Is international R&D tax competition a zero-sum game? Evidence from the EU[*]

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Abstract

Using time series data on US states, Wilson (2009) finds that R&D tax credits re-arrange R&D between US states; that is, a 1% fall in the user cost of R&D in US state A raises R&D activity in that state by 2.5%, but a 1% fall in the user cost of R&D in adjacent US state B lowers R&D activity in state A by exactly the same, 2.5%. Using EU data, this paper finds the same qualitative effect as Wilson's US study. Using data for 10 European countries, 1995-2007, we find a 1% fall in R&D costs in country A raises R&D investment by about 1%, but the same fall in a rival country lowers R&D investment in county A by about 1%.

1 Introduction

Theory suggests that reducing the price of R&D should increase R&D performed. Evidence suggests an elasticity of R&D performed with respect to its user cost of around -1 (Hall and Van Reenen (2000)). To lower R&D prices, many countries have been introduced R&D tax credits: as the OECD (2011) documents, 12 countries used R&D tax credits in 1995: in 2011, 26 countries do so.

If R&D is mobile between countries (more generally regions with tax discretion) it might respond to *in-country* tax credits, but also *out-of-country* tax credits. To examine this, Wilson (2009) uses data on 50 US states, 1981-2004 and measures how state R&D tax credits affect the state-level user-cost of R&D. Regressing state R&D spend on in-state and out-of-state user costs, he finds a 1% fall in the user cost of R&D in US state A raises R&D activity in that state by 2.5%, but a 1% fall in the cost of R&D in adjacent US state B lowers R&D activity in state A by exactly the same, 2.5%. This suggests that R&D tax credits simply re-arrange R&D between US states ("beggar thy neighbour" effects).

To the best of our knowledge however, there is no comparable investigation of international competition for EU countries: there may be less R&D mobility between EU member states than within the US, but nonetheless, given the policy importance of this question it seems worth investigating. Bloom et al. (2002)and Guellec and Van Pottelsberghe De La Potterie (2003)use a panel of countries over time and find a negative relation between in-country user costs and R&D spend, but do not look at out-of-country user costs (as a check, if we use a similar specification to Bloom et al. (2002) we find almost exactly the same lag structure and elasticity for in-country user costs). Bloom and Griffith (2001)use the same data as Bloom et al. (2002) and, for Australia, Canada, France, Germany, Italy, Japan, UK, USA look at in-country and out-of-country costs, finding some evidence of response to both cost types, depending on the inclusion of the USA: we study EU countries, use more recent data and *ex post* instead of *ex ante* user costs.

Using data on 10 EU countries, 1995-2007, we test response of country R&D spending to in-country and out-of-country R&D (tax-adjusted) user cost. The out-of-country R&D user cost is measured in a variety of ways, the simplest being the unweighted average of R&D user costs in the 9 other countries. To preview our results, the long run elasticity of R&D spending to in-country user costs is around -1 and to out-of-country user costs is +1. Using a number of measures of out-of-country user costs, we cannot reject the hypothesis these effects are equal and opposite. This suggests, like in the US, beggar-thy-neighbour effects.

In studying this question, there are at least two methodological problems. First, to construct the tax-adjusted user cost of R&D requires the pre-tax user cost of R&D and a tax adjustment. The tax adjustment data is provided by the OECD. Theory suggests the before-tax user cost for R&D is the Hall and Jorgenson (1967) rental cost for R&D. Since R&D is not rented, this cost has to be calculated for each country. It can be done *ex ante*, as in Bloom et al. (2002), where a cost of capital is assumed, or *ex post* where the cost of capital is derived from the rental rate that exhausts payments to all capital assets. We shall use this *ex post* method but it requires capitalising and building R&D stocks for all countries which is not implemented in standard cross-country data sets e.g. EU-KLEMS. So this part of the work is new.

Second, since there are potentially many ways to calculate an out-of-country cost of R&D we experiment. Our simplest measure is to take a simple average of other-country user costs. We also weight other country user cost: by their share of R&D spend, their geographical distance and their technological distance (measured by international patenting).

The rest of this paper is as follows. In the next section we set out some theory, and section three some data. Section four shows results and section five concludes.

2 Theory and measurement

2.1 Theory

Following Wilson (2009), suppose the firm has a CES production function where one of the inputs into output Q is the R&D capital stock, R. Profit maximising firms will have a demand curve for R of the form $R_{it} = \zeta Q_{it} \rho_{it}^{-\gamma}$ where ζ is the CES distribution parameter and γ the elasticity of substitution, and ρ_{it} is the user cost of R&D. Now imagine that R&D input corresponding to output in country i, can, in principle be situated in any country. So one might imagine a sub-demand system where the stock of R&D knowledge input R in country i, is in fact an aggregate of R&D inputs in a number of possible countries, the relative demand for which depends on relative user costs, denoted by superscripts "in" and "out". Thus we may write the demand for R&D in country i as

$$R_{it} = \zeta Q_{it} (\rho_{it}^{in})^{-\theta} (\rho_{it}^{out})^{-\phi} \tag{1}$$

The user cost of R&D, per unit of R&D investment (the financial user cost, or financial cost of capital), can in turn be written in terms of a tax adjustment factor and the pre-tax user cost

$$\rho_{it} = (B_{it})(r_{it} + \delta_{it}^{R\&D} - \pi_{it}) \tag{2}$$

Where the first term is the tax adjustment factor, B, and r, $\delta^{R\&D}$ and π are the rate of return, depreciation and capital gain to R&D assets respectively. With this theory in mind, we can set out the various approaches to this question.

Wilson (2009) uses state-time data for the USA. He therefore assumes that only B varies across states and relegates $(r + \delta - \pi)$ to the fixed and time effects (in also tries ex ante measures but these do not affect his results). Bloom et al. (2002) have country-industry-time variation and hence all parts of the tax-adjusted user cost vary. They carefully construct the B index and then the cost of capital is derived in *ex ante* fashion, using country-time long-term interest rates on government bonds and the GDP deflator as the country inflation rate. Guellec and Van Pottelsberghe De La Potterie (2003) also have country-time data and use B term (and public R&D spend), but not the pre-tax user cost term.

What is the variation driving these studies? Taxes vary at the country or US state level and so this seems a sensible level of aggregation to study the issue (using firm or industry data for example would increase variation on the left hand side, but to the extent that tax credits vary by state and country not by firm and industry there is no meaningful increase in variation on the right hand side). There is of course bias to such country regressions if country-level tax decisions are endogenous to R&D spend. We try to minimise such bias by using lagged user-costs, and country dummies, discussed more below.

2.2 Measurement

We have country data for 10 EU countries, 1995-07, Austria (AT), Denmark (DK), Spain (ES), Finland (FI), France (FR), Germany (DE), Italy (IT), Netherlands (NL), Sweden (SW) and the United Kingdom (UK). To measure the variables we proceed as follows. First, the equation is in terms of R&D stocks, but we shall use, as the other papers do, R&D flows, that is, real R&D spend (see below for some experiments with R&D stocks: real R&D is deflated by the GDP deflator which is conventional). Second, to measure ρ we need a measure of B and of $(r + \delta - \pi)$ (we call the latter the pre-tax rental cost of R&D capital, (denoted $P_{R\&D}$).

2.2.1 Tax adjustment

The B-index represents the present value of before-tax income necessary to cover the initial cost of R&D investment and to pay corporate income tax such that it is profitable to perform research activities. Following Hall and Jorgenson (1967) and Warde (1981) for example, we write $B = (1 - A)/(1 - \tau)$ where A is the combined net present value of allowances and credits due to R&D outlays and τ the corporate tax rate. The more favourable a country's tax treatment of R&D the lower its B-index.

2.2.2 Pre-tax capital cost, $(r + \delta - \pi)$

To measure of $(r + \delta - \pi)$, there are a number of possible approaches. The *ex ante* approach would require gathering data on the rate of return r and asset inflation π. This is possible to do, but runs the risk that the rate of return times the actual capital stock is divorced from observed profit in the economy. Thus we adopt the *ex post* approach which ensures that total capital costs equal total gross operating surplus by allowing r to adjust endogenously.

To see this, we build capital stock for asset a, K_a^{it} using the perpetual inventory method so that $K_{it}^a = I_{it}^a + (1 - \delta^a)K_{it-1}^a$ where I_{it} is real investment in asset a. We may calculate gross operating surplus residually from nominal value added less labour costs ($GOS_{it} = P_{it}^Q Q_{it} - P_{it}^L L_{it}$.) and then assume that $GOS_{it} = \sum_a \rho_{it}^a K_{it}^a$. Since we know GOS and K we then let r vary so equation 2 is satisfied and so can solve for ρ_{it}.

Note that we cannot use the EU-KLEMS (www.euklems.net) dataset, the leading cross-country data set, to do this. The EU-KLEMS does not capitalize R&D and so has the wrong $P_{it}^Q Q_{it}$ [1]needed to derive the labour costs GOS_{it}which determines the ρ. Thus we re-build the market-sector EUKLEMS data with R&D captialised. That is to say, we take the market sector nominal investment data for existing EUKLEMS assets, add R&D investment (from the OECD) and build all new capital stocks for all assets with the addition of R&D capital. We then recompute value added treating R&D spending as investment and then compute the appropriate ρ such that the $\sum_a \rho_{it}^a K_{it}^a$ with a including R&D equals the operating surplus measure including R&D.[2]

Oulton (2007)discusses the *ex-ante/ex post* distinction and makes the following points. First, the ex-post approach produces capital costs that are consistent with national accounts aggregates (in that nominal capital rental fees add up to nominal operating surplus, where operating surplus is calculated as value added less labour costs). Second, as Berndt and Fuss (1986); Hulten (1986) argue, the ex post measure is the appropriate measure where capital utilisation varies. Third, the choice of an ex-ante measure is somewhat arbitrary: the cost of marginal R&D capital might be that faced by multinationals or small firms in which case the *ex ante* costs would be quite different. Fourth, the derivation of operating surplus residually implies constant returns and no mark-ups (Hulten (2010)). Estimation of returns and mark-ups using *ex ante* methods has not found substantial evidence of deviations from constant returns and normal profits at least for the economy as a whole (see e.g. Basu et al. (2001)).

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[1] EU-KLEMS value added is gross output less intermediates, where R&D is treated as an intermediate. If R&D is a capital asset, which is what the theory depends upon so that it has an associated cost of capital, value added as to be recalculated by taking R&D out of intermediates. This affects Q and also the user cost of R&D (and other capital assets) since such capital costs are derived as a residual from PqQ less labour costs.

[2] There is a complication here. Since $GOS_{it} = \sum_a \rho_{it}^a K_{it}^a$ we should calculate the implied ρ^a using equation 2. However that would require B for each asset, which we do not have for all countries. Thus we omit B from equation 2, calculate $(r + \delta^a - \pi^a)$, for each asset a, then calculate$\rho^{R\&D}$ using equation 2 for R&D. This biases our measure of $\rho^{R\&D}$ but we expect the bias to be small and to be absorbed by country dummies and lagged effects.

Figure 1: cross country data on B_{it} and $B_{it}(r + \delta - \pi)_{it}$.
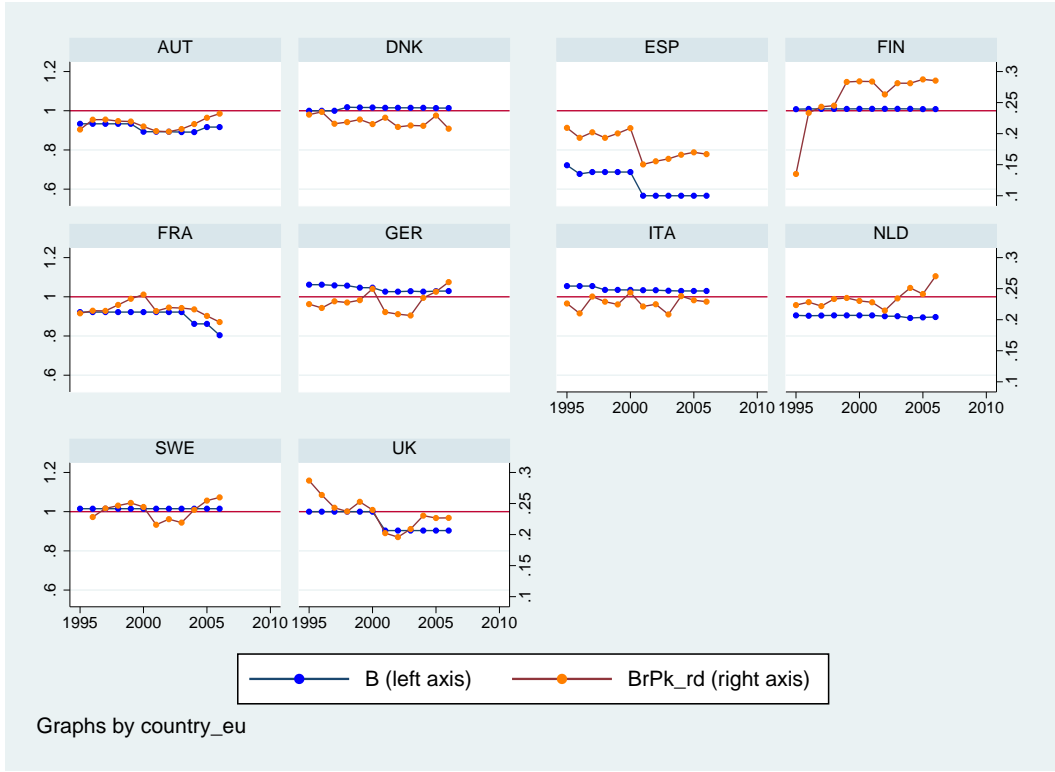
2.2.3 In-country and out-of-country tax adjusted rental cost of R&D capital

Figure 1 shows how $\rho_{it}^{in} = B(r + \delta - \pi)$ varies according to B_{it} and $B_{it}(r + \delta - \pi)_{it}$. Germany appears to have the least favourable R&D tax treatment over the time period with Spain receiving the most favourable, denoted by the relatively high and low values of B, respectively, over time. Spain and the UK show a lower B in the early 2000s i.e. a more favourable tax treatment of R&D. As the graph shows, $(r + \delta - \pi)$ has also varied over the period. Below we shall test the responsiveness of R&D spend to both B and $(r + \delta - \pi)$ and we find variation in both to be associated with relative spend.

We try a number of ways to construct ρ_{it}^{out} which we write as a weighted average of other country in-country ρ_{it}^{in}

$$\rho_{it}^{out} = \sum_{j \neq i} W_{jt}^i \rho_{jt}^{in} \tag{3}$$

We try a number of different weights.

1. A simple mean: $W_{jt} = 1/J$ of ρ_{it} in the J outside countries.

2. the share of the outside country's R&D stock in total outside R&D stock, on the basis that a country with a very low R&D stock gets a low weight: $W_{jt} = (P_K^{R\&D} K^{R\&D})_{jt} / \sum_{j \neq i} (P_K^{R\&D} K^{R\&D})$. The intuition for this weight is that a higher relative R&D capital stock implies that the country is a desirable country for R&D expenditure along dimensions which are potentially independent of the tax-adjusted user cost of R&D capital in that country (to avoid endogeneity issues we use the weights for the first year of our data, 1995).

Figure 2: Relation between ρ_{it}^{in} and ρ_{it}^{out} (simple average of outside countries) for 1995, 2000, 2006.
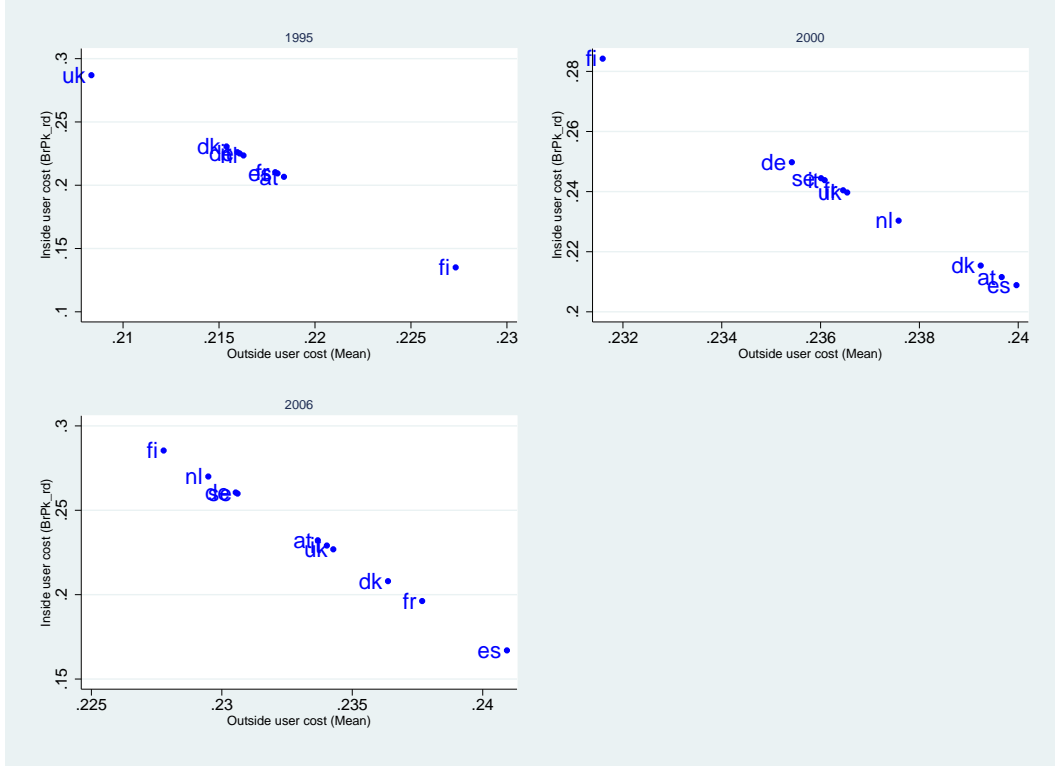

Source: author's calculations, see text.

3. The inverse Euclidean distance$W_{jt} = E_j$ (Hammadou et al. (2014)) between each outside country and country i: each outside country's tax-adjusted user cost is weighted by the (inverse) Euclidean distance between the outside country and country i. A smaller Euclidean distance between the outside country and country i potentially proxies a closer degree of substitution of cross-country R&D expenditure between the two countries and so that out country gets a higher weight..

4. Cross-border patent ownership: $W_{jt} = POI_{jt}^i/POA_{it}$where POI_{jt}^i denotes the number of patents owned by country i in country j and $POA_{it}$the total number of patents owned abroad by country i. So, each outside country's tax-adjusted user cost is weighted by the fraction of the total foreign-owned patents in the outside country owned by country i. A higher fraction of foreign-owned patents in the outside country owned by country i implies the outside country is a desirable place for R&D expenditure for country i, and suggests a high level of R&D inter-relatedness between the outside country and country i.

2.2.4   Inside and outside user costs in the EU

To see how these measures vary, consider Figure 2. which shows ρ_{it}^{in} and ρ_{it}^{out} where ρ_{it}^{out} is the simple weighted average of other country's ρ_{it}^{in} , for 1995, 2000 and 2006. A number of points are worth making. First, if all the ρs were the same, the graphs would be a cluster of points in the middle of the graph. The graphs are downward-sloping straight lines because ρ_{it}^{out} is, by construction, linear ρ_{it}^{in}. Consider the upper left panel, which shows the UK and Finland have the highest and lowest ρ_{it}^{in} in 1995. Thus the UK

Figure 3: $ln(\rho_{it}^{in}/\rho_{it}^{out})$ using different weighting matrices
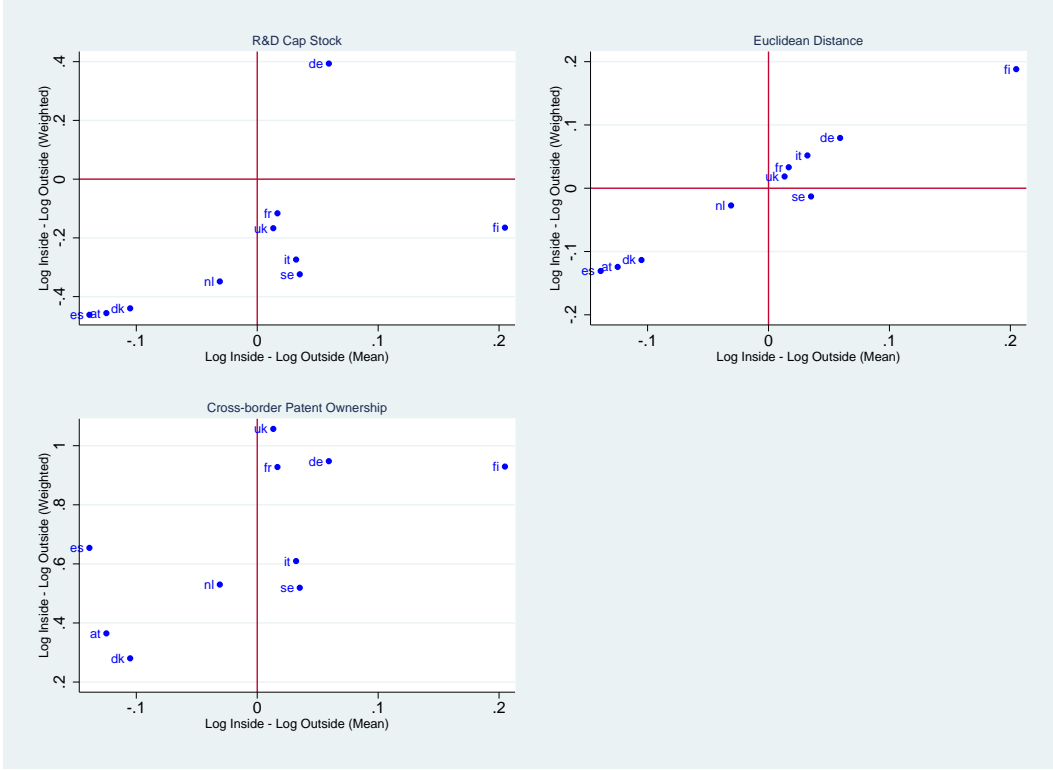
is at the top left since it has the highest ρ_{it}^{in} meaning it would have the lowest ρ_{it}^{out} since its high ρ_{it}^{in} is by construction excluded from its ρ_{it}^{out}. Finland is at the bottom right for the opposite reason. Most countries have similar ρ_{it}^{in} and so their ρ_{it}^{out} is not much affected by the exclusion of that country in the ρ_{it}^{out} calculation: this is why there is a cluster of points in the middle of the diagram.

Second, the other panels show that countries change their location along the line according to the extent to which their ρ_{it}^{in} varies over time. Thus by 2006, Finland and the Netherlands had a particularly high ρ_{it}^{in} and France and Spain a particularly low ρ_{it}^{in}. So between 1995 and 2006, there is significant variation in the rank ρ_{it}^{in} and so of ρ_{it}^{out}. This is important given we use a fixed effects models which requires within-country time-series variation for identification.

Figure 3 plots $ln(\rho_{it}^{in}/\rho_{it}^{out})$ where in each case the x-axis uses a simple average to construct ρ_{it}^{out} but each panel y-axis use different weights to construct the ρ_{it}^{out} and so $ln(\rho_{it}^{in}/\rho_{it}^{out})$. Consider the top left panel, which uses the R&D capital stock to construct ρ_{it}^{out} on the y-axis. Spain (ES) and Austria (AT) are low on the x-axis indicating they have a relatively low unweighted $(\rho_{it}^{in}/\rho_{it}^{out})$: that is to say, it is a relatively cheap place to do R&D, as opposed to Germany (DE) and Finland (FI). Spain is also relatively low on the y-axis, indicating that the user cost of non-Spanish countries, weighted by their share of non-Spanish R&D stock is relatively low. Germany, by contrast is relatively high on the y-axis, indicating that the non-German R&D weighted user costs are relatively low, rendering Germany relatively expensive on this R&D-weighted measure.

The top left shows the distance measure, taken from Hammadou et al. (2014). Finland, on the top right, is relatively expensive on the x-axis, but is geographically close to relatively expensive countries and so is high on the y-axis as well. Sweden seems the only country that geographically close to more expensive

countries, making it more competitive in distance-weighted terms (i.e. lower on the y-axis).

Consider now the bottom panel. Once again, the x-axis shows Finland to be relatively expensive to do R&D, Austria relatively cheap and the UK in the middle. The y-axis shows relative expense weighted by cross-border patent ownership. The UK changes from being in the middle to being relatively the most expensive. This implies that $\rho_{it}{}^{out}$ for the UK is relatively low, suggesting that the UK primarily engages in cross-border patent ownership and cooperation with countries with low tax-adjusted user costs. Compare this with Spain and Italy. Using simple weights, $ln(\rho_{it}^{in}/\rho_{it}^{out})$ is high in Italy relative to Spain. But using patent weights reverses the ranking, indicating Italy conducts cross-border patent ownership with higher user costs countries compared with the countries Spain conducts cross-border patent ownership with.

These are averages over the whole period. In our data we shall try all these measures, making use of time as well as country variation.

3 Econometric method and results

3.1 The transition to econometric work

Following others we write the following empirical model

$$ lnR_{it}^{in} = \lambda lnR_{it-1}^{in} - \theta ln\left(\rho_{it-1}^{in}\right) + \phi ln\left(\rho_{it-1}^{out}\right) + \delta lnQ_{it} + \kappa lnZ_{it} + f_i + f_t + v_{it} \tag{4} $$

where Q is real R&D-adjusted value added (i.e. market sector value added with R&D capitalised), Z are other controls and the short and long run in-country and out-of-country elasticites are $-\theta$, $+\phi$ and $-\theta/(1-\lambda)$ and $+\phi/(1-\lambda)$.

In implementing this model we have taken a number of steps. First, following others, we have included a lagged dependent variable to capture costs of adjustment. Second, there are presumably a host of country-specific variables that affect the demand for R&D in the particular country e.g. language, local amenities, the science base etc. We shall try some controls for this, but use fixed effects to account for them. Third, and related, we enter a number of variables in Z. One is log government performed R&D spend, as a measure of the local science base (we ended up dropping this, it was positive but never statistically significant). Another is (log) physical/tangible capital, since a number of studies suggest R&D might be situated geographically close to where the product is physically manufactured (R&D might for example relate to the manufacturing process).

A number of econometric issues arise. First, estimating by LSDV with the lagged dependent variable introduces Nickell (1981) bias of $O(1/T)$ to λ (we have 10 years, of data, suggesting a bias around 0.1: Nickell's equation (27) also suggests an downward bias to θ). Thus we use Arrelano-Bover-Blundell-Bond type estimators to correct for this (Arellano and Bond (1991)). Second, reverse causation would be a concern if individual countries changed their tax credits in response to investment in R&D in that country. To minimise this concern, we lag user costs, so that reverse causation would have to operate if countries changed their user costs in anticipation of future R&D spend. Endogeneity would lead to bias if a common unobserved shock affected both R&D spend and user costs. Modelling investment is notoriously hard, but a typical shock that drives investment would be business sentiment/confidence, the correlation of which with tax credits is hard to sign. Another possible shock that affects business R&D would be public spending on R&D or the skills/science base more generally. We can enter controls for this, above and beyond time and country dummies, but it is worth saying that it is in addition difficult to sign the bias, since it might be that

Table 1: Correlations

	$lnB_{i,t}^{in}$	$ln(r+\delta-\pi)_{i,t}^{in}$	$ln\rho_{i,t}^{in}$	$lnB_{i,t}^{out,avg}$	$ln(r+\delta-\pi)_{i,t}^{out}$	$ln\rho_{i,t}^{out,avg}$	$ln(B^{in}/B^{out,avg})_{i,t}$	$ln(r+\delta-\pi)_{i,t}^{in/out}$	$ln(\rho^{in}/\rho^{out,avg})_{i,t}$
$lnB_{i,t}^{in}$	1								
$ln(r+\delta-\pi)_{i,t}^{in}$	0.0684	1							
$ln\rho_{i,t}^{in}$	0.6124*	0.8233*	1						
$lnB_{i,t}^{out,avg}$	0.4014*	-0.1523	0.102	1					
$ln(r+\delta-\pi)_{i,t}^{out}$	-0.1284	0.4906*	0.3556*	-0.2044*	1				
$ln\rho_{i,t}^{out,avg}$	0.0758	0.4380*	0.3926*	0.3022*	0.8706*	1			
$ln(B^{in}/B^{out,avg})_{i,t}$	0.8854*	0.1518	0.6152*	-0.0702	-0.0362	-0.0708	1		
$ln(r+\delta-\pi)_{i,t}^{in/out}$	0.1771	0.7888*	0.6939*	-0.0236	-0.1487	-0.1459	0.2049*	1	
$ln(\rho^{in}/\rho^{out,avg})_{i,t}$	0.6141*	0.6317*	0.8477*	-0.0647	-0.1202	-0.1551	0.7016*	0.8295*	1

Notes: variables are all deviations from country means. Stars denote statistically significant correlations at 5% level.

increased public support for R&D might come with our without changes to its price. Finally, since $ln\rho^{out}$ is a combination of the outside $ln\rho^{in}$ terms, it is likely highly collinear with time dummies and so we shall experiment with dropping them.

Finally, a word on variation in the data. Since lnR is known to be very autocorrelated, using lnR_{it-1} will account for a lot of variation. We also remove more variation by controlling for country effects (via differencing). In addition, the explanatory variables are highly collinear. Table 1 shows high correlations between the variables, even in deviation from country mean format, in particular between the "in" and "out" measures. This means, as we shall see, entering the "in" and "out" variables together results in imprecise results.

3.2 Regression results

Table 2 shows the main results: robustness checks are set out below.

We start with just $ln\rho_{it-1}^{in}$ own-country user costs. Column 1 runs a simple regression, using LSDV with fixed effects and time dummies. The coefficient on $ln\rho_{it-1}^{in}$ is -0.142 and on lnR_{it-1} of 0.839. Note that these results are very similar to ?. Using data on nine countries 1979-1987 they find a coefficient $ln\rho_{it}^{in}$ of -0.144 and on lnR_{it-1} of 0.813. Note too the very high $R^2 = 0.99$ in this regression: the lagged dependent variable, fixed effects and time dummies account for a lot of variation and so the ρ_{it}^{in} effect is detected on little variation.

The inclusion of fixed effects in a panel with a lagged dependent variable renders column 1 subject to Nickell (1981) bias an so column 2 shows the GMM estimation of the same relation. The coefficient on $ln\rho_{it-1}^{in}$ falls to -0.11. [3]

Note finally on these two columns that an OLS with no fixed effects version of Column 1 gives a coefficient on lnR_{it-1} of 1.01. Bond (2002)suggests that a robustness check of GMM estimates on lnR_{it-1} is that they should lie within Column 1 estimated by OLS and LSDV: this is indeed the case.

The rest of the columns in the tables introduce the "out-of-country" measure, $ln\rho_{it-1}^{out}$. Column 3 uses $ln\rho_{it}^{out}$ as a simple average of $\rho_{jt}^{in}, j \neq i$, entered in addition to $ln\rho_{it-1}^{in}$. Recall from Table 1 that these variables are collinear: not surprisingly therefore, the terms are not that well determined. Column 4 enters $ln\rho_{it-1}^{in}$ and the outside cost in relative terms, $ln(\rho^{in}\rho^{out})_{i,t-1}$ and column 5 just the $ln(\rho^{in}\rho^{out})_{i,t-1}$ term:

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[3] This column is not strictly comparable to Bloom et al, since it excludes time dummies, to make it comparable with the other columns. If we include time dummies and use GMM we obtain a statistically significant coefficient on ρ_{it}^{in} of -0.133 (t=2.97). The coefficient on the lagged dependent rises to 0.948, giving a long run elasticity of -2.6, rather higher than the Bloom elasticity of -1.1. The elasticity might have risen over time as R&D becomes more mobile; and note that Wilson's long run elasticity using in-state user costs only is -2.2, close to this estimate.

Table 2: Regressions (dependent variable: lnR_{it})

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$ln\rho^{in}_{i,t-1}$	-0.14	-0.11	-0.13	0.10		-0.15	0.02		-0.16	-0.03	
	(-3.75)	(-1.81)	(-2.73)	(0.49)		(-3.08)	(0.18)		(-2.73)	(-0.53)	
$ln\rho^{out,avg}_{i,t-1}$			0.23								
			(1.26)								
$ln(\rho^{in}/\rho^{out,avg})_{i,t-1}$				-0.23	-0.15						
				(-1.26)	(-3.54)						
$ln\rho^{out,R\&Dwght}_{i,t-1}$						0.18					
						(1.72)					
$ln(\rho^{in}/\rho^{out,R\&Dwght})_{i,t-1}$							-0.18	-0.17			
							(-1.72)	(-3.72)			
$ln\rho^{out,Patentwght}_{i,t-1}$									0.13		
									(4.87)		
$ln(\rho^{in}/\rho^{out,Patentwght})_{i,t-1}$										-0.13	-0.12
										(-4.87)	(-4.82)
$lnR^{in}_{i,t-1}$	0.84	0.85	0.88	0.88	0.89	0.89	0.89	0.90	0.84	0.84	0.85
	(20.88)	(17.18)	(26.25)	(26.25)	(18.53)	(25.26)	(25.26)	(20.43)	(18.08)	(18.08)	(15.90)
$\Delta lnK^{tan}_{i,t}$	1.28	1.86	1.39	1.39	1.56	1.51	1.51	1.50	1.77	1.77	1.72
	(2.50)	(7.84)	(2.85)	(2.85)	(7.88)	(4.26)	(4.26)	(6.03)	(6.24)	(6.24)	(6.58)
$lnQ_{i,t-1}$	0.11	0.07	0.01	0.01	0.01	-0.00	-0.00	-0.01	0.09	0.09	-0.00
	(0.86)	(0.33)	(0.04)	(0.04)	(0.06)	(-0.01)	(-0.01)	(-0.05)	(0.38)	(0.38)	(-0.00)
$\Delta lnQ_{i,t}$	0.51	0.37	0.25	0.25	0.35	0.36	0.36	0.39	0.21	0.21	0.14
	(1.22)	(1.70)	(0.94)	(0.94)	(1.54)	(1.46)	(1.46)	(1.56)	(0.92)	(0.92)	(0.47)
R-squared	1.00										
Number of countries		10	10	10	10	10	10	10	10	10	10
No. of instruments			32	32	31	32	32	31	32	32	31
AR(1) in FD			0.0261	0.0261	0.0318	0.0288	0.0288	0.0322	0.0297	0.0297	0.0294
AR(2) in FD			0.733	0.733	0.691	0.711	0.711	0.695	0.496	0.496	0.496

Notes: Estimation by first difference GMM (not system GMM) except in first column which uses LSDV (OLS with fixed effects). Equations include constant but not time dummies (see text). Instruments are lag of lnR_{it-1},and all right hand side variables. There are 10 countries, 1995-2007. Estimation uses xtabond2 on STATA, Roodman (2009).

Table 3: Robustness checks of Table 2(dependent variable: lnR_{it} unless indicated in top row)

VARIABLES	1 all TD	2 lnR/Q	3 lnR/Q	4 $lnK^{R\&D}/Q$	5 $lnK^{R\&D}/Q$	6 B and $P_{R\&D}$	7 B and $P_{R\&D}$	8 B and $P_{R\&D}$	9 B and $P_{R\&D}$	10 B and $P_{R\&D}$
$ln\rho^{in}_{i,t-1}$		0.06 (0.28)		-0.03 (-0.61)						
$ln(\rho^{in}/\rho^{out,avg})_{i,t-1}$	-0.16 (-2.57)	-0.21 (-1.02)	-0.16 (-4.74)	-0.00 (-0.01)	-0.03 (-1.19)					
$lnB^{in}_{i,t-1}$						-0.37 (-1.87)	-0.19 (-0.24)			
$lnB^{out}_{i,t-1}$						0.18 (0.25)				
$ln(P^{in}_{R\&D})_{i,t-1}$						-0.11 (-2.17)	0.13 (0.51)			
$ln(P^{out}_{R\&D})_{i,t-1}$						0.24 (1.05)				
$ln(B^{in}/B^{out})_{i,t-1}$							-0.18 (-0.25)	-0.30 (-1.81)	-0.22 (-1.10)	
$ln(P^{in}_{R\&D}/P^{out}_{R\&D})_{i,t-1}$							-0.24 (-1.05)	-0.13 (-3.33)		-0.12 (-3.22)
Number of countries	10	10	10	10	10	10	10	10	10	10
No. of instruments	41	17	16	17	16	34	34	32	31	31
AR(1) in FD	0.0312	0.0106	0.0128	0.717	0.865	0.0217	0.0217	0.0282	0.0316	0.0355
AR(2) in FD	0.552	0.705	0.680	0.686	0.877	0.652	0.652	0.642	0.698	0.756

Notes: Estimation by first difference GMM/IV. First column includes constant and time dummies, other columns do not. Instruments are lag of lagged dependent and all right hand side variables. There are 10 countries, 1995-2007. Equations also include lagged dependent and $\triangle lnK^{TAN}, lnQ_{t-1}, \Delta lnQ_{t-1}$: these are not reported.

the relative term is a statistically acceptable restriction, with the implied long run elasticity with respect to $ln(\rho^{in}\rho^{out})_{i,t-1}$ of -1.4.

Columns 6 to 11 all find qualitatively the same. The ρ^{out}_{it} measures are the other country tax-adjusted user costs weighted by respectively: in column 6-8, other country share in total non-host country R&D spend: columns 9-11 share of outside patents in host country external patents (we obtained similar measures for the distance terms).

In each case the qualitative findings are the same. First, the long run elasticity with respect to $ln(\rho^{in}_{it}/\rho^{out}_{it})$) is -1.7 and 0.8 (which we for shorthand describe as about -1). Second, in all cases, we cannot reject the hypothesis that it is relative costs only that determine lnR, in line with "beggar thy neighbour" effects.

3.3 Robustness tests

Table 3 sets out some robustness checks of Table 2, which uses the $ln(\rho^{in}\rho^{out,avg})_{i,t-1}$ i.e. the unweighted average. The equations include (not reported) lagged dependent variables and the various controls in the bottom part of Table 2.

Columns 1 includes all time dummies, and get a similar significant $ln(\rho^{in}\rho^{out})_{i,t-1}$ term. Columns 2 and 3 replace lnR with lnR/Q and likewise obtains a similar significant relative term. Columns 4 and 5 replace R&D spending with R&D stock, with the stock built using a PIM with depreciation rate of 15%: the results are not as well determined.

Columns 6 to 10 break $ln(\rho^{in}_{it}/\rho^{out}_{it}) = ln[(B_{it}(r+\delta-\pi)_{it})^{in}/(B_{it}(r+\delta-\pi)_{it})^{out}]$ into terms in lnB_{it} and

$ln((r + \delta - \pi)_{it})^{in}$. As column 6 shows entering all the terms separately gets the expected pattern of signs and magnitudes, but, likely due to the collinearity in Table 1, the individual terms are not well determined. Column 7 enters the relative terms with the level "inside" terms, again the terms are not well determined. Column 8 just enters the relative terms, both are better determined, with the $ln(B^{in}/B^{out})$ terms borderline significant (an F test fails to reject the hypothesis the terms are equal). The lagged dependent variable (not reported is 0.88), which gives a long run of -2.5 (compare with Wilson's of -2.2). The final two columns, for completeness, enter the terms individually.

Finally, some other checks. First, we also used an ex-ante measure of $(r+\delta-\pi)_{it}$ being the BBB borrowing rate, adjusted for country inflation and taking $\delta = 0.15$. This gave a relative $ln\rho$ term of =0.06 (t=0.41). Second, we entered as well a policy uncertainty term, derived from Bloom (2013), for four countries: it was insignificant, with the $ln(\rho^{in}/\rho^{out})_{it-1}$ term of -0.12 (t=3.56). Third, as a check on the GMM procedure, As a partial check, we simply re-ran by LSDV the basic in-country and relative-country columns 4 and 5 in table 2. The results are very similar: with coefficients (t stats) on in-country and relative country of 0.05(t=0.31), -0.17(t=1.11) and relative country only user costs -0.12(t=3.81). Finally, we interacted the relative cost term with the share of the country R&D that is foreign, but this was insignificant.

4 Conclusion

If R&D is mobile between countries it might respond to both in-country tax credits, but also out-of-country tax credits. Using data on 10 EU countries, 1995-2007, we test response of country R&D spending to in-country and out-of-country R&D user cost. The out-of-country R&D user cost is measured in a variety of ways, the simplest being the unweighted average of R&D user costs in the 9 other countries. We find the long run elasticity of R&D spending to in-country user costs is around -1 and to out-of-country user costs is +1. Using a number of measures of out-of-country user costs, we cannot reject the hypothesis these effects are equal and opposite. This suggests, like in the US, beggar-thy-neighbour effects.

Does this mean that if a country becomes tax uncompetitive it loses all its R&D? Not quite, since our regressions include a fixed effect, suggesting that they will have less R&D investment relative to a country fixed effect of investment. Does the finding of beggar-thy-neighbour effects mean that R&D tax policy should be centralised? Principles of fiscal federalism suggest that centralisation is to be preferred with externalities, but that can be outweighed by superior local information and accountability. Judging this balance is wider than the scope of this paper.

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