Institutions and the sources of innovation: the determinants and effects of international R&D collaboration

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Abstract: This paper examines the phenomenon of international R&D collaboration in the form of cross-national patenting. Using a unique dataset on patents from the USPTO for a maximum of 125 countries over the period 1975–2005, we show that, despite the potential for technological advancement arising from R&D collaboration with tier 1 countries, there is no evidence that relatively poor and open countries raise their technical efficiency by doing so. In fact, the overall picture is one in which a poor, open, developing country is hurt by tier 1 collaboration. We have also identified non-linearities in the effects of overall patenting on technical efficiency, indicating that a certain threshold in numbers of patents per capita must be reached before technical efficiency increases. These results can be attributed to the keen international competition for researchers and research investment and the inability of firms in the home country to take advantage of such patenting and attract investments.

Keywords: international R&D collaboration; productivity change; total factor productivity; TFP; economics of growth; intellectual property rights; democracy.

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1 Introduction

Inter-country R&D collaboration is just one of several forms of international coordination and collaboration. Others include bilateral or multilateral trade talks, programmes with international agencies, international joint venture investments, and other forms of coordination among firms and other sub-national entities. International R&D collaboration is distinct from these other forms in that the transferred product is not always tangible, the direction of the transfer is not clearly delineated, and the degree to which the benefits may accrue to all collaborating countries and even beyond them is unclear. But, it is a form of international collaboration that (as shown below) has grown very rapidly over the last few decades, probably more rapidly than the other aforementioned forms of international cooperation, despite counter-claims of technology-nationalism (Ponds, 2009). Yet, research on its effects has grown only slowly and often omits institutional analyses (Wagner, 2005), leaving gaping holes in the analysis of its determinants and effects, including those on total factor productivity (TFP) growth.

This paper attempts to answer three questions that should help in improving understanding of these issues:

1 To what extent does international R&D collaboration have significant effects on TFP growth of participating countries involved in the collaboration?

2 To what extent do these effects vary across countries?

3 What are the determinants of international R&D collaboration?

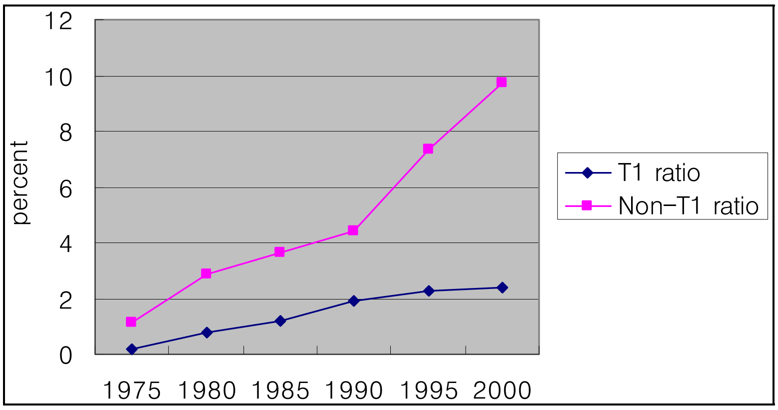
The latter question is of interest not only for its own sake but in order to mitigate potential endogeneity in assessing the effects of international R&D collaboration on TFP growth.

To that end the remainder of the paper is organised as follows. Section 2 provides a concise review of relevant literature linking R&D collaboration with economic growth. Section 3 describes the empirical specification of the model including the way TFP is calculated. Section 4 presents the empirical results, revealing sizable differences in the effects of international R&D collaboration across countries at different levels of GDP per capita, openness to trade, and pre-existing levels of TFP as well as the important role of institutions in the determination of such collaboration. Section 5 contains our conclusions.

2 Patents, R&D collaboration, institutions and growth

A common measure of R&D effectiveness is the number of patents generated, e.g., in a particular country and year. Patents are registered at the national level, the USA being the world leader in number of patents registered, in this case by the US Patent Trademark Office (USPTO). USPTO (2008) data show that the number of patents in the USA has increased rapidly from 27,000 in 1975 to over 91,000 in 2000.[1] As in most other countries, the patents registered in the USA are by no means limited to those registered by US firms or individuals. Yet, almost everywhere firms from a small number of countries hold the preponderance of registered patents. In the US case, five countries alone have consistently accounted for about 70% of all the patents registered. Even the composition of the top five countries has been quite stable over time, the USA, Japan and Germany being among the top five in every year, with France and the UK being the other two in years prior to the mid 1990s but with UK replaced by Taiwan beginning in 1995 and France by Korea in 2000. As shown in Figure 1, the USPTO (2008) data also show that the percentage of such patents with collaborators from different countries has increased rapidly from a little over 1% in 1975 to over 12% in 2000.

Figure 1 Percentage of total patents represented by collaboration with researchers or firms in different countries (see online version for colours)



Notes: Tier 1 (T1) and non-tier 1 (non-T1). 'T1' represents tier 1 countries, and 'non-T1' is all other countries.

Numerous scholars [starting with Romer (1990), Aghion and Howitt (1992), Helpman (1993)] developed R&D-based endogenous growth theory as a means of explaining continuing steady growth in high income, highly capital-intensive countries for which the convergence properties of neoclassical growth theory would otherwise suggest declining growth rates for these countries over time. Yet, in fact, in the case of internationally collaborative patents, their growth has been considerably greater among countries outside of the top five patenting countries. For example, Figure 1 shows that the share of patents registered in the USA accounted for with collaboration with firms and individuals exclusively from top five countries (which we henceforth call tier 1 countries) rises to only over 2% by 2000 whereas the share of those with collaboration from non-tier 1 countries rose to almost 10% by the same year. The explosion of collaborative R&D, especially that involving some collaborators from non-tier 1 countries, would offer the possibility that it could influence technological growth (i.e., TFP) and thereby raise overall growth and facilitate catch-up by technologically backward countries. One objective of the present paper is therefore to examine this effect empirically.

An early empirical attempt to examine internationalisation and technological collaboration was that of Dodgson (1993), which describes triadic collaboration among the USA, Europe, and Japan.[2] Applying a case study approach, Dodgson concludes that collaboration is done primarily by firms to increase skills or learning opportunities, and that publicly promoted R&D collaboration has generated relatively little in the way of cross-border R&D collaboration, witnessed for example by IBM's many failed attempts to join the Europe's public-funded ESPRIT programme. Although Dodgson mentioned that the flow of information generated from such collaborative R&D could help technology-trailing countries, to the best of our knowledge this hypothesis has not been explored empirically at the macro-level. Also unexplored has been the extent to which specific policies of non-tier 1 countries may have contributed to the rapid growth of collaborative R&D.

On the other hand, there is some existing evidence on the potential importance of R&D collaboration in economic growth in general. First, Kim (1999) investigates the important role of informal mechanisms in transferring technology to technology lagging countries when the latter are endowed with high levels of absorptive capacity. Second, for a number of OECD countries over time, Frantzen (2002) finds that both international and domestic R&D spillovers increase TFP for large economies. Frantzen, however, does not control for the expected positive correlation between domestic R&D intensity and the propensity for international R&D spillovers.[3] Third, Park (2004), in exploring the effects of R&D in domestic and foreign for 14 OECD countries, Korea, Taiwan, and Singapore, identifies international R&D spillovers from foreign manufacturing research efforts by tracing trade flows and outsourcing across countries and sectors.[4] The last two of these TFP-based analyses focus on the world's most R&D-productive countries and measure international technological diffusion based on the unrealistic assumption that all countries are equal in their ability to imitate technology and/or reverse engineer.

In growth accounting, several attempts have been made to extend the neo-classical model in ways that come close to capturing R&D collaboration effects on growth. Somewhat akin to the approach taken here, both Jones (1995) and Barro and Sala-i-Martin (2003) use endogenous models of technological progress and diffusion via dynamic panel datasets, but neither makes explicit use of international R&D collaboration. By incorporating international R&D collaboration into these earlier models, we deepen our understanding of the determinants of TFP, and more specifically assess the extent to which this rapidly growing source of collaboration in R&D can allow poorer countries to catch up in TFP. We also investigate the connection between domestic capabilities and policies and the facilitation of such collaboration.

Much existing research on institutions and growth links high rates of investment in physical and human capital and other sources of growth to institutions. For example, building on the work of North (1990) and others, Hall and Jones (1999) measure the key institutions or 'social infrastructure' by institutions which are designed to encourage productive activity, those limiting the diversion of resources into rent-seeking, and those protecting property rights.[5] These approaches, which we follow as well at least partially, serve to alleviate some of the confusion about how research is disseminated internationally and the role of institutions therein,[6] although in our case only in terms of their impact on the propensity to collaborate with tier 1 countries.

3 Empirical specification

3.1 Overview

The model presented here is a two-staged one, assessing both the determinants and the effects of international R&D collaboration. Stage one assesses the direct effects of the relevant institutions on both patenting in general and tier 1 collaboration in particular, while stage two uses these variables to examine their effects on TFP. When generating estimates for panel data, though, we are faced with the issue of how to treat country-level effects over time. Fixed effects control for constant unobserved heterogeneity, such as a particular non-changing country characteristic. When unobserved heterogeneity is not constant over time, country-specific differences may be considered random disturbances. To remedy this, we account for country-specific time trends in patenting and in TFP, controlling for omitted variables that differ between cases but change over time.

Measurements of TFP are based on the residual from the growth accounting regressions in which the log of GDP per capita is a function of physical and human capital per capita. To mitigate the effects of business cycle fluctuations and other short term shocks, the time periods adopted here are five year averages. Labour is measured by the number of workers in time period *t*, and labour productivity is found by dividing real GDP (in constant prices) by the total number of workers, both in time period *t*. Capital is a stock measure based on the flow of investment. Both the physical capital and human capital measures are taken in per capita terms and in logs, and the residual from the GLS regression is a weighted average of the random-error component and the overall error component.[7] Full details are provided below.

The number of per capita patents is the total number of patents generated by a country divided by the population (in thousands). Since the effects of patenting activity per capita on aggregate TFP would certainly not be instantaneous, we examine the effects of lagged patenting on the current level of TFP and also allow for non-linearities in these effects. We also distinguish between the effects of patenting in general and in those done in collaboration with tier 1 patenting countries. The latter is measured in terms of the percentage of total patenting represented by collaborative patents. The basic empirical framework is therefore as follows:

$$TFP_{it} = f\begin{pmatrix} \text{lag of total patenting, non-linear patenting effects,} \\ \text{patenting with tier 1 collaboration,} \\ \text{country-specific time trends} \end{pmatrix}_{it}. \tag{1}$$

In order to identify a number of the aforementioned mechanisms related to international R&D collaboration which might affect TFP, a number of additional explanatory variables are added to (1). Following Park (2004) and Keller (2002), we include openness, both by itself and interacted with the intensity of tier 1 collaboration. Then, in line with Frantzen's (2002) claim that spillovers increase TFP more for larger or higher income economies, we add to the right hand side of (1) the interaction between tier 1 collaborative intensity and GDP per capita. Finally, consistent with Kim (1999), since absorptive capacity may be partially captured in our measurement of TFP, we introduce an interaction between tier 1 collaborative patents and lagged TFP. This more elaborate model is represented by (2):

$$TFP_{it} = f\begin{pmatrix} \text{lag of total patenting, non-linear patenting effects,} \\ \text{patenting with tier 1 collaboration, openness,} \\ \text{tier 1 collaboration} \times \text{GDP,} \\ \text{tier 1 collaboration} \times \text{openness,} \\ \text{tier 1 collaboration} \times \text{lag TFP,} \\ \text{country-specific time trends} \end{pmatrix}_{it}. \quad (2)$$

3.1.1 Determinants of tier 1 R&D collaboration

We cannot properly estimate either (1) or (2) without first understanding the determinants of the intensity of tier 1 collaboration, in line with the two-staged model outlined above. Two institutions deemed to be of considerable relevance to R&D collaboration and for which measures are available for all countries in our sample are intellectual property rights (IPRs) and a Political Constraints (POLCON) index. The latter is a measure believed to assure stability in relevant policies and institutions (Henisz, 2000), thereby potentially at least having a positive effect on the willingness of agents to invest in R&D. IPRs, on the other hand, can attract technology to a country (Mansfield, 1995; Caselli and Coleman, 2001) especially after the returns to innovation resulting from such IPRs become apparent (Kim, 2003).[8]

In her review of the literature, Aron (2000) also confirms that both key political institutions (in her case civil liberties) and property rights are determinants of economic growth. Her conclusions, however, were probably not robust given the likelihood of simultaneity issues between institutions and growth to be discussed below and the fact that her measure of political institutions was perhaps not the most relevant one to patenting and R&D collaboration. Just as Barro (1998) concluded in his examination of the connection between growth and democracy that there is a non-linear relationship between political rights and economic growth, we deem it appropriate to allow for threshold effects in the effects of institutions on international collaboration and TFP.[9]

There is also a possibility that the effects of IPR and POLCON on international collaboration may not be independent of one another. They could be either substitutes or complements. For this reason we shall also introduce interaction terms between them among the explanatory variables. We also cannot rule out the possibility that existing levels of absorptive capacity (measured by the lag of TFP and GDP per capita) will impact tier 1 collaboration. These relationships are also included in (3):

$$\text{Tier 1 collaboration}_{it} = f\begin{pmatrix} \text{IPRs, political institutions,} \\ \text{IPRs} \times \text{political institutions,} \\ \text{GDP per capita,} \\ \text{IPRs} \times \text{GDP per capita,} \\ \text{political institutions} \times \text{GDP per capita,} \\ \text{lag TFP} \end{pmatrix}_{it}. \quad (3)$$

The same set of right-hand side variables in (3) is also used to predict the change in the log of all patents. This allows us to compare the effects of these institutions on the change in overall patenting with those on the intensity of tier 1 collaborative patenting. It also provides us with predicted values for these for use in the second stage of the analysis: taking the predicted values for tier 1 collaboration based on (3) and the predicted values for the change in the log of total patents and then inserting them into (1) and (2).

Finally, it is important to recognise that there could be a potential endogeneity problem in our estimates of the effects of institutions on collaboration and TFP just as in many such studies using institutional measures to explain growth. This is because growth may affect institutions just as much as institutions may affect growth. As a result, there is a large literature which attempts to control for the endogeneity of institutional analysis in a growth framework, wherein growth may affect institutions instead of only institutions affecting growth.[10]

We acknowledge that the endogeneity problem could be pronounced for IPR and hence instrument the IPR index with the interactive effect of a country's legal origins and the pressure to strengthen IPR imposed by the US Government in the form of putting the country on its Special 301 status watch list, as shown in equation (4). In the case of POLCON, however, for any country its index is likely to reflect its constitution which may have been determined far back in history and/or by the vagaries of frequently changing party coalitions. As such, POLCON may affect the stability of government commitments and hence the incentives for R&D investments and TFP but not likely the other way around.[11, 12]

$$\text{IPRs}_{it} = f\begin{pmatrix} \text{lag Special 301 status} \times \text{common law origins,} \\ \text{lag Special 301 status} \times \text{French law origins,} \\ \text{lag Special 301 status} \times \text{German law origins,} \\ \text{lag Special 301 status} \times \text{Scandinavian law origins,} \\ \text{lag Special 301 status} \times \text{socialist law origins} \end{pmatrix}_{it}. \tag{4}$$

As was the case with (3), the right-hand side of (4) is also used as to predict the change in patents over time and limit the potential biases arising from omitted variables and endogeneity via the following revised procedure for estimating TFP:

$$TFP_{it} = f\begin{pmatrix} \text{lag of total patenting*, non-linear patenting effects*,} \\ \text{patenting with tier 1 collaboration*, openness,} \\ \text{tier 1 collaboration}* \times \text{GDP,} \\ \text{tier 1 collaboration}* \times \text{openness,} \\ \text{tier 1 collaboration}* \times \text{lag TFP,} \\ \text{country-specific time trends} \end{pmatrix}_{it}. \tag{2'}$$

where * denotes predicted values.[13]

3.1.2 Calculating TFP

Our model of TFP begins from the following constant returns to scale production function,

$$Y = K^{\alpha}(AH)^{1-\alpha}, \tag{5}$$

with GDP per capita, Y, physical capital flows, K, A (for TFP), and human capital flows, H, where α and $1 - \alpha$ are measured by the capital and effective labour shares, respectively. The use of this labour-augmenting technological change formulation provides comparability with other studies and is consistent with the majority of all R&D-based growth models, such as Romer (1990) and Jones (1995, 1999). As a result, rather than looking at the rates of change between each time period, we examine the levels of physical and human capital in each particular time period.

Notice that A or TFP represents labour-augmenting technology, but as shown below, we drop the assumption that it is exogenous. Following Hall and Jones (1999), we use it to go beyond the standard neoclassical growth model by emphasising cross-country and longitudinal differences in the residual, in a way that incorporates institutional influences. In particular, we use a technology-related measure, namely, the ratio of the number of per capita international collaborative patents to total patents, at least crudely capturing the effects of patenting and collaborative R&D on TFP. Patenting activity can generate income streams, perhaps through licensing and higher productivity, and perhaps also encourage further research through spillover effects, thereby serving to contribute to a virtuous growth cycle.

Since Benhabib and Spiegel (1994, 2002) have demonstrated that average levels of human capital (but not the growth rates thereof) are significant predictors of per-capita income growth, we use year-specific average number of years of schooling for a country's population aged 15 or older (from Barro and Lee, 2000) as our measure of educational attainment H.

It is generally assumed that individuals accumulate human capital by learning new skills while not working, meaning through education. We apply the Mincerian formulation and consider human capital as a function of s, the average years of schooling of the total population aged 15 and over, with ψ representing the returns to schooling each year, and assuming that people complete their full time schooling before beginning full time work (Mincer, 1974; Klenow and Andres, 1997):

$$H = e^{\psi s} L, \tag{6}$$

where L is the labour force, defined as the population of a country aged 15 and over. But, since the correlation between the size of the entire population and that aged 15 and over is sufficiently high, and labour force participation is subject to measurement errors quite possibly varying in magnitude and direction across countries, for simplicity we assume that L can be proxied by the population. We will assume that ψ is 0.10, or 10%, which is consistent with the estimates provided by Bils and Klenow (2000).

Capital stock accumulation is given by:

$$\dot{K} = I_K - \delta K, \tag{7}$$

where the change in physical capital stock is the difference between I_K, the level of gross investment in physical capital, and δK, the depreciating capital. If we divide both sides of (5) by AL, and define y, k and h as Y/L, K/L and H/L, respectively, we have

$$\frac{y}{A} = \left(\frac{k}{A}\right)^{\alpha} h^{1-\alpha}. \tag{8}$$

Using (~) notation to show the ratio of a variable to A or TFP,

$$\tilde{y} = \tilde{k}^{\alpha} h^{1-\alpha}, \tag{9}$$

capital accumulation per technology-adjusted worker is:

$$\dot{\tilde{k}} = I_K - (n + \gamma + \delta)\tilde{k}, \tag{10}$$

where, for a particular period, n is the geometric mean of the average growth of the labour force as defined above, γ is the average TFP growth and δ is the fixed depreciation rate. Different studies have estimated or simulated with different fixed depreciation rates in similar models. For example, Benhabib and Spiegel (2002) assign δ a value of 0.03, and Jones (1997) assigns γ a rate of 0.03 for developed (OECD) countries and 0.01 for developing countries. The values of α and $1 - \alpha$ are set at one-third and two-thirds for all developed (OECD) countries[14] but at one-half for all remaining (developing) countries. The latter are chosen to be consistent with both values for developing countries assumed or estimated in other studies, and reflecting the higher scarcity value of capital in developing countries. We apply these rates in our empirical analysis, with developed countries defined by OECD membership status in 1970.

Our model is based on the assumption that there is an initial level of capital accumulation from which the capital stock shifts. Since our focus is on the entire period from 1975 to 2005, the values of capital-labour ratios for the initial (1975–1979) as well as for each subsequent five-year period can be calculated from the steady-state level of physical capital, presented in (10):

$$\tilde{k} = \frac{I_K}{n + \gamma + \delta}\tilde{y} = \frac{I_K}{n + \gamma + \delta}\tilde{k}^{\alpha} h^{1-\alpha}, \text{ as } \dot{\tilde{k}} = 0, \tag{11}$$

$$\tilde{k}^* = \left(\frac{I_K}{n + \gamma + \delta}\right)^{\frac{1}{1-\alpha}} h. \tag{12}$$

After substituting this into (7) and dividing by $\tilde{y} = \frac{y}{A}$, we have

$$y(t) = \left(\frac{I_K}{n + \gamma + \delta}\right)^{\frac{\alpha}{1-\alpha}} hA(t). \tag{13}$$

As in Jones (1997), (13) expresses the level of income per capita as a function of the per capita accumulation of factors of production.

Equations (11) to (13) treat productivity A as exogenously determined and as a public good, implying that it is non-excludable and non-rivalrous, as specified by Solow (1957). A, thus, receives no compensation and may be exploited without limits. Arrow (1962) on the other hand, claims that increases in capital goods, K, increase knowledge through 'learning by doing',[15] to which we would add that which is accumulated while not working (i.e., before doing). But responding to the Romer (1990) critique that exogeneity would prevent firms from intentionally investing in R&D, we instead treat A as endogenous, arising from the intentional actions of firms to invest in R&D with or without international collaboration. These actions may be affected by both changing market conditions and institutions. While many institutions could be relevant, given the focus of this study, as indicated above we focus on two:

1. the country- and period-specific incentive to engage in R&D, collaborative or otherwise (as captured by a country and period-specific IPR index)
2. the political constraints index (POLCON).

4 Results

The empirical estimates presented in this section are based on an almost balanced panel dataset for 125 countries over the period 1975–2005. When the IPR indexes (along with other variables) are included as in the second-stage of the analysis, however, data availability is limited to 111 countries. The estimates of the GLS fixed effects model are preferred because the modified Hausman tests (for the inclusion of country-specific time effects) provide evidence in support of the fixed effects model. GLS modelling techniques allow for higher weights to be applied to countries with higher output and smaller disturbance variances than countries with lower output and larger disturbance variances (Greene, 2002). This effectively controls for the volatility which remains after using five year averages of the data. The definitions of all variables and descriptive statistics are presented in the Appendix.

While the inclusion of time trends allows exogenous common movements in TFP to be captured, it fails to isolate any country-specific time trends. Aside from patents and related variables, which are the only country-specific time varying explanatory variables used in the model, there can be other unmeasured country-specific factors that might vary over time. Thus, we also allow for country-specific time trends in most of the analysis to help us to avoid the potential biases that would arise if these country-specific time trends were not allowed.

Table 1 presents our estimates of the effects of the lagged value of all patents (in per capita and logarithmic terms), tier 1 collaboration intensity, and the aforementioned other controls (including interaction terms).[16] In estimating the effects of the lagged number of all patents per capita, non-linearities are allowed for by the inclusion of an additional square term in each of the ten columns in the table, each column corresponding to a different specification of other variables. Across all columns the results provide strong support for the non-linearity, showing specifically that, up to a certain threshold, TFP falls with the number of patents but that, after that threshold is reached, its effect on TFP becomes positive. Bearing in mind that the patents are registered in the USA, the negative effect of the linear term means that these patents hurt rather than benefit TFP at home since they may well favour production in the USA or other developed countries to take advantage of the greater availability of skills and stronger institutions there. But, once a certain threshold in numbers of patents per capita is surpassed, this would seem to reflect their use in the home country, reflected in a positive effect on that country's TFP.

Another consistent finding across all specifications in Table 1 is that the effect of the intensity of tier 1 collaborative patenting, measured by the ratio of tier 1 patenting to the total number of patents, is negative and significant in all columns except

Column (4). The positive coefficient of the interaction term between the intensity measure of tier 1 collaborative patenting and the log of GDP per capita, however, suggests that these negative effects are offset if a country has a high enough level of GDP per capita (columns 3, 5, 7, and 10 of Table 1).[17] This means that the negative impact of having more tier 1 patents as a share of total patenting is smaller in countries with high levels of GDP per capita (in log terms), and indeed at high enough levels of GDP per capita (such in most OECD countries), the net effect can even become positive. This underscores the importance of absorptive capacity and complementary resources in international R&D collaboration with tier 1 countries. The positive coefficients estimated for the interaction term between tier 1 intensity and lagged TFP may reflect the same factors, though in this case their statistical significance is weaker.

Openness, either by itself as in column (2) or interacted with either the ratio of tier 1 collaborations to all patents as in columns (4), (5) and (10) or the lag of all patents per capita as in column (8), has a consistent negative and significant effect on TFP. This indicates that openness tends to reduce any benefits of tier 1 collaborative patenting. This could be the result of a country focusing on industries in which there is less growth of output because of openness. If products from other countries are taking over the market of country *i*, the interaction between openness and tier 1 collaborative patenting can negatively affect TFP. On the whole, these results suggest that poor, open developing countries may have little to benefit from tier 1 collaboration.

Backing up now to the determinants of the ‘first stage’ of our analysis, Table 2 presents the estimates obtained from (3) above. IPRs and POLCON exercise positive (though not always statistically significant) effects on the ratio of tier 1 collaborative patenting. None of the other terms, such as the log of GDP, lagged TFP or interactions between IPR and either POLCON or log GDP, however, have significant effects on tier 1 intensity. The results in column (7) are for a specification identical to that in column (1) except that IPR is instrumented by a term representing the interaction between legal origins and an index of US Special 301 behaviour. The results show that the effects of this interaction term are consistently positive and significant.

The other component of the first-stage analysis is a method for obtaining predicted values for the lagged log of all patents. Since it is only lagged values that are needed, we could argue that predicting lagged values would be unnecessary. Nevertheless, since patenting is at least closely related to TFP with or without lags, and could be jointly determined, we choose to estimate equation (3) anyway but in terms of changes. We then use the actual double lagged levels along with lagged values of the predicted changes to construct the lagged levels of all patents (in log terms). The parameter estimates for five different specifications of the change in the log of all patents are presented in Table 3. In each case the estimated coefficients both IPR and POLCON are positive and in most cases they are statistically significant as well. The greatest exception is in column (3) where an interaction term between the two variables is included and, because of collinearity among all three of these variables, none turns out to be significant. In column (4), where lagged TFP is included, the coefficient of this variable is negative and significant, suggesting that a low value of lagged TFP can constitute a motive for increased patenting activity. Column (5) uses the same specification as in column (1) but in this case making use of the aforementioned instruments for IPR, legal origins and the Special 301 status.

Table 1 Determinants of TFP while not accounting for institutions

	TFP									
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
Lag log (all patents)	–0.0491431***	–0.0550921***	–0.0560724***	–0.053793***	–0.0632937***	–0.0500294***	–0.0573677***	–0.0519785***	–0.0530328*	–0.0642483***
	(0.0131866)	(0.0129945)	(0.013437)	(0.0135977)	(0.0136346)	(0.0135325)	(0.0137761)	(0.013682)	(0.0315118)	(0.0140471)
Lag log (all patents squared)	0.0057612***	0.0065381***	0.0067403***	0.0064482***	0.0076483***	0.0059183***	0.0069728***	0.0071511***	0.0056052***	0.0078366***
	(0.0017809)	(0.0017655)	(0.0018189)	(0.0018568)	(0.0018565)	(0.0018495)	(0.0018877)	(0.0019037)	(0.0021207)	(0.0019372)
Ratio of tier 1 to all patents	–0.0938542**	–0.0837218**	–0.6611796***	–0.0675007	–0.9843606***	–0.0818981**	–0.6692805***	–0.0927457**	–0.0942288**	–0.9932304***
	(0.0370475)	(0.0358207)	(0.02484758)	(0.0428632)	(0.2722505)	(0.038313)	(0.2485521)	(0.0371857)	(0.0372071)	(0.2727674)
Openness		–0.3263507***								
		(0.0652812)								
(Ratio of tier 1 to all patents) * (log(GDP per capita)			0.0757232**		0.1436801***		0.0786868**			0.1472961***
			(0.0327994)		(0.0412416)		(0.0329046)			(0.0413507)
(Ratio of tier 1 to all patents) * (openness)				–0.0428632	–0.2820638**					–0.2856446**
				(0.0916902)	(0.1132642)					(0.1130995)
(Ratio of tier 1 to all patents) * (lag TFP)						0.0984483	0.1073715*			0.1119422*
						(0.066437)	(0.0660393)			(0.0657968)
(Lag log (all patents)) * (openness)								–0.0067577		
								(0.0061449)		
(Lag log(all patents)) * (log(GDP per capita))									0.0006284	
									(0.0046226)	
Country-specific time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	556	543	556	543	543	537	537	543	556	525
F-stat	4.66***	5.07***	4.73***	4.49***	4.72***	4.47***	4.55***	4.52***	4.61***	4.69***
R2	0.6284	0.6498	0.6346	0.6218	0.6361	0.6253	0.6322	0.6230	0.6284	0.6405

Notes: Standard errors in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 2 Determinants of tier 1 collaborative intensity

	Ratio of tier 1 to all patents						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
IPR	0.0490478***	0.0270203	0.0280658	0.0914888	0.0282548	0.0332252**	0.0648148***
	(0.0153126)	(0.020513)	(0.0484758)	(0.1154666)	(0.0211351)	(0.0163122)	(0.0156201)
POLCON	0.0181046**	0.0152297**	0.011967	0.014319*	0.0284416	0.0226671***	0.0160263**
	(0.007354)	(0.0075764)	(0.0153345)	(0.00775)	(0.0541125)	(0.0084157)	(0.0064954)
Log(GDP)		0.048264		0.0648266	0.0563951		
		(0.0305265)		(0.0422539)	(0.0449561)		
IPR * POLCON			0.0036164				
			(0.0079267)				
IPR * log(GDP)				–0.0071442			
				(0.0125917)			
POLCON * log(GDP)					–0.0017412		
					(0.007061)		
Lag TFP						0.0828224	
						(0.0606643)	
Country-specific time trends	No	No	No	No	No	No	No
Instruments for IPR	No	No	No	No	No	No	Legal origins * Special 301 status.
N	583	580	583	580	580	434	794
F-stat	11.72***	8.13***	7.87***	6.17***	6.10***	6.98***	17.09***
R2	0.0473	0.0495	0.0477	0.0502	0.0496	(0.0590)	(0.0505)

Notes: Standard errors in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 3 Determinants of the change in overall patenting

	Change in log(all patents)				
	(1)	*(2)*	*(3)*	*(4)*	*(5)*
IPR	0.2813257***	0.26038***	0.0382013	0.1898734**	0.1736707
	(0.095181)	(0.1299105)	(0.3142377)	(0.097901)	(0.2165024)
POLCON	0.1191674***	0.1299105***	0.0464741	0.1310133***	0.0833223**
	(0.0375579)	(0.0377302)	(0.0971059)	(0.0412906)	(0.0395203)
Log(GDP)		0.1384317			
		(0.536136)			
IPR * POLCON			0.0391854		
			(0.0482632)		
Lag TFP				–0.8693434**	
				(0.3364033)	
Country-specific time trends	Yes	Yes	Yes	Yes	Yes
Instruments for IPR	No	No	No	No	Legal origins * Special 301 status.
N	350	348	350	323	413
F-stat	1.86***	1.91***	1.84***	2.09***	1.27*
R2	0.4588	0.4730	0.4608	0.4858	0.3735

Notes: Standard errors in parentheses. $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 4 Determinants of TFP while accounting for institutions

	TFP							
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Lag log (all patents)	–0.0642483***	–0.0565879***	–0.135197*	–0.0136863**	–0.013793**	–0.0144675**	–0.0151853**	–0.0214085***
	(0.0140471)	(0.0092515)	(0.0070033)	(0.0069876)	(0.0069615)	(0.0069776)	(0.0068514)	(0.0055659)
Lag log (all patents squared)	0.0078366***	0.0065304***	0.0016104**	0.0016412**	0.0017145**	0.0016212**	0.0017862**	0.0011617**
	(0.0019372)	(0.0010495)	(0.0008024)	(0.0008007)	(0.0008005)	(0.0007977)	(0.0007864)	(0.0005782)
Ratio of tier 1 to all patents	–0.9932304***	–1.101212***	–0.9506178**	–5.222684*	–0.347527	–0.9958004**	–6.981835**	–4.821058***
	(0.2727674)	(0.2706992)	(0.4118071)	(2.811349)	(0.4743951)	(0.409995)	(2.83169)	(1.163402)
(Ratio of tier 1 to all patents) * (log(GDP per capita)	0.1472961***	0.1610117***		0.5305302			0.8488027**	0.555139***
	(0.0413507)	(0.0401029)		(0.3453818)			(0.3543528)	(0.1254854)
(Ratio of tier 1 to all patents) * (openness)	–0.2856446**	–0.2926724**			–0.89561***		–1.268206***	–0.0398703
	(0.1130995)	(0.12131)			(0.346206)		(0.3573881)	(0.2289404)
(Ratio of tier 1 to all patents) * (lag TFP)	0.1119422*	0.2236981***				–0.4869043**	–0.6000446**	0.3515081***
	(0.0657968)	(0.0597914)				(0.233644)	(0.2357989)	(0.1063372)
Country-specific time trends	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Predicted values for explanatory variables	No	No	Yes	Yes	Yes	Yes	Yes	Yes
N	525	525	503	503	491	503	491	491
F-stat	4.69***	13.81***	4.34***	4.34***	4.43***	4.39***	4.63***	12.92***
R2	0.6405	0.1688	0.6230	0.6261	0.6296	0.6287	0.6454	0.1695

Note: Standard errors in parentheses. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Next, we bring together both sets of the aforementioned results into the integrated approach identified in equation (2') above. The results in column 1 are simply copied from Table 1, while those in column 2 represent estimates for the same specification in column 1 but omitting the country-specific time trends. Since the results in column 2 are very similar to those in column (1), this serves as a robustness check for the assumption with respect to country-specific time trends.[18] The remaining columns in Table 4 report results for TFP with specifications similar to those in Table 1, but in these cases using the two stage procedure in which the lagged log of all patents (and its square) and the ratio of tier 1 collaborative patents to total patents are those predicted from the preferred first stage equations in Tables 2 and 3.

As indicated above, the lagged log of all patents is calculated by adding the predicted values from the estimation of Table 3, column 1 to the actual double-lagged log of all patents (and squaring that sum to obtain the values for the squared term). The results presented for the most parsimonious specification are given in column 3 of Table 4 and those with additional interaction terms added one at a time in columns (4) to (6), and with them all together in column (7). In all these cases, the signs of the coefficients for the first three terms remain the same and in almost every case they also remain statistically significant even when the predicted values are used instead of their actual values. The same holds true in columns (4) to (8) for the interaction terms in columns (4) to (8), with the exception of the interaction between the ratio of tier 1 collaborative patents to all patents. The results for this one do turn out to be quite sensitive to the estimation method used.

With the exception of that one interaction term, therefore, the results presented in Table 4 show the robustness of the following results that were already seen in Table 1. The lagged value of the log of all patents has a non-linear impact on TFP, being negative up to some threshold and positive thereafter. The intensity of tier 1 collaborative patenting tends to have a negative effect on TFP of the home country in general, but the positive effects of its interaction with the log of GDP per capita shows that for countries with sufficiently high GDP per capita, the net effect turns out to be positive, once again consistent with the earlier findings of Romer (1990) and others that high income countries can raise their TFP by investing in R&D and patenting. We show that this happens also for investments in collaborative patenting with tier 1 countries. The negative effect of the interaction between the negative effect of the intensity of tier 1 collaboration and openness from column (1) is confirmed in columns (2), (5), (7) and (8).

5 Conclusions and policy implications

Based on a slightly unbalanced panel dataset of 125 countries over the period 1975–2005, our results show that registering patents in the USA raises a country's TFP only when the number of such patents exceeds some threshold. Similarly, the result reported in column (9) of Table 1 of a positive coefficient of the interaction between number of patents and GDP per capita, although not quite significant at the 10% level, seemed to suggest that the net effect of patenting in the USA on home country TFP could be positive at sufficiently high levels of GDP per capita.

These results may be explained by the keen international competition for researchers and research investment and that the ability of firms in the home country to take advantage of such patenting in order to raise productivity at home may be limited by insufficient endowments of relevant skills and capital and perhaps more importantly weak institutions to attract investments and enforce property rights.

Similarly and more the focus of this study, the intensity of nationals and firms in collaborative patenting with those from tier 1 countries has a rather consistently negative effect on TFP unless offset by the positive effects of interaction with GDP per capita or possibly the lagged level of TFP. The interaction of such collaborative patenting with tier 1 countries with the openness indicator, however, has an additional negative effect on TFP. Quite importantly, all these findings on the determinants of TFP are found to be quite robust to the specification of both the first and second stage regressions, the use of instruments, the exclusion of certain observations because of missing data and the use of country-specific time trends.

As shown in Tables 2 and 3 IPR indexes and POLCON indexes seem to be important determinants of both numbers of patents and the ratio of those patents done in collaboration with tier 1 countries to total patents. These results too are reasonably robust to alternative specifications and estimation procedures.

Our primary explanations for the negative effects of patenting activity in the USA and especially of collaborative patenting with tier 1 countries on TFP reported above, therefore, hinge on such factors as the shortage of inputs complementary to R&D expenditures and patenting activity, the inabilities to attract investment and/or to credibly commit to a consistent set of policies over the long-term, and to weak enforcement institutions.

Nevertheless, another quite plausible explanation is that patenting may impede the ability of countries at relatively low levels of patenting, GDP per capita, and TFP to imitate and reverse engineer with foreign technology. Imitation and reverse engineering have long been known as lower cost means of raising TFP for such countries than patenting (Kim, 1999). Stronger IPRs help suppress reverse engineering and imitation efforts, so they may in fact help limit the disbursement of knowledge and the growth of key capabilities. Indeed, as Maskus et al. (2005) note, this is the balancing act between protectionism and development, although this study has shown that development (as captured by the interaction terms with GDP per capita in Tables 1 and 4) trumps protectionism.

Mention can also be made of the connection between national and global welfare, which is a peripheral impetus to this study of international R&D collaboration. Much like Barrett's (2007) discussion of global public goods, international R&D collaboration has the potential not only to increase income for individual countries, but also to increase global welfare through the generation of advances in science and technology which would not have been available under non-collaborating conditions. This practice reflects the internationalisation of externalities which had previously been isolated to individual countries, particularly shared environmental and economic costs within regions. Along these lines, increased regional integration will continue to advance science and technology. Analyses of how international R&D collaboration is treated within regional pacts should be given full attention as this pattern continues, as research of economic geography attempts to address how different institutional factors facilitate and/or hinder flows of information and knowledge across firms, regions, and nations.[19]

But, given the rather strong and robust results presented here that international collaboration in R&D with tier 1 countries has a generally adverse effect on TFP of even the countries (from outside of tier 1) that engage in that collaboration, and the two quite different explanations articulated above for such finding, an important topic for future research will therefore be to distinguish between these two alternative explanations.

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Notes

1 These years actually denote aggregated patent data over five-year periods; i.e., '1975' represents 1975–1979.

2 This same geographic area was later treated by Hagedoorn (2002). Other efforts to address international collaboration apply a network analytical framework (Wagner and Leydesdorff, 2005).

3 Direct measures for domestic R&D intensity are available through the OECD's MSTI dataset, although this data is limited to the OECD and a small number of additional countries.

4 See Keller (2002) for a similar study.

5 These institutions are measured by combining an Index of Government Antidiversion Policies (accounting for expropriation risk, contract enforcement, government corruption, law and order, and bureaucratic quality) and the Sachs-Warner index of trade openness (a composite measure based on the degree of tariffs, non-tariff trade barriers, black market premiums, socialist orientations, and government monopolisation of major exports).

6 See Mowery (1998) for a discussion of this with regard to the US case.

7 The variable list and descriptive statistics can be found in the Appendix.

8 Yang and Maskus (2003) dissent from this view, claiming instead that stronger IPRs may discourage innovation and reduce international technology transfer in countries at early stages of development.

9 Specifically, Barro (1998) demonstrated that political rights can have a positive effect on growth up to a certain threshold level of such rights but then a negative effect on growth after that threshold is reached. Feng (2005) has identified other variables intervening in the relation between democracy upon economic growth while Brunetti (1997) found political rights measures to be less statistically significant than measures of political volatility and subjective perceptions of politics.

10 Frankel and Romer (1999), e.g., instrument trade openness (expressed as total exports and imports divided by GDP) with a gravity equation for trade flows. Acemoglu et al. (2001) instrument for the quality of institutions with the mortality rates of colonial settlers, since property rights and the rule of law developed with intensity when European settlers had less health problems. These methods have subsequently been employed by Rodrik et al. (2004) in their study which confirms the importance of institutions over all else. To account for the potential endogeneity of social infrastructure, Hall and Jones (1999) instrument it with distance from the equator, colonial language usage, and use of the English language.

11 Nevertheless, we did try to identify suitable instruments for POLCON but without success.

12 La Porta et al. (2008) divide legal origin assignments into Common, French, German, Scandinavian, and socialist.

13 To clarify the process of using the predicted values of the change in the log of all patents to calculate the lag log of all patents, we take the former and add it to the lagged log of all patents.

14 These conform with Benhabib and Spiegel (2002).

15 'Learning by doing' is the education process which occurs during production. This education may occur in a training facility (college- or firm-based) separate from the production floor.

16 It should be noted that, in order to achieve increasing values in the squared terms, patents (total and collaborative) have been multiplied by 1,000,000. This was the minimum factor which could be applied to per capita patents, given that the smallest untreated per capita overall patent value was around .000002 (China). This scale is the same for per capita collaborative patents.

17 This is also shown for the interactive effects of all patents and GDP per capita (Table 1, column 9), albeit at an insignificant level.

18 This check is not so much a relaxation of the assumptions about country-specific time trends but more to check for whether the inclusion of country-specific time trends in the determination of the lag log of all patents (based on the results from Table 3, column 1) have not significantly affected our two-stage results. They do not.

19 See Polenske (2007), particularly the chapters by Alice Lam and Saxenian.

Appendix

Description of variables

Variable name	*Variable description*
TFP	Revised TFP measure, based on (13)
Lag log (all patents)	Lagged (1 period) natural log of the number of per capita patents generated in a particular time period, multiplied by 1 million, from USPTO (2008)
Ratio of tier 1 to all patents	Percentage of all patents done in collaboration with tier 1 countries. That is, the number of per capita collaborative patents with tier 1 countries generated in a particular time period, divided by the number of per capita patents generated in a particular time period.
Openness	Imports and exports as a share of gross domestic product, from Heston et al. (2006)
GDP per capita	Gross domestic product per capita, from Heston et al. (2006)
IPR	Ginarte-Park IPR index score, from Ginarte and Park (1997)
POLCON	POLCON checks-and-balances score, from Henisz (2002)