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Are Many Heads Better Than Two? Recent Changes in International Technological Collaboration

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Abstract

There are two counter-intuitive trends in technological collaboration currently at work, making collaborative patent applications less common but where they exist, the collaborations involve more partners. Patent data are used to examine these trends along with the impact of recent policy changes.

Introduction

A large share of economic growth comes directly from technological change (see for example Jorgenson, 2005), whether by innovation or technology adoption. Both of those conduits rely heavily on the cross-fertilization of ideas between people, by the transmission of ideas from one location to another, by the sharing of knowledge by experts within or between disciplines, and by the combination of existing ideas into new applications (the latter frequently requiring more than one inspired mind to work in collaboration).

International technological collaboration should have become more frequent over the past three decades, given advances in information, communication and travel technology. Examples abound, from the enormous number of international conferences on scientific and technological topics, to transnational joint ventures and strategic alliances, to international teams of researchers applying jointly for patent protection of their work.

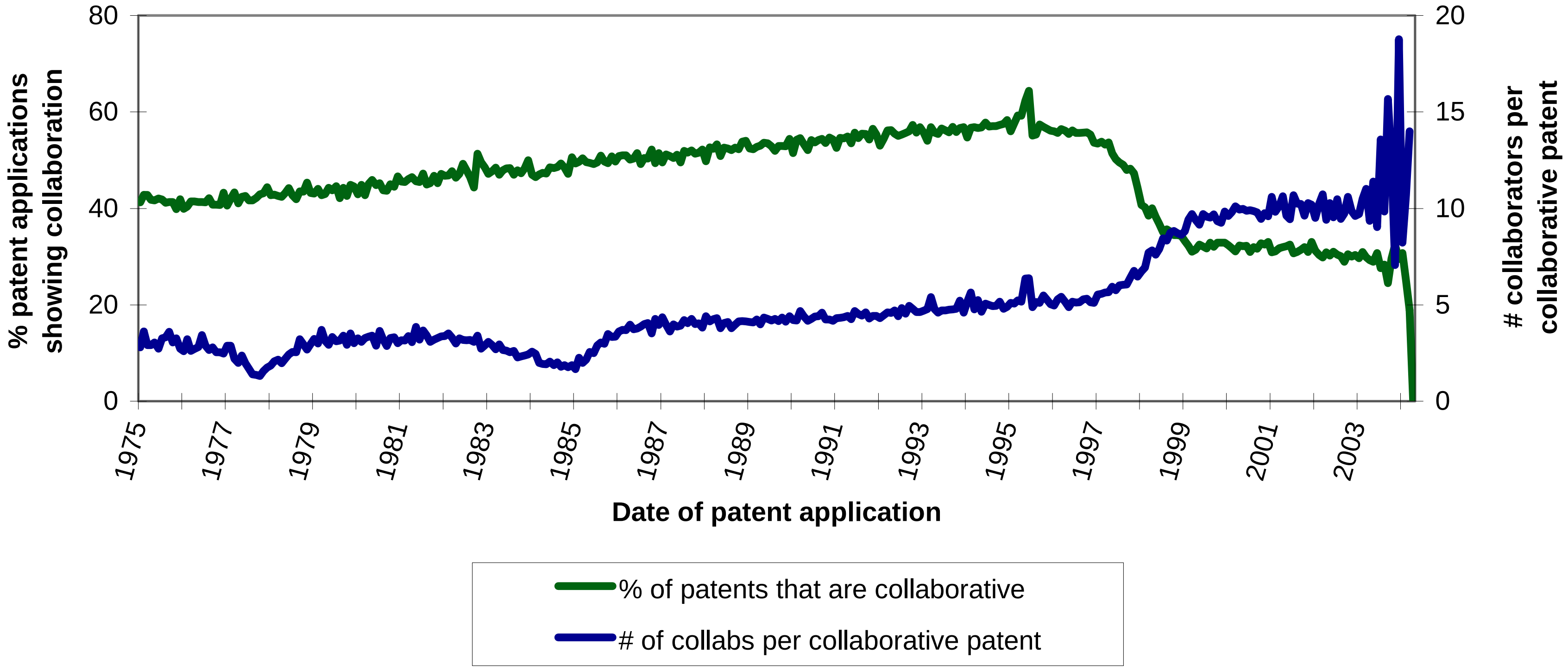
However, policy changes in science and technology (and perhaps immigration and national security) have potentially had a counteracting impact. This paper uses data from U.S. granted patents to identify which types of nations, technologies, and inventors have been most affected by changes in policy and political climate, changes which have a lasting impact on technological progress and therefore on economic growth.

While one could define collaboration in various manners, this paper relies on one objective and publicly accessible record, namely the record of co-applicants on patent documents. In order to substantiate a legal claim to ownership, all individuals involved in the creative activity of innovation leading to a patentable product or process sign their name to a patent application. U.S. law requires that applicants file as individuals with full contact addresses, giving a subsequent opportunity for firms or other legal entities to act as assignees if and when appropriate. Thus this paper exploits the public U.S. record of technological collaboration to trace the physical locations of collaborating inventors over time.

One could correctly argue that the number of collaborative names on a patent document is an imperfect indicator of the international transmission of knowledge. However, the presence of more than one name definitely indicates a sharing of information between locations, just as co-authored pieces of academic research indicate conversations between creative minds. It is an imperfect measure to be sure, but before collecting costly survey data, this paper offers these data as one view into the potentially salient characteristics of patentable technological collaborations.

Figure 1 presents two interesting changes in recent patenting activity, as reflected by all patents granted by the U.S. Patent Office between 1975 and 2004. First, approximately forty percent of all successful U.S. patent applications in 1975 showed more than one inventor of record. That share trended upward slowly but steadily, such that more than half of all patent applications through the late 1990s were collaborative in nature. The share then dropped

Figure 1: Collaborative patent activity



precipitously in the late 1990s, hovering around thirty percent through the early part of this decade. This will be referred to as “trend #1” for the remainder of this paper.

Second, among patents which show collaborative activity, the average number of collaborations has risen remarkably since 1995. Collaborative patents in the 1970s and 1980s tended to have two or three inventors, an average which grew to five by the 1990s and has exploded this decade to average more than ten per patent. This marks either a remarkable shift toward larger research teams or a legal and logistical move to include more marginal actors as joint patent applicants. This will be “trend #2” for the remainder of this paper.

In combination, the two trends suggest that patentable research collaborations are becoming rarer or less frequent than in the past, with those rarer collaborative patents each averaging more partners than before. There are naturally a number of possible reasons for these changes, some substantial and others less significant. The particular interest here is to decompose the trends into four groups of interest, to determine whether those groups have behaved similarly over the last thirty years in the face of changing IT infrastructure and U.S. foreign policy. The four groups of interest here are U.S.-only collaborations (i.e. Americans collaborating with other Americans), foreign-only (i.e. non-U.S. residents collaborating with other non-U.S. residents in the same nation), U.S.-foreign collaborations (i.e. one or more U.S. residents collaborating with one or more non-U.S. residents), and foreign-foreign collaborations (i.e. two or more non-U.S. residents from differing nations).

One reviewer has suggested that disputes about intellectual property may be partly responsible for the observed trends. For example, ongoing disputes between the U.S. and China surrounding patentable technology domains may have discouraged U.S.-Chinese collaborations in particular. While presenting a tantalizing possibility, there is no evidence of a China-specific effect, but leave that exploration for subsequent work, hoping that a follow-up paper will examine U.S.-Chinese technological collaborations in particular.

While many policy changes might conceivably impact the rate and complexity of technological collaborations, the goal here is to test the importance of two in particular, as they have been cited frequently as factors motivating behavioral differences among patent applicants. On June 8, 1995 the U.S. began a transition period designed to accord with the General Agreement on Tariffs and Trade (GATT), including a change in the rules governing the period of patent protection (USPTO, 1995). Since applications filed before June 8 were given the option of being grandfathered into the old system, there was a spike in applications preceding the change, followed by an inevitable drop in applications as the pipeline fell dormant. Interestingly, that marked a major turning point for collaborative activity, as the U.S. patent system has subsequently dealt increasingly with either single-inventor patents or many-inventor patents, and less often with two-inventor patents. This fact led to the title of this piece, as it led the authors to speculate on whether many heads truly are preferred to two.

The period between September of 2001 and April of 2002 was also an unusual one for the science and technology community, as new immigration and Homeland Security regulations were composed and enforced in the U.S. (U.S. Patriot Act, 2001; Homeland Security Act, 2002). The post-2002 period has been anecdotally described as one of potentially more limited intellectual exchange and technological growth due to the increased costs of collaborative activities requiring academic conferences or student/work visas (American Chemical Society, 2004; Brooks, 2004). In order to test the impact of these policy shifts with the data below, the model simply allows the data to explain the significance (or insignificance) of those potential temporal breaks in trend.

The following section will describe the method and data, including the regression model. The third section presents results, while the fourth section concludes with the larger implications of this study’s findings.

Method and Data

The number of observed collaborations (or patents with multiple co-applicants) could potentially be explained in part as a function of characteristics of the technology, the time period and of the nationalities themselves. There is no structural model proposed here, but rather a reduced form linearization as an indication of possible patterns and impacts. Interesting results will suggest a subsequent modeling exercise based on social network theory or matching theory, but that work would have to be more theoretical than empirical given the nature of the information available. The current analysis is purely heuristic, to determine whether there is indeed anything interesting to explain in a full model.

Thus, a simple model of the number of collaborations per patent is proposed, where each of the four types (U.S.-only, foreign-only, U.S.-foreign, and foreign-foreign) may have their own propensity to collaborate and trend over time, and where the similarities of the nationalities involved and characteristics of the particular technology under patent may affect the rate of collaboration.

The data are clustered (or grouped) for the purposes of estimation, in keeping with the literature on patent citations (Caballero and Jaffe, 1993). Each patent could have been treated as the level of observation, but then it becomes unclear what the dependent variable should measure. For a patent with five applicants from three nations, collaboration could be binary (more than one applicant or not), or it could be the number of collaborators, or the number of possible pair-wise matches between collaborators, or something else entirely. If descriptive statistics about the relevant nationalities 'explain' the presence or absence of collaborations, then which nation's characteristics should be used? Similar questions arise if one treats pair-wise matches between collaborators as the level of observation, except that there is the additional concern of what to do with non-collaborative patents which would not enter the dataset at all.

Two separate measures of collaboration have been created for each patent document, a binary indicator (multiple applicants or not), and a count of the number of pair-wise matches between all co-applicants. The current analysis uses pair-wise matches rather than a count of applicants because each pair then includes at most two nationalities, allowing comparison of the similarity of the applicants in each pair using their nationalities as a guide. For example, do nations similar in political structure collaborate more freely than other nations? In a group of five nationalities, the measure of 'similar' is difficult, while in a pair of two, the measure becomes much easier. Pair-wise matches also offer a wider range to the dependent variable (0 pairs for 1 applicant, 1 unique pair for 2 applicants, 3 unique pairs for 3 applicants, 6 unique pairs for 4 applicants, 10 unique pairs for 5 applicants, 15 unique pairs for 6 applicants, etc.) than simple applicant counts would, potentially offering more opportunity for explanation.

In grouping the data, descriptive characteristics of the underlying patents were chosen to serve as categories for observation. For example, one group might include all patents with a 36-month lag between application and grant, in the field of biotechnology, with an application date of March 1995, and the potential (even if not the actual observation) of U.S.-France collaboration. The dependent variable is then expressed as the share of all patents within this group which display a U.S.-France collaboration. In accordance with clustered estimation procedures, estimated standard errors are all corrected using appropriate group size weights (Greene, 1993).

Using all patents granted by the U.S. between 1975 and 2004 (as available publicly from the U.S. Patent Office), the following characteristics were chosen to distinguish groups:

a) Type of collaboration (U.S.-only, foreign-only, U.S.-foreign, and foreign-foreign). Every patent was deemed to have the potential for each type of collaboration, but obviously only a fraction of all potential collaborations occur. That fraction becomes the dependent variable to test trend #1, and the average number of pair-wise collaborations becomes the dependent variable to test trend #2.

b) Date of application. Not only have application processes changed over time, but there might simply be a time trend to explain part or all of the dynamics seen in Figure 1. For maximum flexibility, each type of collaboration (U.S.- only, foreign-only, U.S.-foreign, and foreign-foreign) is permitted its own time trend.

c) Income differences between nations (measured in thousands of real 2000 dollars per capita [WDI online]). Potential collaborations were grouped using income to test the hypothesis that high-income nations collaborate more with other-high income nations. The estimation controls for that pattern where it exists, so that, for example, it does not contaminate tests of the importance of immigration law changes in 2001.

d) Population differences between nations (measured in billions [WDI online]). This grouping variable was included to determine whether large or populous nations tend to find partnerships with other large nations.

e) Intellectual property rights (IPR) differences between nations (measured on the 5-point scale of strength and enforcement [Ginarte and Park, 1997]). This grouping variable is included in order to test whether strong IPR regimes collaborate more with nations that also respect IPR strongly, controlling for factors such as population and income. If this popular intuition is true, it lends power to the argument that a nation should protect IPR strongly if they are interested in research collaborations with those nations which perform most research. The U.S., Europe and Japan all have scores approaching the top of the 5-point scale.

f) Political regime differences between nations (measured on a binary scale of "similar" or "different"). Regimes are categorized by the Statesman's Year-book (1986-2000) and were further aggregated by the authors into i) parliamentary or republican democracies including monarchical democracies, ii) monarchies, iii) single-party or military regimes, iv) other situations including transitional governments or civil unrest. This variable was included to test whether similar political structures might promote international research collaborations over and above the power of IPR laws.

g) Short, medium and long grant lags for patents (measured as less than 18 months, 18-36 and more than 36 months from application to grant respectively). The literature has used short and long lags as indicators of scientific importance and market value (Johnson and Popp, 2003), so this variable might indicate whether more or less valuable patents see collaborative influences, *ceteris paribus*.

h) Specific technologies (biotechnology and computer-related technology have been singled out here for special notice). Both practitioners and academics have widely recognized that these sectors have significant differences warranting special treatment, including longer review windows by the U.S. Patent Office, higher application rates and a faster rate of fundamental technological progress (Popp et al., 2004). Definitions published by the U.S. Patent Office are used here, alongside tests of whether collaboration in these sectors behaves differently.

Further, three policy period are estimated separately to test for changes in each coefficient listed above: i) January of 1975 through April of 1995 (pre-GATT patent law change), ii) August of 1995 through August of 2001 (post-GATT patent law changes and pre-Patriot Act), and iii) April of 2002 to April of 2004 (post-Patriot Act).

Naturally, as a reviewer has pointed out, while all variables noted in the preceding literature have been included, along with some novel variables that may have an impact here, some variables of importance may still be missing. As in all statistical work, estimation relies on the estimated error term to capture any residual effects.

This grouping exercise leaves 3,829,899 clusters or groups of data, each with two dependent variables (a above) and a list of independent variables (b through h above). Thus the clustered data offer evidence on the viability of a linearly-approximated reduced form model, a model which is proposed to be

$$\text{collabs/patent} = \alpha_{US\text{-}US} + \alpha_{US\text{-}other} + \alpha_{other1\text{-}other2} + \gamma_{date}(\text{month}) + \beta_{GDP}(\text{GDP}) + \beta_{pop}(\text{pop}) + \beta_{IPR}(\text{IPR}) + \beta_{short}(\text{short}) + \beta_{long}(\text{long}) + \beta_{tech}(\text{technology}) + \beta_{pol}(\text{political}) + \text{constant} + e,$$

where collabs/patent is the share of patents displaying collaboration (trend #1), or the number of pair-wise collaborative relationships per patent (trend #2),

$\alpha_{US\text{-}US}$ is an indicator of a purely domestic U.S.-only collaboration,

$\alpha_{US\text{-}other}$ is an indicator of collaboration between a U.S. and a non-U.S. researcher,

$\alpha_{other1\text{-}other2}$ is an indicator of collaboration between non-U.S. researchers of different nations,

month is the date of application of the granted patent (as a time trend),

GDP is the difference between the per capita gross domestic product of each collaborator's nation of residence,

pop is the difference between the population of each collaborator's nation of residence,

IPR is the difference between the Ginarte/Park intellectual property rights (IPR) index of each collaborator's nation of residence,

pol is a binary indicator of similarity or difference between the political regimes of each collaborator's nation of residence,

short is an indicator of patents with 18 months or less between application and grant,

long is an indicator of patents with 60 months or more between application and grant,

tech is a set of indicators of whether the patent is in biotechnology, computers, or another technology field, and

e is the linearization error.

Notice that the coefficients for foreign-only collaborations and medium lag patents have been omitted to avoid obvious multicollinearity issues. This is not a calculation of the dependent variables, but rather a proposed explanation of them, including a linearization error term to capture complexities in functional form which is not modeled here.

Results

Estimation uses a censored normal distribution, as the number of collaborations must be non-negative, and using weights appropriate for grouped data estimation. Table 1 shows multiple regression results for the two dependent variables corresponding to trend #1 and trend #2 respectively. Virtually all estimated coefficients are significant at the 1% level (as indicated in the table), offering some support for the choice of variables.

Table 1: Estimated coefficients

		Trend #1: Share of patents that are collaborative			Trend #2: Number of collaborative pairings per patent		
Variable		**Estimate**	**t-statistic**		**Estimate**	**t-statistic**	
Constants		-0.06	43.51	***	-9.57	35.87	***
U.S. only	$\alpha_{US\text{-}US}$	0.20	58.56	***	16.17	25.42	***
U.S.-foreign	$\alpha_{US\text{-}other}$	-0.05	24.55	***	-8.61	25.14	***
Foreign-foreign	$\alpha_{other1\text{-}other2}$	-0.27	115.68	***	-50.56	118.62	***
Application month (trend)							
U.S. only	$\gamma_{U.S.\text{-}U.S.,\ 1975\text{-}1995}$	9.62 x 10^{-4}	45.51	***	4.20 x 10^{-2}	10.36	***
	$\gamma_{U.S.\text{-}U.S.,\ 1995\text{-}2001}$	6.23 x 10^{-4}	41.82	***	2.60 x 10^{-2}	9.15	***
	$\gamma_{U.S.\text{-}U.S.,\ 2002\text{-}2004}$	-3.99 x 10^{-4}	8.80	***	7.70 x 10^{-2}	9.78	***
U.S.-foreign	$\gamma_{U.S.\text{-}other,\ 1975\text{-}1995}$	6.98 x 10^{-4}	74.76	***	12.42 x 10^{-2}	74.29	***
	$\gamma_{U.S.\text{-}other,\ 1995\text{-}2001}$	4.40 x 10^{-4}	61.23	***	8.22 x 10^{-2}	64.29	***
	$\gamma_{U.S.\text{-}other,\ 2002\text{-}2004}$	-2.71 x 10^{-5}	0.81		7.99 x 10^{-6}	0.01	
Foreign only	$\gamma_{other1\text{-}other1,\ 1975\text{-}1995}$	3.17 x 10^{-4}	37.77	***	4.76 x 10^{-2}	30.96	***
	$\gamma_{other1\text{-}other1,\ 1995\text{-}2001}$	2.85 x 10^{-4}	39.22	***	5.27 x 10^{-2}	40.26	***
	$\gamma_{other1\text{-}other1,\ 2002\text{-}2004}$	-2.59 x 10^{-4}	7.38	***	2.08 x 10^{-2}	3.47	***
Foreign-foreign	$\gamma_{other1\text{-}other2,\ 1975\text{-}1995}$	9.01 x 10^{-4}	84.59	***	16.19 x 10^{-2}	85.50	***
	$\gamma_{other1\text{-}other2,\ 1995\text{-}2001}$	7.64 x 10^{-4}	95.15	***	13.73 x 10^{-2}	96.84	***
	$\gamma_{other1\text{-}other2,\ 2002\text{-}2004}$	-2.48 x 10^{-4}	5.81	***	-4.39 x 10^{-2}	5.90	***
GDP difference	$\beta_{GDP,\ 1975\text{-}1995}$	-1.32 x 10^{-3}	18.46	***	-0.24	18.81	***
	$\beta_{GDP,\ 1995\text{-}2001}$	-5.63 x 10^{-4}	10.78	***	-0.10	10.55	***
	$\beta_{GDP,\ 2002\text{-}2004}$	-1.85 x 10^{-3}	3.61	***	-0.41	4.51	***
Population difference	$\beta_{pop,\ 1975\text{-}1995}$	-0.04	10.65	***	-6.30	10.57	***
	$\beta_{pop,\ 1995\text{-}2001}$	-0.02	10.19	***	-2.10	7.14	***
	$\beta_{pop,\ 2002\text{-}2004}$	0.07	4.45	***	13.10	4.92	***
IPR difference	$\beta_{IPR,\ 1975\text{-}1995}$	-0.07	79.93	***	-12.10	80.32	***
	$\beta_{IPR,\ 1995\text{-}2001}$	-0.03	52.76	***	-6.00	53.38	***
	$\beta_{IPR,\ 2002\text{-}2004}$	-0.07	11.22	***	-11.96	11.20	***
Political similarity	$\beta_{pol,\ 1975\text{-}1995}$	0.01	12.13	***	1.82	9.93	***
	$\beta_{pol,\ 1995\text{-}2001}$	-1.74 x 10^{-3}	1.61		-1.06	5.56	***
	$\beta_{pol,\ 2002\text{-}2004}$	0.05	4.88	***	6.82	3.69	***
Short lag	$\beta_{short,\ 1975\text{-}1995}$	-0.06	65.35	***	-9.77	63.62	***
	$\beta_{short,\ 1995\text{-}2001}$	-0.09	82.03	***	-16.62	87.37	***
Long lag	$\beta_{long,\ 1975\text{-}1995}$	-0.46	168.53	***	-87.81	169.91	***
	$\beta_{long,\ 1995\text{-}2001}$	-0.35	113.33	***	-66.23	114.59	***
Computer technology	$\beta_{tech=comp,\ 1975\text{-}1995}$	-0.22	136.44	***	-43.38	141.93	***
	$\beta_{tech=comp,\ 1995\text{-}2001}$	-0.10	79.11	***	-19.70	84.90	***
	$\beta_{tech\ =comp,\ 2002\text{-}2004}$	-0.15	19.12	***	-30.61	22.68	***
Biotechnology	$\beta_{tech=bio,\ 1975\text{-}1995}$	-0.09	87.63	***	-17.74	97.77	***
	$\beta_{tech=bio,\ 1995\text{-}2001}$	-0.07	68.42	***	-14.52	74.91	***
	$\beta_{tech=bio,\ 2002\text{-}2004}$	-0.22	24.62	***	-40.18	26.38	***
Observations		3829899			3829899		
Pseudo R^2		0.88			0.58		

Notes: *** indicates significance at the one percent level.

Unsurprisingly, U.S.-only collaborations are the most likely form of collaboration seen in U.S. patent data. Remembering that the constant coefficients are measured relative to the omitted reference group of foreign-only collaborations, U.S.-only research teams are twenty percent (0.20) more likely and have 16 more collaborations than foreign-only. Due to the way in which collaborations are counted, i.e. as pair-wise matches between collaborators, 16 more collaborations means that U.S.-only teams might average close to 8 members (offering 28 pair-wise matches) while foreign-only teams average closer to 5 (offering 10 pair-wise matches). U.S.-foreign collaborations are both less likely and less numerous when they occur, and foreign-foreign collaborations are the least likely and smallest (when they do occur) of all types.

With the passage of time (via the application month coefficient), each type of collaboration has become less probable. The share of U.S.-only patents displaying collaborations rose at a rate of 9.62×10^{-4} per month from 1975 through 1995, rose at the slower rate of 6.23×10^{-4} per month (from 1995 through 2001), and has actually fallen at the rate of 3.99×10^{-4} per month since 2002. Notice that these values amount to U.S.-only collaborations rising at annualized rates of 1.15 percent and 0.75 percent in 1975-95 and 1995-2001 respectively, before *falling* at an annualized rate of 0.48 percent since 2002. Although each type of collaboration has followed the same pattern, the rates of growth and decline have been most dramatic for U.S.-only collaborations.

On the other hand, the time trend coefficient shows slightly different patterns for trend #2 (the average number of collaborators) depending upon the type of collaboration. While the rates of growth in the number of collaborators fell for each type of collaboration between 1975-95 and 1995-2001, U.S.-only patents have actually seen a fairly dramatic rise in the post-2002 rate of growth (to 7.70×10^{-2} per month). That contrasts sharply with the precipitous decline in foreign-foreign collaborations patenting in the U.S., measured at -4.39×10^{-2} per month. In annualized rates, U.S.-only collaborations were rising by 0.92 while foreign-foreign collaborations were falling by 0.53. Both U.S.-foreign and foreign-only collaborations continued to increase after 2002, but at slower rates than ever before.

Notice that these time trends hold while controlling for other differences between nations. For example, income differences between nations have always been correlated negatively with the probability of collaboration and with the number of collaborators on an average patent. Those differences appeared to wane in importance in 1995-2001, but have rebounded to exceed their pre-1995 levels of importance since 2002. In short, high-income nations collaborate most with other high-income nations, even holding other factors constant.

Population differences have historically been associated with lower collaboration rates between nations, a pattern which has reversed since 2002. Since that time, greater differences between populations have been associated with both more frequent and more numerous collaborative teams. This turnaround is probably largely due to the birth of China and India as serious research hotbeds who increasingly patent their internationally collaborative work in the U.S.

Differences in IPR strength and enforcement are fiercely negatively correlated with collaboration. The 1995-2001 period saw a weakening of that correlation, but it has returned to its previous level since 2002. In short, for every point of difference on the 5-point Ginarte/Park scale, there are 7 percent fewer collaborations and the average collaboration is 12 pairs smaller (the difference between having 6 collaborators and having only 3).

Nations with similar political structures seem to collaborate more frequently and in greater numbers, although the pattern is insignificant or even reversed between 1995 and 2001. In general the effects are small at best, with similar nations having 1 to 5 percent more collaboration (the range depending on the time period of observation), and sharing 1.82 to 6.82 more collaborative pairings (equivalent to the difference between five collaborators and having two or three).

While patents with short grant lags (and therefore perhaps lower value) are less likely to be collaborative, patents with long grant lags are far less likely to be collaborative. In other words, there appears to be an inverse-U shaped correlation between grant lag and collaboration. Quick or short-lagged patents are 6 to 9 percent less likely to be collaborative than average patents are, while slow patents are 35 to 46 percent less likely to be collaborative (ranges depending on the time period). This is consistent with the findings of Popp et al. (2004) that both short-lagged and long-lagged patents are often presented by government agencies who either hurry or delay the process for secrecy reasons (and therefore have relatively few researchers on the applicant list). Independent inventors may also take a long time in the patent process due to lack of in-house legal counsel or a lack of familiarity with the patent system, so would also support negative correlations between the number of collaborators (few in most cases of independents) and grant lag time.

Surprisingly, computer and biotechnology patents appear to be less frequently collaborative than other patents, and have far fewer collaborators in their applicant teams. Computer patents were 22 percent less likely to be collaborative than other technologies between 1975 and 1995 (biotech was 9 percent less likely), and by 2002-04 while computer technology was 15 percent less likely, biotech had become 22 percent less likely to be collaborative. In 2002-04, computers show 30.81 fewer collaborative pairings (the difference between 9 applicants and 3 applicants) while biotechnology shows 40.18 fewer pairings (the difference between 10 applicants and 3 applicants). Secrecy concerns may be at work here, but intuition suggests that larger teams would be required for the increasingly interdisciplinary research involved in these two technologies, so the results are surprising. Regardless, the use of indicator variables for these two technologies, which are dragging down the all-industry average collaboration rate, supports the primary story--- that collaboration frequency has decreased since 2002 even while controlling for these two sectors.

Conclusion

After decades of growth in documented collaboration on patent applications, the share of granted patents which show multiple applicants is falling on a monthly basis. This startling fact remains true even taking into account controls for other potentially confounding effects (such as differences between nations, between patent documents, and between technologies).

In contrast, among patents which show multiple applicants, the number of collaborators has been rising (albeit at an increasingly faster rate for U.S.-only patents, and at a diminishing rate for U.S.-foreign and foreign-only patents, while it has been falling in absolute terms among foreign-foreign patents).

Results confirm some previous intuition. High-income nations tend to collaborate with other high-income nations, a pattern which has not changed much over time. Nations with similar political structures and similar IPR protection tend to see more collaboration between them. Patent documents which are quickly granted or very slowly granted are all less likely to be collaborative than the average patent document (due to the nature of their applicants).

However, the results conflict with the fundamental intuition that advances in information, communication and travel technologies should be making long-distance collaboration easier (and therefore more frequent and with more numerous participants) than in the past. Leaving rigorous modeling of the reasons for collaboration for future work, this paper offers nothing more than data-driven evidence that these two trends bear further investigation.

Are policy shifts responsible? The change in U.S. patent law in 1995 to conform to GATT protocols does not appear to be associated with greater collaboration rates overall. However, two interesting changes in the data occur during this period which may (and only may) be attributable to the policy shift. First, 1995-2001 is the only period in the data where political similarity between nations does not show up positively correlated with collaboration. In fact, during this period political similarity appears ***negatively*** correlated with the number of collaborators on an average patent. Is it possible that the change in law opened up possibilities for international collaborators across cultures that were previously deemed too challenging for institutional or political reasons? Second, 1995-2001 marked the only period where the average number of collaborators rose for any kind of collaboration involving non-U.S. participants. Granted, it only rose marginally, and only for U.S.-foreign collaborations, but it did rise. Could this rise be due to the relaxing of logistical constraints on such activity as the U.S. conformed to international standards?

Examination of another policy break, in 2001-02, grew from a suspicion that changes in U.S. foreign policy might be associated with obvious breaks in the underlying data. Indeed, several changes are evident. On one hand, population differences are now associated with more collaboration rather than less, suggesting more diverse international interactions than ever before. On the other hand, political similarity swung back from the 1995-2001 period to now be more important than ever. While the average number of collaborators on U.S.-only patents has risen (suggesting that such collaborations are desired and affordable by U.S. inventors), all other kinds of collaborations have fallen in size. The share of patents that are collaborative have unambiguously changed course from slow but decreasing rates of increase to rates of decrease instead.

It is of course unclear that policy is responsible for this 2001-2002 turnaround. This paper is merely providing contemporaneous evidence. Further, perhaps it is not collaboration which has declined since 2002 but simply this paper's measure of it. Perhaps collaboration now is taking different forms, via trade secrets instead of patents, or via patents in markets other than the U.S. Nevertheless, the sudden directional shift is disturbing.

To return to the title of this paper, it cannot be determined whether many heads are indeed better than two. Whether they are better or not, current trends are leading toward less frequent collaboration (i.e. one head rather than two). Where collaborations exist, they are increasingly large teams of researchers rather than a few (i.e. many heads rather than two). This paper has embarked on a path that supports many heads or one rather than two, and it is unclear that society has done so deliberately. A wise (and the authors would argue immediately necessary) next step would be to evaluate the correlation between collaborations and patent value.

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