and different parent firm sizes.

We include time varying (non-tax) location characteristics. These include a measure of the presence of real innovative activity associated with the intellectual property. This controls for the fact that some firms, for reasons other than the tax rate they will face in a particular location, may wish to co-locate legal ownership of intellectual property with real innovative activity. If decisions over the location of real innovative activity are influenced by corporate tax rates, then failure to control for this would result in an inconsistent estimate of the impact of tax on patent location choice. We also control for the strength of intellectual property rights protection in the location, market size and technological innovativeness — all factors that vary over time and location, and may be expected to impact on intellectual property location choices.

Identification of the tax coefficients also relies on the presence of informative variation in taxes in the data; specifically we need to observe variation in the set of taxes in potential locations across patent choice situations, conditional on all other factors that influence location choice. Crucially, it is necessary that there is variation in *differences* in taxes between locations across choice sets. So, for instance, if the only source of tax variation was that all tax rates changed simultaneously

by the same amount, the marginal effect of tax on the payoffs would not be identified.

Such variation arises in our framework for two reasons. First, there is variation over time in statutory tax rates; as outlined below in Section 2, over the period for which we have data (1985–2005) there has been a general pattern of declining statutory tax rates. The size of this decline has varied across countries, and the changes have occurred at different times, meaning that tax reforms have given rise to variation in the set of tax rates across locations. Second, in addition to this time series variation, CFC regimes lead to another source of variation; two parent firms taking a decision at the same point in time, but resident in different countries, can face a different set of tax rates due to cross country differences in CFC rules. The variation in location choices, conditional on other factors, in response to this variation in tax rates pins down the impact of tax on location choice.

3. Data

To estimate the model we need information on where firms have chosen to locate the legal ownership of their patents, the corporate tax regime and other conditioning variables.

3.1. Patents data

We use data on patent applications filed at the European Patent Office (EPO) by the European and US subsidiaries of parent firms located in fourteen European countries. We exclude from our analysis firms that patent infrequently. The number of patent applications by location of the subsidiary that filed the patent application is shown in Table 3.1. Our data include 1083 parent firms that collectively have 4,823 patenting subsidiaries, which file 379,849 patent applications over the period 1985–2005. These account for a 70% of all corporate applications filed at the EPO by firms parented in these fourteen European countries during this period.

Each patent application lists the firm that files the application (the applicant), this is the legal owner of the patent.[4] We identify the parent firm using information from company accounts (from Amadeus), company websites, business directories and other sources (see Abramovsky et al. (2008) for details). We use ownership information at a fixed point in time (2004), and we do not observe changes in ownership after an application has been filed.

For each patent application this gives us a mapping between the location of the parent firm and the location of the subsidiary that legally owns the patent. We also observe the location of the inventors (individuals) that created the technology underlying the patent application.[5] There are often inventors located in multiple countries, and often in different countries to that of the applicant.[6] The location of both the applicant and the inventors are distinct from the patent office to which the firm is applying for protection. For patent applications filed at the EPO, each application also designates the individual countries in which final patent protection will be sought; it is these individual countries, not the EPO, that grants patent protection.

We use Thomson's Derwent database to classify patent applications based on the technology embodied in the patent and the markets in which the technology is used. We use three broad industry groups — Chemical, Electrical and Engineering. A patent application can be relevant for more than one industry group if it has applicability in more than one of these industries. Where this is the case we include the patent application in each of the industry

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[4] In most EPO applications there is one applicant. For the handful of patent applications that are filed by multiple applicants in multiple locations we randomly select one of them.

[5] A small number of patent applications (0.07% of those filed by all applicants in the 15 countries we consider) have missing inventor data. We exclude these applications.

[6] This is different to data on patents filed at the US Patent and Trademark Office for which the inventors are the patent applicants.

Table 3.1
Patent applications and tax rates by applicant country.

Applicant country	Number of patent applications	% patent applications:						Statutory tax rate			Number of rate changes
		By industry			By firm size		High quality				
		Chemical	Electrical	Engineering	Large	Medium		min	max	mean	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Belgium	6935	47.8	22.9	29.3	74.2	25.8	29.0	34.0	45.0	40.4	5
Denmark	4975	56.9	15.2	27.9	65.7	34.3	31.2	28.0	50.0	36.0	7
Finland	10151	13.9	72.6	13.5	83.1	16.9	33.8	25.0	60.2	36.8	7
France	50017	26.6	45.2	28.2	87.5	12.5	37.1	33.3	50.0	38.6	13
Germany	166606	29.1	34.3	36.6	78.5	21.5	35.8	38.3	61.7	52.5	15
Ireland	387	70.6	7.7	21.7	52.5	47.5	26.0	10.0	12.5	11.3	1
Italy	11155	34.1	26.3	39.5	47.9	52.1	29.9	37.3	53.2	44.6	7
Luxembourg	792	52.9	25.6	21.4	32.8	67.2	41.4	30.4	39.4	37.5	6
Netherlands	34918	29.3	51.4	19.3	90.2	9.8	36.1	31.5	43.0	37.2	4
Norway	1083	35.3	29.4	35.3	47.7	52.3	36.8	28.0	50.8	39.4	1
Spain	994	44.7	19.8	35.5	23.9	76.1	33.5	35.0	35.0	35.0	1
Sweden	17300	21.1	49.0	29.9	82.7	17.3	43.3	28.0	52.0	36.7	2
Switzerland	30221	45.6	23.7	30.7	73.8	26.2	39.6	21.3	28.5	25.1	6
United Kingdom	27955	45.0	30.0	25.0	67.3	32.7	38.2	30.0	40.0	33.8	5
United States	16360	48.7	29.9	21.4	88.6	11.4	37.9	34.0	49.5	40.1	5
Total	379849	32.3	36.8	30.8	78.8	21.2	36.5	10.0	61.7	43.2	6

Notes: Applicant country refers to the location of the subsidiary that is the applicant on a patent application. The final row gives means across all patent applications in our data. The mean tax rate in the final row is averaged across all choice options, so it differs from Table 3.3.

sub-samples, and when we calculate the market level elasticities we weight each patent application so that the sum of the weights equals one (so if a patent application is in two industries it will get a weight of 0.5 in each). Table 3.1 columns (2)–(4) shows the industry split of patent applications, 32.3% are in Chemical, 36.8% in Electrical and 30.8% in Engineering, but this varies across countries. We restrict our analysis to firms that are above the 20th percentile in terms of the number of patent applications per firm in their industry. We distinguish large firms as those with a level of patenting above the 80th percentile in their industry. 78.8% of patent applications in our sample are held by large firms.

Firms often take out a number of related patent applications at the same time; we allow for correlation in these decisions. We group together related patent applications that can be considered to be part of the same idea. We identify patent applications as part of the same idea if they are made by the same parent firm, are filed in the same quarter (i.e. three month period), are classified in the same industry and share a network of common inventors. The number of patent applications in an idea varies: on average an idea contains one patent application; ideas containing more than one application account for 26% of all patent applications.

The importance of ideas in our empirical strategy is that we allow correlation across patent applications at the level of the idea; the decisions over where to locate ownership of these related patent applications is unlikely to be independent, and the inclusion of random coefficients at this level allows for them to be correlated.

3.1.1. Patent quality

There is a large literature that highlights the skewness of patent value and quality (Pakes (1985, 1986), Blundell et al. (1999), Lanjouw and Schankerman (2004) and Hall et al. (2007)). Firms file patent applications for a variety of reasons; some are filed to protect valuable new ideas, others are filed strategically to provide option values or to block competitors. Patent value also varies because some ideas are commercially more valuable than others. We identify high quality patent applications as those that are part of a triadic patent family, i.e. a related patent application has been filed at each of the EPO, the US Patent and Trademark office and the Japan Patent Office. The OECD uses triadic patent families "… *to improve the international comparability and quality of patent-based indicators … patents included in the triadic family are typically of higher economic value: patentees only take on the additional costs and delays of extending the protection of*

their invention to other countries if they deem it worthwhile." (OECD, 2012).

We expect triadic patent applications to be of a higher value since there is a cost to filing patent applications at each of these patent offices, and the main incentive to do this is if firms expect the technology to have a wide application. Each idea (group of patent applications) is classified as high quality if over half of the associated patent applications are triadic. As seen in Table 3.1 (column (7)) on average 36.5% of patent applications are classified as being part of a high quality idea.

3.1.2. Patent ownership and income from patents

We model the impact of tax on where firms choose to locate the legal ownership of patents. In the introduction we discuss the reasons that we might expect tax to affect a firm's decision of where to hold legal ownership of intellectual property.

The extent to which firms have arranged their activities in such a way that income can reasonably be deemed to be attributable to the subsidiary that legally owns the intellectual property will differ; firms will differ in how aggressively they seek to manage their tax liabilities. For some firms, the choice of where to earn income may be a choice between those countries in which real innovative activities already takes place; others may employ strategies that allow them to earn income in a separate country.

There are many factors that affect the costs and benefits of choosing a particular location. For tax havens these costs may be particularly high: CFC rules are more likely to bind; the transfer of profits to locations where there is little real activity will be more difficult; tax havens are likely to be less attractive locations along non-tax dimensions such as intellectual property rights protection. We would not expect legal ownership of all patents to be located in such countries. However, it is possible that some firms are particularly aggressive in their tax planning and organise their activities in such a way that income is earned in a location that is not where legal ownership is located. We do not observe income flows, so we do not explicitly model this behaviour; to the extent that it makes the decision over the location of legal ownership less related to tax we would be less likely to find an impact of tax. In our model we aim to capture this variation in behaviour across firms, and within firms across ideas, by the inclusion of observed and unobserved heterogeneity.

An additional complicating factor is that a firm might file a patent application from one subsidiary, but later transfer ownership of that patent to another related firm. However, firms have an incentive to

consider tax when making the initial location decision, because in many situations there are tax costs to transferring the ownership of intangible assets. For there to be a tax benefit to the sale or transfer of an asset it must be the case that this can happen at a value below the true market value. The transfer of intellectual property will be subject to transfer pricing rules, which will act to limit how much value can be shifted to a low tax country. In addition, many European countries operate exit taxes that attempt to levy tax on the net present value of the expected revenue stream on an intangible asset when it is moved out of the country. Such tax provisions reduce (if not remove) any tax advantages to re-locating to a lower tax jurisdiction. If firms do intend, with some positive probability, to re-locate the ownership of a patent in the future, and if transfer pricing rules and exit taxes do not act to perfectly off-set any tax advantages of doing so, this would reduce the importance of corporate tax in the initial location decision. This is an additional reason that it is important that we allow heterogeneity in the importance of corporate tax across intellectual property.

The place where we need to make more restrictive assumptions about the relationship between legal ownership and income from intellectual property is when we carry out the ex ante analysis of the Patent Box tax reforms and calculate the revenue implications of these reforms. In order to do this we need to assume that the relationship between legal ownership and income is not changed by the policy reform.

3.2. Taxes

We measure the impact of tax on payoffs using the statutory tax rate. We assume that returns from intellectual property are expected to be sufficiently high that deductions such as capital allowances are relatively unimportant, so that the effective tax rate faced by the firm is approximately the statutory tax rate (see Devereux and Griffith (2003), where Fig. 1 shows that the marginal effective tax rate asymptotes to the statutory tax rate as profitability increases).

Our identification strategy relies on variation over time and across countries in the tax rate. Table 3.1 (columns (8)–(11)) summarise the variation in corporate tax rates. In general, main statutory tax rates fell in the two decades up to 2005, but with the timings of changes differing across countries. The Scandinavian countries – Denmark, Finland, Norway and Sweden – reduced tax rates significantly around 1990. Italy enacted a reduction of over 10 percentage points in 1998, as did Germany in 2001. France and the UK have enacted a series of gradual reductions.

There can be additional tax levied in the parent firm's home country as a result of Controlled Foreign Company (CFC) rules, which aim to prevent firms locating income in lower tax countries in order to avoid taxation in their home country. CFC rules set out criteria for identifying subsidiaries that are located in a country deemed to be 'low-tax' and earning a significant amount of 'passive income' (income that is not associated with real activity). When a CFC regime is in place in a parent firm's country of residence, and a subsidiary is located in a country that is deemed a 'low tax' location (as judged against parent firm country specific thresholds), then we set the tax variable, τ_{fjt}, equal to the parent firm country's statutory rate. A description of the country pairs for which this is the case is given in Table 3.2. There is variation in whether a parent firm country operates a CFC regime (some regimes are introduced during the period for which we have data) and in the applicant countries that are deemed low tax (which differ over time when statutory rates change). This definition of whether CFC rules bind effectively assumes that the income received from a patent is deemed to be passive income, and that the share of passive income is sufficient to trigger the CFC rules. This is clearly an approximation. However, if we look across all location options that firms in our data face and that are deemed low tax by CFC regimes, then it is rarely the case that the parent firm has both inventors and holds legal ownership of a patent application in the same location. The results we present below are robust to the alternative assumption that patent applications with ownership located in countries where associated real innovative activity is also located would be treated as active income, so that CFC rules do not bind.

3.3. Descriptive statistics

The variables included in the model are defined and summarised in Table 3.3. The top panel contains the observed location attributes we include. These comprise the tax rate that the parent firm would face if it earned income from the application of intellectual property in the location, a measure of the presence of real innovative activity in a location defined as an indicator of whether at least one of the inventors associated with the patent applications that form the idea are located in that country and country-time varying observable characteristics. The latter includes a measure of intellectual property rights protection. This is based on a measure developed by Ginarte and Park (1997) and Park (2008). The countries we consider all have advanced systems of property rights and therefore rank relatively highly on the protection of intellectual property. We define a country as having a strong intellectual property regime if it scores above the median of countries in our sample. Other country-time varying variables include market size, as measured by Gross Domestic Product (GDP) and the technological innovativeness of a country, proxied by business R&D investment in the country as a share of GDP.

Table 3.2
Number of firms and CFC regimes by parent firm country.

Patent firm country	Number of parent firms	CFC regime introduced	Applicant countries for which CFC ever binds (no. of years)
Belgium	28	–	–
Denmark	27	1995	FI (1 year), IE (all years)
Finland	25	1995	IE (11 years)
France	108	1980	CH (6 years), IE (all years)
Germany	446	1972	CH (all years), FI (8 years), GB (1 year), IE (all years), NO (9), SE (10)
Ireland	4	–	–
Italy	75	2002	–
Luxembourg	8	–	–
Netherlands	58	–	–
Norway	7	1992	IE (14 years)
Spain	8	1996	CH (7 years), FI (2 years), IE (all years)
Sweden	48	1990	CH (1 year). IE (11 years)
Switzerland	106	–	–
United Kingdom	135	1984	CH (2 years), IE (all years)

Notes: Country codes: Belgium (BE); Switzerland (CH); Denmark (DK); Finland (FI); France (FR); Germany (DE); Ireland (IE); Italy (IT); Luxembourg (LU); Netherlands (NL); Norway (NO); Spain (ES); Sweden (SE); United Kingdom (GB).

Table 3.3
Variable definitions and summary statistics.

Variable	Definition	Min	Max	Mean	Standard deviation
Location characteristics					
Tax rate (τ_{fjt})	Statutory tax rate in applicant country; or statutory tax rate in parent firm county when binding CFC regime	10.00	61.70	41.79	11.34
Real activity	Dummy equal to one when any of the inventors associated with the patent applications that form an idea are located in that country	0.00	1.00	0.86	0.35
Strong intellectual property protection	Measure of applicant countries' relative degree of intellectual property rights protection	0.00	1.00	0.76	0.43
Market size	GDP measured in millions of constant PPP US dollars	0.01	12.56	1.90	1.97
Technological innovativeness	Business investment in R&D as a share of GDP	0.29	3.20	1.53	0.40
Patent characteristics					
Large firm	Large parent firms are those for which the total number of patent applications is above the 80th percentile	0.00	1.00	0.79	0.41
High quality	Ideas are classified as high quality if over half of the associated patent applications were filed at each of the EPO, USPTO and JPO	0.00	1.00	0.36	0.48
Electrical	Instrumentation, computer, electronics, communications, electrical	0.00	1.00	0.37	0.42
Chemical	Chemicals, pharmaceuticals, printing, petroleum	0.00	1.00	0.32	0.42
Engineering	General and mechanical engineering	0.00	1.00	0.31	0.38

Notes: Statistics are based on all patent applications in our data. GDP is measured in constant PPP US dollars (expenditure measure) using a 2005 base year. Business Investment in R&D as a share of GDP (BERD) is from OECD Main Science and Technology Indicators. GDP and BERD are available at http://stats.oecd.org.

We allow the valuations firms place on location characteristics to vary across patent applications. A summary of observable patent (or idea) characteristics is given in the bottom panel of Table 3.3. In estimation we allow all coefficients to vary with the industry the patent application belongs to and the size of the associated parent firm. This allows the model to capture, for example, that large firms are more likely to have organisational structures that assist the location of intellectual property for tax purposes. The tax rate is interacted with a measure of the idea quality, reflecting the possibility that firms' location choices may be more responsive to tax when they expect intellectual property to earn higher returns.

4. Results

Table 4.1 shows the estimated coefficients of the choice model outlined in Section 2. The model is estimated using simulated maximum likelihood (see Train (2003)). We allow all coefficients to vary across industry and firms size, indicated by the different columns. We include a full set of location–industry–firm size fixed effects (not reported in Table 4.1, but available upon request).

The top row of Table 4.1 shows that the mean marginal impact of tax on the payoff from placing legal ownership of a patent in a location is negative and statistically significant across all industries and parent firm size groups. The second row shows that in both the electrical and engineering industries the payoff for high quality patents is more sensitive to taxes. This is true both for large and medium firms. In the chemical industry the payoff for a high quality patent is estimated to be marginally less responsive to tax than for lower quality patents for large firms, with there being no statistically significant difference between the high and low quality patents for medium firms. Row three shows that there is a substantial degree of unobserved heterogeneity in the importance of tax on location choice across ideas, the standard deviations of the random coefficients on tax are both large and statistically significant across all industries and size categories.

The fourth row shows that, ceteris paribus, having real innovative activity in a location is associated with a higher payoff from placing legal ownership of a patent in that location across all industries and size categories; the fifth row shows that there is a significant amount of variation in the importance of this characteristic across ideas.

Together the large and statistically significant standard deviations on the random coefficients on tax and real innovative activity (in all industry-firm size groups) indicates the presence of important correlations in payoffs, both across locations for a given patent, and across patents in a given idea. These correlations will generate patterns of substitution that will depart from the more restrictive patterns implied by a standard multinomial logit model.

The remaining three rows of Table 4.1 describe the impact of having strong intellectual property protection, and the marginal impacts of market size and technological innovativeness, on the payoff function. For five of the six industry-firm size groups, a location having strong intellectual property protection is, all else equal, associated with firms obtaining higher payoffs from locating legal ownership of their patents there (the exception is medium electric firms, for which the strong intellectual property rights dummy is negative). Larger market size is associated with statistically significantly larger payoffs for five of the size industry-firm size groups, and a higher degree of technological innovativeness is associated with statistically significantly larger payoffs for four of the size industry-firm size groups.

Table 4.2 shows the matrix of own and cross tax elasticities implied by the choice model. It contains the elasticities of the share of patents located in each of 14 European countries with respect to the rate of corporate tax set in each of these countries and in the US. These are calculated as described in Section 2. We report the matrix of elasticities using tax rates and the distribution of patent applications for the most recent year in our data, 2005. Each cell shows the elasticity of the share of patents located in the country indicated in column 1 with respect to the tax rate set by the country in row 1. The emboldened diagonal shows the own tax elasticities. For all locations, except Luxembourg, the own tax elasticities are less than one in magnitude.

There is a limited literature on the elasticity of the location of corporate income with respect to tax. De Mooij and Ederveen (2008) report that empirical studies considering the effect of differences in statutory tax rates on various measures of profitability (with a view to indirectly capturing the effects on profit shifting) tend to find a semi-elasticity of around −1.2. As in this paper, Karkinsky and Riedel (2012) consider the link between corporate tax rates and patent applications. They estimate a semi-elasticity that, depending on the functional form of their model, implies that a 1 percentage point increase in the rate of corporate tax translates into a 3.5%–3.8% fall in patent applications

Table 4.1
Estimated parameters.

Industry	Electrical		Engineering		Chemical	
Size	Large	Medium	Large	Medium	Large	Medium
Tax rate (mean)	−3.48	−4.93	−4.91	−4.88	−6.54	−4.03
	(0.13)	(0.32)	(0.14)	(0.24)	(0.13)	(0.28)
Tax rate x quality	−0.67	−1.98	−0.69	−0.66	0.34	0.08
	(0.14)	(0.37)	(0.15)	(0.28)	(0.14)	(0.31)
Tax rate (std. dev.)	3.59	3.67	2.35	3.17	3.36	4.24
	(0.16)	(0.40)	(0.23)	(0.27)	(0.15)	(0.27)
Real activity (mean)	5.60	7.27	6.20	7.03	6.11	6.55
	(0.03)	(0.12)	(0.05)	(0.09)	(0.04)	(0.09)
Real activity (stand. dev)	2.50	2.76	2.80	2.96	2.95	2.59
	(0.03)	(0.10)	(0.04)	(0.08)	(0.04)	(0.08)
High IP property protection	0.63	−0.22	0.28	0.19	0.68	0.60
	(0.04)	(0.11)	(0.06)	(0.10)	(0.06)	(0.10)
GDP	−0.20	0.66	0.53	0.43	0.39	0.20
	(0.02)	(0.07)	(0.03)	(0.05)	(0.02)	(0.05)
R&D expenditure/GDP	0.26	0.03	0.23	0.09	0.18	0.00
	(0.02)	(0.05)	(0.03)	(0.04)	(0.02)	(0.05)

Notes: The dependent variable is location choice in one of the locations shown in Table 3.1. Estimation is based on 379,849 patent applications. Industry–location–firm size fixed effects included. Large firms are those associated with a total number of patent applications above the 80th percentile in each industry.

from that location. Direct comparison with our results is made difficult by the fact that our model allows tax effects to vary across all locations. We find that the share of patents held in Luxembourg is most sensitive to tax (the Luxembourg semi-elasticity is 3.9%) and least sensitive for Germany (the German semi-elasticity is 0.5%).[7]

Theoretically, we might expect smaller countries to have relatively high own tax elasticities, as a change in their tax rate will not affect the market rate of return, making the cost of capital more responsive to tax changes (see Wilson (1999)). This may be one of the reasons that such countries are more likely to compete for corporate income using low rates; a change in the rate leads to a larger change in the relatively small tax base (see, for example, Bucovetsky and Haufler (2007)). The own tax elasticities in Table 4.2 show some evidence of this; they are higher for the Benelux countries than for France and Germany.

The importance of allowing for observed heterogeneity and correlation in locations' payoffs can be seen by looking at the cross tax elasticities. In a multinomial logit with no observed or unobserved heterogeneity all cross tax elasticities in a column would be the same — a reduction in the tax rate in location A would lead to patent applications switching from other locations in proportion to their original shares. This implausibly restrictive pattern of substitution is not imposed in our more flexible model, meaning that elasticities vary substantially within a column. In particular, our model allows the data to capture the fact that firms are more likely to choose to switch between locations with similar characteristics (whether that be because the firm has inventors located in several locations, or because locations have similar tax rates).

5. Policy simulations

One of the advantages of estimating the model outlined above is that it captures patterns of substitution across locations, and it therefore

allows us to simulate counterfactual policy situations. We illustrate this by considering a recent set of policy reforms.

A number of European countries have introduced polices that offer substantially reduced rates of corporation tax on the income derived from patents, and in some cases other forms of intellectual property (these are often called Patent Boxes). Firms are able to declare that some portion of their profits are derived from either the use or licence of patents, and these profits are taxed at a lower rate. Patent Box rules differ across countries, for example, in terms of how eligible income is measured, how the rules that apply when calculating how much income can be allocated to patents, and how the related expenses are treated.[8] None of the countries require that the R&D underlying the intellectual property took place in that country, as this is not permissible under European law.

We use the most recent year of our data (2005) to simulate the impact of the two sets of policies. First we consider the introduction of Patent Boxes in the Benelux countries, and second the later introduction in the UK. We simulate the impact of these policies on the share of new patents for which legal ownership is placed in each of these countries using the choice model presented above. For illustrative purposes, we assume that the total level of patenting activity by European firms is not affected by the policy reforms. We also consider the impact of these policy reforms on tax revenue; this requires the further assumption that the relationship between where tax is levied and the location of legal ownership is not altered by the policy reform.

The policies are summarised in Table 5.1. In 2007 Belgium introduced a Patent Box that reduced the tax rate on income derived from patents from 34% to 6.8%, and the Netherlands introduced a Patent Box that reduced the rate from 31.5% to 10%. In 2008 Luxembourg reduced the rate from 30.4% to 5.9%. The UK government introduced a Patent Box at the rate of 10% in 2013; the main rate of corporate tax in the UK was 30% in 2005, but had fallen to 24% by 2013. We simulate the impact of the reduction from 30% to the Patent Box rate.[9]

Table 5.2 sets out the results of these simulations for the four locations that introduced Patent Boxes.[10] A note of caution in interpreting these results is that the lowest tax rate we observe in the

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[7] Note that in Table 3.2 we adopt of the convention of reporting tax elasticities. Roughly speaking these can be interpreted as telling us the % change in the share of patents in location A associated with a 1% change in the rate of tax in location B. These can readily be converted to semi-elasticities (which, roughly speaking, tells us the % change in the share of patents in location A associated with a 1 percentage point change in the rate of tax in location B) by dividing by the appropriate tax rate. So for instance the 2005 rate of corporate tax in Germany was 38.3% and the German own tax elasticity is 0.201. Hence the German own tax semi-elasticity is given by $100 \times (0.201 / 38.3) = 0.52\%$.

[8] Evers et al. (2013) provide further details on the policies and incorporate the rules into effective tax rates.

[9] For further discussion of the UK Patent Box see Griffith and Miller (2010, 2011). A number of other European countries (Cyprus, Liechtenstein, Malta, Spain, and the Swiss canton of Nidwalden) have since introduced similar policies.

[10] The full set of results, including the impact on other countries, is available on request.

Table 4.2
Own and cross price elasticities of locations with respect to statutory tax rates.

	Belgium	Denmark	Finland	France	Germany	Ireland	Italy	Luxembourg	Netherlands	Norway	Spain	Sweden	Switzerland	UK	US
Belgium	**−0.569**	0.010	0.018	0.085	0.174	0.001	0.016	0.006	0.079	0.003	0.003	0.030	0.036	0.025	0.038
Denmark	0.016	**−0.410**	0.015	0.044	0.145	0.000	0.013	0.007	0.060	0.003	0.004	0.033	0.047	0.025	0.037
Finland	0.015	0.008	**−0.465**	0.096	0.190	0.000	0.015	0.003	0.103	0.002	0.002	0.046	0.031	0.021	0.043
France	0.013	0.004	0.017	**−0.311**	0.118	0.000	0.009	0.002	0.052	0.001	0.001	0.017	0.017	0.011	0.021
Germany	0.007	0.004	0.009	0.032	**−0.201**	0.000	0.006	0.002	0.035	0.001	0.001	0.012	0.016	0.008	0.012
Ireland	0.048	0.031	0.033	0.103	0.279	**−0.404**	0.063	0.017	0.162	0.007	0.009	0.048	0.176	0.054	0.352
Italy	0.011	0.006	0.012	0.041	0.095	0.001	**−0.373**	0.004	0.043	0.002	0.002	0.017	0.035	0.019	0.017
Luxembourg	0.062	0.040	0.029	0.126	0.450	0.002	0.055	**−1.197**	0.125	0.012	0.019	0.058	0.093	0.073	0.079
Netherlands	0.022	0.010	0.034	0.094	0.234	0.001	0.017	0.004	**−0.569**	0.003	0.003	0.037	0.039	0.027	0.048
Norway	0.036	0.022	0.030	0.095	0.279	0.001	0.030	0.013	0.099	**−0.783**	0.009	0.082	0.070	0.046	0.050
Spain	0.012	0.009	0.008	0.032	0.097	0.000	0.012	0.008	0.047	0.003	**−0.336**	0.017	0.007	0.016	0.010
Sweden	0.017	0.012	0.032	0.066	0.166	0.000	0.015	0.003	0.078	0.004	0.002	**−0.432**	0.033	0.026	0.033
Switzerland	0.023	0.017	0.024	0.086	0.282	0.001	0.028	0.006	0.093	0.004	0.003	0.036	**−0.278**	0.029	0.049
UK	0.014	0.008	0.013	0.038	0.106	0.000	0.015	0.004	0.053	0.002	0.002	0.024	0.018	**−0.321**	0.030

Notes: Each cell contains the elasticity of the share of patent applications in the country indicated in column 1 when the tax rate changes in the country in row 1. Numbers are calculated using tax rates and patent applications in 2005.

data is 10% in Ireland, whereas two of the Patent Box rates are below this level, and so are outside the observed range of taxes in our data.

We carry out the simulation on the full set of patent applications, shown in the top panel. It may be the case that many patents do not earn much income, and so in the bottom panel we carry out the simulation using only the high quality patents, under the assumption that these are the patents that are expected to earn the highest income. The estimates suggest that the location of these patents were on average more sensitive to tax.

The first column shows the actual share of patent applications in each location in 2005 (prior to the introduction of Patent Boxes). The second column shows the predicted share of patent applications in each location after the introduction of Benelux Patent Boxes. The standard error of these predicted shares are shown in parenthesis. The third column expresses the % change from column 1 to column 2. The introduction of Patent Boxes in the Benelux countries leads to a large and statistically significant increase in the share of new patents whose legal ownership is located in Belgium and Netherlands. The increase in Luxembourg is proportionally large, but is not statistically significant. There is no change in the share in the UK. There is a decline in the share of patent applications located in other non-Patent Box locations (not shown).

The fourth column shows the predicted shares after the introduction of the UK Patent Box (in addition to the Benelux Patent Boxes). The fifth column shows the % changes from column 1 to column 4. The UK Patent Box leads to a reduction in the share of new patent applications made by subsidiaries located in the Benelux countries, but for Belgium and the Netherlands they still have a statistically significantly higher share than prior to the introduction of any Patent Boxes. The share of new patent applications made by subsidiaries located in the UK increases

by a statistically and economically significant amount. The results with high quality patents are similar.

In columns (6)–(8) of Table 5.2 we consider the impact on tax revenue from income derived from patents. These combine two effects. The reduction in the statutory tax rate will reduce revenue, but the increase in the share of income from patents will increase it. We demonstrate the impact on tax revenue by computing the product of the statutory tax rate in each country and the share of patent applications. We index this to 100 before the introduction of any Patent Boxes. In the upper panel of the table we assume that all patents are equally valuable, and that the relationship between legal ownership and taxable income is not affected by the reform. All countries experience a decline in revenue. Although the countries that introduce Patent Boxes attract more new patents, the increased share is not sufficient to outweigh the effect of the lower tax rate. With all four Patent Box policies in place, revenues are less than half of their previous levels in these countries. Ernst et al. (2013) provide evidence that lower rates of tax on patent income attract particularly innovative projects with high earning potential. In the lower panel we consider the effect on revenue when we consider only high quality patents. The picture is here is similar; the introduction of Patent Boxes results in a substantial reduction in revenues.

6. Summary and conclusion

The literature has emphasised the downward pressure on corporate income tax rates that arises from factor mobility. There is also a large literature that discusses the strategies firms use to shift income for tax purposes and to circumvent anti-avoidance rules, and that highlights an important role for intangible assets. However, we know relatively

Table 5.1
Patent Box regimes.

Applicant country	Year introduced	Patent Box	Effective rate
	(1)	(2)	(3)
Belgium	2007	Applies to gross income from patents and supplementary certificates	6.8%
Luxembourg	2008	Applies to net income from patents and some other forms of intellectual property	5.9%
Netherlands	2007	Applies to net income from patents and some other forms of intellectual property. Policy substantially broadened in 2010.	10%
United Kingdom	2013	Applies to net income derived from patents and similar types of intellectual property.	10%

Notes: Effective Patent Box rates are those that were in place when the policy was first introduced. Each policy is associated with criteria that define which income is eligible. All policies include licence and embedded income. Policies differ in the conditions under which acquired intellectual property is eligible. Net and Gross refers to development costs. A number of other European countries now also operate policies akin to a Patent Box, and a similar policy has been proposed in the US.

Table 5.2
Impact of Patent Boxes on location of and tax revenue raised from new patents.

	Share of new patent applications					Tax revenue		
	Prereform	Benelux Patent Boxes	% change	UK Patent Box	% change	Prereform	Benelux Patent Boxes	UK Patent Box
All patents								
Belgium	2.39	3.53 (0.34)	47.6%	3.42 (0.34)	−3.1%	100	30	29
Luxembourg	0.33	0.60 (0.34)	83.9%	0.56 (0.34)	−7.0%	100	36	33
Netherlands	7.92	12.51 (0.38)	58.0%	12.16 (0.38)	−2.8%	100	50	49
UK	4.15	4.15 (0.31)	−0.1%	5.25 (0.32)	26.6%	100	100	42
High quality patents								
Belgium	1.90	3.29 (0.35)	73.2%	3.17 (0.35)	−3.9%	100	35	33
Luxembourg	0.42	0.76 (0.35)	82.8%	0.71 (0.35)	−7.3%	100	35	33
Netherlands	7.00	12.48 (0.39)	78.3%	12.09 (0.38)	−3.1%	100	57	55
UK	4.89	4.39 (0.31)	−10.2%	5.64 (0.33)	28.5%	100	90	38

Notes: The top panel provides numbers based on all patent applications; the bottom panel provides numbers on high quality patents only. Column 1 shows the actual share of patent applications in each location; columns 2 and 4 give the predicted share of patent applications in each location following the introduction of the Benelux Patent Boxes and following the additional introduction of the UK Patent Box. Standard errors are in parenthesis. Column 3 and 5 show the corresponding percent changes in shares relative to column 1. The final three columns show revenue raised from new patents, assuming that all patents have equal expected values. Revenues are indexed to 100 in the pre Patent Box period. Numbers are based on simulations using data for 2005.

little about the extent to which the location of intangible assets responds to tax. The evidence there is on the impact of tax on the location of capital more generally has tended to suffer from the imposition of restrictive a priori assumptions placed on the underlying model of firm behaviour. From a policy perspective it is clearly important to understand how responsive firms are to corporate income taxes when they make location decisions.

In this paper, we estimate a model of firms' decisions over where to locate the legal ownership of their patents. We find that corporate tax rates are an important determinant of location choice. We extend the current literature on the determinants of firm location choice by estimating a flexible choice model, which accounts for both observed and unobserved heterogeneity in behaviour. We are able to generate own and cross tax elasticities across locations that capture complex patterns of substitution in the data. The model can be used to conduct ex ante analysis of policy changes. We find that this heterogeneity is important for explaining location choices.

Our model also shows that other factors influence where firms choose to hold legal ownership of patents. For instance, firms are more likely to locate patent ownership in countries where they have associated real innovative activity. This may reflect co-location externalities, or the influence of tax rules which seek to limit the extent to which income and real innovative activity can be geographically separated. Firms also value other non-tax location characteristics. Such factors, along with tax rules like the operation of CFC regimes that limit the tax advantages of locating patent ownership in low tax jurisdictions, help explain why we do not see firms choosing to hold all legal ownership of patents in the lowest tax locations.

We use the model to consider the impact of the recent introduction of preferential tax regimes for income from patents. These Patent Boxes are likely to attract patent income, but our estimates suggest that they will also lead to substantial falls in tax revenues. Of course some of this revenue loss might be offset by gains from attracting activities that yielded positive externalities; these would need to be taken into account in a calculation of the welfare impact of the policy. It is also possible that the tax reforms will affect firms' decisions over whether to apply for a patent on a new technology or whether to rely on secrecy. We do not have information that

would allow us to directly estimate this margin, but this would be an interesting avenue for future research.

The introduction of Patent Boxes by several European countries in a relatively short space of time has given rise to concerns that countries are engaging in tax competition for patent income. In future work we intend to build on the framework developed here to consider whether governments are engaged in a strategic game to attract income from intellectual policy that ultimately will continue to exert downward pressure on corporate taxes.

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