WHO COLLABORATES INTERNATIONALLY IN DEVELOPING COUNTRIES?: THE CASE OF COLOMBIA[1]

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Abstract:

International research collaboration is a growing social phenomenon taking place at a particularly rapid pace in developing countries. Most of the literature on the topic claims that research collaboration is an important source of creativity, which in the right set of conditions may increase scientific productivity, research quality, innovative capacity, science and technology human capital, and help the consolidation of research agendas and the expansion of research areas. However, risks and costs associated with international collaboration are also found in the literature, including the privatization and capture of traditional 'public' knowledge, the 'mercantilization' of knowledge and human capital as resulting from public-private research partnerships, high opportunity costs, and crowding out effects. The purpose of this paper is to contribute to a better understanding of the determinants of international research collaboration in developing countries using Colombia as a case study. In fact, knowing the factors affecting the choice of collaborating internationally will help the design of policies aimed at creating local S&T capabilities through the encouragement of the internationalization of the local S&T community, or at reducing the negative effects derived from that process. The research tests the hypotheses formulated using logit models. It considers different types of collaborative activities and different types of partners while controlling for team

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characteristics, team leader characteristics, scientific field, characteristics of the home institution and team location. Econometric findings and policy implications are discussed.

1. Introduction

International research collaboration is a growing social phenomenon (Wagner and Leydesdorff 2006; NSF-NSB 2008). It results in part as a strategy to deal with increasingly complex problems and the rising costs of research (Luukkonen, Persson; et al. 1992; Gibbons, Limoges et al. 1994; Adams, Black et al. 2005). It also responds to government policies oriented to favor globalization (Georghiou 1998; Wagner, Brahmakulam et al. 2001). Finally, the continuous fall of communication costs and the increased mobility of scientists and students across borders are also contributing to this phenomenon.

According to the US National Science Foundation (NSF), the number of international articles with authors from at least two countries more than doubled in share between 1988 and 2003 from 8% to 20%. The number of countries collaborating on an article also expanded. In 2003, more than 60 countries had co-authored with other countries, compared with 32 in 1996 (NSF-NSB 2006). Over the period, 1995-2005, intercontinental co-authorship increased as a percentage of total article output for the US (from 17% to 27%), for the EU (from 18% to 26%), and for Asia (from 16% to 19%)(NSF-NSB 2008), resulting in an increasing level of international interdependence of the research enterprise (Narin, Stevens et al. 1991; Glänzel and Schubert 2004; Glanzel and Schubert 2005; NSF-NSB 2008).

This trend is not only taking place in developed countries but is arguably happening at a particularly rapid pace in developing countries. More importantly, policy discourse and literature increasingly claim positive effects of international collaboration on local scientific and technological capabilities in developing countries. In fact,

international collaboration is assumed to give local scientists and engineers in developing countries access to new knowledge and research resources they would not have otherwise within their national boundaries (Wagner, Brahmakulam et al. 2001). It may raise the quality of the research performed in those countries, increasing the possibility for local scientists and engineers to benefit from the expertise brought about by international partners.

In contrast to the literature on the characteristics and on the determinants of research collaboration, the literature on the *impacts* of research collaboration on research performance is rather scarce, and that on the effects of international research collaboration is almost inexistent. In the literature, research collaboration is mostly portrayed as an important enabler of science and technology development. It is considered to be 'better' than individualistic research in several respects. Many argue that research collaboration has greater epistemic authority (Wray 2002; Beaver 2004); facilitates diffusion of information and ideas; increases access to new knowledge and research tools; and offers visibility and feedback (Crane 1972; Beaver and Rosen 1979; Rigby and Edler 2005). These are crucial elements for the use and production of new knowledge and technology.

More importantly, most of the literature on the topic claims that research collaboration is an important source of creativity (Farrell 2001; Burt 2004; Levine and Moreland 2004; Uzzi and Spiro 2005), which in the right set of conditions may increase **a)** scientific productivity (Beaver and Rosen 1979; Landry, Traore et al. 1996; Adams, Black et al. 2005; Lee and Bozeman 2005; Turner and Mairesse 2005), **b)** research quality (Diamond 1985; Katz and Hicks 1997; Basu and Aggarwal 2001; Frenken, Hölzl et al. 2005; Rigby and Edler 2005), **c)** innovative capacity (Allen 1977; Georghiou 1998; Le Bas, Picard et al. 1998; Tsai and Ghoshal 1998; George, Zahra et al. 2002; Landry, Amara et al. 2002; Belderbos, Carree et al. 2004; Granovetter 2005), **d)** science and

technology human capital (Coleman 1988; Rogers 2001; Rogers and Bozeman 2001; Seibert, Kraimer et al. 2001; Bozeman and Rogers 2002; Bozeman and Corley 2004), and **e)** help the consolidation of research agendas and the expansion of research areas.

Others, however, warn about the negative impacts of research collaboration on productivity (Fox and Faver 1984; Landry and Amara 1998; Carayol and Matt 2004b; Cummings and Kiesler 2005); output quality (Herbertz 1995; Kleinman 1998); innovative capacity (Gelijns and Thier 2002); human capital (Behrens and Gray 2001; Stephan 2001; Slaughter, Campbell et al. 2002); and relevance of the research (Kleinman 1998; Florida 1999; Sagasti 2004; Shrum 2005). Risks and costs identified include the privatization and capture of traditional 'public' knowledge, the 'mercantilization' of knowledge and human capital as resulting from public-private research partnerships, opportunity costs, and crowding out effects.

Empirical studies on the effects of research collaboration are currently on the rise. Less is being done regarding the effects of *international* research collaboration and, with the exception of Ordonez 2008 and a handful number of projects underway, no empirical research have been done on the effects of international collaboration on local S&T capabilities in the framework of a developing country. An extant and up-to-date literature review on the topic is presented in Ordonez 2008.

According to Ordonez 2005 who uses data from more than 5,400 journal articles published by Colombian scientists and engineers between 1980 to 2005, the country's recent good performance is explained by its increased international collaboration (Ordonez 2005). As shown in Figure 1, while the number of articles published by Colombians alone is rather small, that published in collaboration with foreign partners is large and rising rapidly.

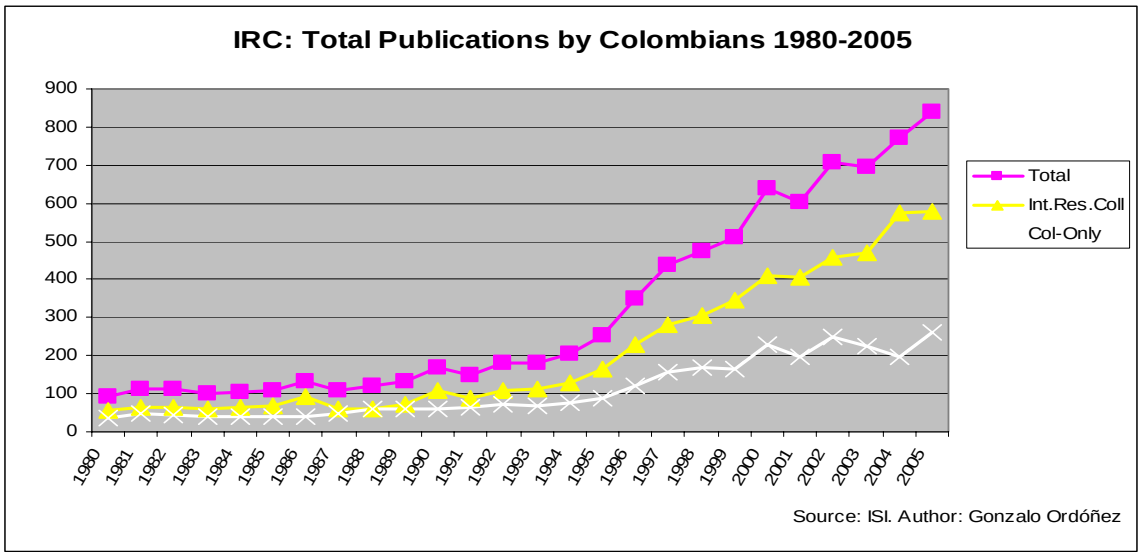

Figure 1. Publications and Research Collaboration: 1980-2005

In a more recent research, Ordonez studied the performance of 1889 Colombian research teams and the role of international research collaboration in such performance. In particular, he studied the ways international research collaboration affects local scientific and technological capabilities, as measured by the ability of research teams to produce bibliographic outputs and to contribute to local knowledge (Ordonez 2008).

Results show that international research collaboration is positively associated with both team output and teams' ability to contribute to local knowledge. The study shows that such effects depend on the type of collaboration chosen and the type of partner involved, however. Particularly, it shows that while co-authoring with colleagues located overseas or receiving foreign funding increases team output, hosting foreign researchers does not seem to affect a team's productivity once all other variables are held constant. It also finds that collaborating with partners from the South yields greater productivity counts than collaborating with partners from the North, and that funding from southern countries is associated with greater productivity rates than any other combination of collaboration activity and origin of partners.

Ordonez's study also finds that hosting foreign researchers does not appear to be associated with the probability of teams to involve Colombia in their research process either, and that receiving foreign funding or co-authoring with colleagues located overseas increases a team's probability to contribute to local knowledge. Similarly, the study finds that collaboration with partners from northern countries is strongly associated with a team's ability to contribute to local knowledge, while collaboration with partners from southern countries is not.

The purpose of this paper is to better understand the determinants of international research collaboration in developing countries using Colombia as a case study. In fact, knowing the factors affecting the choice of collaborating internationally will help us better design policies aimed at creating local S&T capabilities through the encouragement of the internationalization of the Colombian S&T community, or at reducing the negative effects derived from that process.

2. Determinants and Characteristics of International Research Collaboration

The literature on the characteristics and on the determinants of research collaboration is rather abundant. Katz and Martin define research collaboration as the working together of researchers to achieve the common goal of producing new scientific knowledge (Katz and Martin 1997). A variety of 'collaborative activities' has been identified as falling under this broad concept. As Bordons and Gomez (2000) claim, these include the expression of opinions, the exchange of ideas and data, working together during the course of a project, working separately on different parts of a project with the purpose of integrating the results at the end, sharing equipment, and exchanging personnel. (Bordons and Gomez 2000).

However, as Katz and Martin (1997) acknowledge, both the concept of 'working together' and the assumption of a 'common goal' as a distinctive characteristic of a collaborative activity are rather conceptually and empirically problematic since, **a)** it is not clear how closely researchers have to work together in order to constitute a collaboration, and **b)** either no two researchers ever have precisely the same goals, or, conversely, every single researcher in the world is in fact a member of a big collaboration called 'scientific community' for they all work to advance scientific knowledge and are all somewhat interrelated: they all exchange ideas on what experiments to do next, what hypothesis to test, what new instrumentation to build, how to relate their latest experimental results to theoretical models, and so on" (Katz and Martin 1997).

As Bordons and Gomez acknowledge, if we take a narrow definition and agree that collaboration is defined as two or more scientists working together on a joint research project, sharing intellectual, economic and/or physical resources, a wide range of situations still can be included, and a wider array of contributions will in fact be excluded under such definition.

It seems therefore that, as the authors acknowledge, a research collaboration has a very "fuzzy" or ill-defined border, and exactly where that border is drawn is a matter of social convention and is open to negotiation. Furthermore, perceptions regarding the precise location of the 'boundary' of the collaboration may vary considerably across institutions, fields, sectors, countries, actors, and purposes over time. The fact is that, as any other social process, research collaboration is mainly governed by the complexity of human interactions, which we still don't understand completely.

Nevertheless, several types of collaboration are identified in the literature. As Bordons and Gomez (2000) point out, they can be theoretical or technical, the former being based on the exchange of ideas, the provision of advice, or criticism, and the latter being based the share of resources, methods, etc. (Bordons and Gomez 2000). Another typology of collaboration is offered by Hagedoorn, Link et al (2000), who claim that

research partnerships can be either formal or informal and can involve any type of partners (i.e. scientists, technicians, students, employees, etc.), belonging to universities, enterprises or government agencies committed to research projects. While formal research partnerships include research corporations (equity joint ventures focusing on research, and research joint ventures) and contractual arrangements such as strategic technical alliances, etc., informal agreements includes short-term research project-specific endeavors (Hagedoorn, Link et al. 2000), and less visible but not less important social contacts.

In contrast, the literature on the determinants and characteristics of *international* research collaboration is less abundant. Arguably, the similarities between research collaboration and international research collaboration are greater than the differences between the two. However, distinctive aspects of international research collaboration, besides the 'obvious' condition that partners belong to different nations, include a different set of drivers, enablers, modalities, and consequences.

As for the drivers of International Research Collaboration, and according to Wagner and Leydesdorf (2004), these include: **a)** location of specific resources. Marine research for example would probably require accessing different ocean resources from different countries; **b)** unique expertise. The treatment of some disease may well require local expertise in those areas where it has developed and being investigated from the past; **c)** location of large-scale equipment. A space research initiated in Russia would probably need to work at NASA to do some of their experiments; **d)** global problems requiring global solutions. Global warming would probably require research performed in different places of the planet to monitor and understand the causes (Wagner and Leydesdorff 2004).

As for the enablers of international research collaboration is concerned, the literature identifies the following: **a)** the return to home country of former 'brain drained'. It is well known (thought barely tested empirically) that one of the factors driving

international research collaboration are the social networks created by foreign students and professors who return to their home countries and maintain their contacts with their mentors, colleagues or students in the countries where they spend part of their academic lives (Melin 2004); **b)** the Diaspora. Many of those who do not return to their countries of origin keep the contacts made in the past or develop new ones with their co-nationals they meet in international workshops or other academic and social events (Basu and Kumar 2000; Chaparro, Jaramillo et al. 2004); and **c)** the Cultural-, geographic-, historical-, linguistic-, proximity. One is more likely to collaborate with whom one shares more basic characteristics than with those one shares less common characteristics (Frame and Carpenter 1979; Narin, Stevens et al. 1991; Katz 1994; Farrell 2001; Lee 2004; Levine and Moreland 2004; Wagner 2005); In addition, relatively low costs of transportation and communication have contributed importantly to the collaborative enterprise across borders.

Some of the barriers to international research collaboration identified in the literature include **a)** low absorptive capacity. According to Cohen and Levinthal, it is the lack of absorptive capacity of the knowledge and technology produced in developed countries what keeps developing countries from benefiting from the advances of the modern world (Cohen and Levinthal 1990). In fact, very often, researchers from developing countries are not able to take advantage of the knowledge and techniques offered by partners working in developed countries mostly because they lack the basic resources and knowledge necessary to exploit such opportunities (Bayona, Garcia-Marco et al. 2001; Penner-Hahn and Shaver 2005); **b)** strong intellectual property protection (Forero-Pineda and Jaramillo-Salazar 2002); and **c)** political reasons oriented at controlling migration, ensuring national security, etc.

3. Characteristics of Colombian Research Internationalization

Based on the analysis done by Ordonez 2005 of the more than 5,000 articles published by local scientists and engineers between 1980 and 2005, the Colombian S&E community experiences a rapid process of internationalization (Ordonez 2005). This finding is consistent with that by Wagner and Leydesdorff who show that the global network has become denser and that more countries can be counted as part of the core component of the global S&T network (Wagner and Leydesdorff 2006). According to the authors, Colombia was one of the 50 countries joining the list of countries in the "core" component of the global network in 2000 while a decade ago the country was not part of the 33 countries belonging to such core[5]. For a reason not yet explored, the country fell off the list again in 2005, however.

According to the articles' dataset created by Ordonez, Colombian scientists and engineers worked between 1998 and 2005 in collaboration with colleagues and institutions from 118 countries. While in 1998 Colombians collaborated with scientists and engineers from 54 countries, in 2005 they co-authored with S&E from 70 countries (See Table 1), that is, an increase of 30%. In fact, in 1998 there were 559 foreign institutions collaborating with Colombian researchers; in 2005 there were almost twice the number. In 2005 almost 68% of the articles published by Colombians were written with foreign partners.

Table 1: IRC: Co-Authorships

Year	Articles	Authors	Total Addresses	IRC-Articles	% IRC-articles	Partner Countries	Internat. Addresses
1998	498	2069	589	314	63.1%	54	559
2005	886	3909	1134	600	67.7%	70	1098

Source: ISI. Author: Gonzalo Ordonez

[5] Belonging to the "Core" is based on the international co-authorship relations a country has.

Furthermore, based on Ordonez 2008's Research Teams' data, more than 800 foreign researchers and technicians were associated with more than 540 Colombian research teams coming from 59 countries between 2003 and 2005. Among the 1889 teams studied, 736 collaborated either by co-authoring with partners located overseas, by working on foreign funded projects, or by hosting foreign researchers. 1153 teams did not collaborate internationally at all (Ordonez 2008).

What factors explain the collaborative behavior of Colombian research teams? This is the question this paper addresses.

4. Research Hypotheses and Methodology

Among the 1889 Colombian teams studied, 736 collaborated and 1153 did not. What factors explain the collaborative behavior? To answer to that question the following model is tested using logistic regressions.

Pr(IRC05=1) = F(Team Size, Team Age, Total PhDs in 2003, Total Projects in 2003, Total Bibliographic Products in 2003, Leader Writes Well in a Second Language, Leader Studied Overseas, Scientific Field, Sector, Size of Home Institution, Size of City of Location)

Thus, the choice of collaborating internationally may be a function of team's characteristics. That is, larger teams are perhaps more likely to collaborate internationally than smaller ones as each team member may act as a collaborating agent: more agents equal more opportunities for collaboration. Older teams may be more likely to collaborate than younger teams because of their longer exposure to the international scrutiny and the maturity attained in their field. The more PhD holders a team has, the more likely it is to collaborate internationally as team members with PhDs tend to be good counterparts of foreign scientists and engineers, and because they may have had international experience during their personal and professional career. Teams led by someone who writes well in a

second language or who has studied overseas tend to be more likely to collaborate internationally than the other teams. In fact, writing in another language is ‘a must’ for those willing to interact with foreign partners coming from countries other than the Spanish speaking countries. Similarly, having studied overseas may help to establish international linkages that may result in collaboration with mentors, classmates and/or research associates located in the host country. Highly dynamic teams both in terms of the number of R&D projects active and of the number of bibliographic products done tend to engage more in international collaboration than teams that are less dynamic.

International collaboration may also be a function of the field the team specializes in. For instance, it is well known that while R&D projects in physics tend to be mostly collaborative, one can hardly find collaboration around projects on philosophy. Thus, using the UNESCO classification of the data, one can argue that teams working in the natural sciences may be more collaboration-prone than comparable teams working in the social sciences or the humanities given the idiosyncratic nature of the latter types of teams, which may keep them from working with scientists of different origins and epistemic grounds. In contrast, the teams working in the agriculture sciences may allegedly be more likely to collaborate internationally than comparable teams working in the natural sciences mostly because of the international recognition of the former teams attained thanks to their work on tropical agriculture.

International collaboration may also depend on the characteristics of their home institutions and of the sector they operate in. As collaborating with foreign partners requires both financial and institutional support, teams affiliated with big institutions may be more internationally oriented than teams affiliated with mid-size or small institutions in

terms of their R&D budget. Competition among teams of the same institution may also help to explain collaborative behavior, and such competition is typical to big institutions. Teams working in the academic sector may be more likely to collaborate internationally than comparable teams working in the business sector. Allegedly, while the former type of teams tend to work on issues of public interest and therefore are expected to be more 'open' to interact with their peers from overseas, teams working in the business sector tend to work on issues with strategic value that may keep them from sharing information and interacting with foreign peers.

Finally, as discussed in the literature reviewed, international collaboration may also be affected by the characteristics of the environment teams are located. Hence, teams located in/or near big cities may be more likely to collaborate internationally than teams located in mid-size or small cities as the teams of the first group tend to have more opportunities to access valuable information on foreign peers, may be more visible given their greater participation in international workshops, and may engage more human resources of higher productivity than teams located in small cities.

The description of the data used is in Appendix H. The reason why a logit model is used as opposed to other models has been discussed in the previous chapter and it has to do with the characteristics of the dependent variable.

5. The Choice of Collaborating Internationally

As Table 2 shows, larger teams, older team, teams with large numbers of doctorates, teams with many R&D projects active, and highly productive teams are more likely to collaborate internationally than comparable teams of smaller size, with fewer years in existence, with fewer PhD members, fewer projects active and less productive.

Teams led by researchers able to write well in a second language, and teams led by someone who studied overseas in the past are more likely to collaborate than teams of similar characteristics led by someone without either capacities. Teams working in the medical sciences, the social sciences or in the engineering are less likely to collaborate internationally than comparable teams working in the natural sciences. Teams affiliated with large institutions are more likely to collaborate than comparable teams affiliated with small or mid-size institutions. And teams located in small cities are less likely to collaborate internationally than comparable teams located in big cities.

Table 2: Determinants of International Research Collaboration

Variable	Internat. Res. Coll.
Team Size in 2003	0.026
	(1.94)
Team Age in 2003	0.033**
	(2.83)
Total PhDs in 2003	0.253**
	(6.14)
Leader Writes Oth Langua	0.466**
	(3.94)
Leader Studied Overseas	0.453**
	(3.96)
Tot. Proj. in 2003	0.054**
	(4.11)
Tot. Bib. Prods. by 2003	0.008**
	(3.81)
Agrosciences	-0.397
	(1.57)
Medical Sciences	-0.486*
	(2.45)
Social Sciences	-0.366*
	(1.98)
Humanities	-0.176
	(1.10)
Engineering	-0.579**
	(3.03)

Cont'd

Table 2 ***Cont'd***

Variable	Internat. Res. Coll.
Other Sciences	-0.140
	(0.47)
Business Sector	0.234
	(0.65)
Government	0.083
	(0.28)
Other Sector	0.601
	(1.44)
Mid. Home Inst.	-0.297*
	(2.33)
Small Home Inst.	-0.341
	(1.73)
Small City	-1.100
	(1.94)
Midsize City	-0.235
	(1.68)
Constant	-1.820**
	(9.17)
Observations	1889

Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%

Contrary to what one would expect, and as a Wald Test of joint effects shows, the sector where the team works does not appear to significantly affect the probability of collaborating internationally. In fact, there is a 53% probability that the observed results could have occurred by chance. Therefore, we can confidently conclude that the hypothesis that the effects of the sector variables are simultaneously equal to zero cannot be rejected.

As the model without the sector variables shows (see Table 3), the number of PhDs appears to be the variable with the greatest impact on the probability of collaborating internationally in Colombia, followed by the number of projects active, the

past productivity of the team, and the characteristics of the team leader. In fact, a one standard deviation increase in the number of members with PhD increases team's odds of collaborating internationally by 75%, holding the other variables constant; and a one-unit increase in the number of members with PhD increases team's odds of collaborating by 29%, holding the other variables constant.

Interestingly, the odds that a team led by someone who writes well in a language other than Spanish collaborates are 1.61 times as high as that of teams with leaders who do not write well in a second language, holding the other variables constant. And having leaders who are able to write well in a second language increases the probability of collaborating by 11.2 percentage points, holding the other variables constant at their means.

Finally, as the table shows, teams led by someone who studied overseas in the past are more likely to collaborate internationally than comparable teams led by someone who did not study overseas in the past. Holding the other variables constant, the odds that a team led by someone who studied overseas in the past collaborates are 1.57 as high as that of teams led by people who did not studied overseas in the past, and holding the other variables constant at their means, the former type of teams increases the probability of collaborating internationally by 10.6 percentage points.

Table 3: Determinants of International Research Collaboration: Percentage Change in Odds

Internat. Res. Coll.	b	z	P>z	%	%StdX	SDofX
Team size in 2003	0.02745	2.034	0.042	2.8	17.0	5.7171
Team Age in 2003	0.03535	3.030	0.002	3.6	22.9	5.8373
Total PhDs in 2003	0.25248	6.146	0.000	28.7	74.7	2.2106
Leader Writes in Other Lang.	0.47462	4.023	0.000	60.7	26.7	0.4979
Leader Studied Overseas	0.44927	3.940	0.000	56.7	25.0	0.4972
Tot. Proj. in 2003	0.05508	4.203	0.000	5.7	43.9	6.6037

Tot. Bib. Prod by 2003	0.00777	3.846	0.000	0.8	40.6	43.8751
Agrosciences	-0.39975	-1.586	0.113	-33.0	-9.1	0.2392
Medical Sciences	-0.48066	-2.448	0.014	-38.2	-14.8	0.3325
Social Sciences	-0.38446	-2.088	0.037	-31.9	-13.2	0.3681
Humanities	-0.18291	-1.152	0.249	-16.7	-7.5	0.4284
Engineering	-0.59780	-3.143	0.002	-45.0	-18.4	0.3407
Other Sciences	-0.13717	-0.467	0.641	-12.8	-2.7	0.2014
Mid. Home Inst.	-0.28457	-2.263	0.024	-24.8	-12.9	0.4851
Small Home Inst.	-0.20575	-1.260	0.208	-18.6	-7.4	0.3738
Small City	-1.11583	-1.973	0.048	-67.2	-13.6	0.1310
Midsize City	-0.24056	-1.723	0.085	-21.4	-9.5	0.4138

Squared terms for team size, team age, total number of PhDs, total number of projects active and total number of bibliographic products are added to the model to see if there are curvilinear effects. In fact, according to one of the interviewees, “large teams sometimes experience free riding, that is, situations where when the team is too large, few people do the hard work while many get the merits. This situation ends by fatiguing those who do most of the work and affects internal cohesion. This lack of cohesion is sometimes reflected in the quality of the work done, and foreign institutions and foreign researchers perceive that tension.” Another interviewee claimed that, “when there are too many PhDs in a team, there tend to be too many ‘generals’ and too few ‘soldiers,’ which ends by increasing transaction costs of any collaborative enterprise.”

The exploration of this new model shows that such claims are not supported by the data, except for the number of bibliographic products done, which increases team’s odds of collaborating internationally but a decreasing rate. The top number of products at which this positive trend reverses is outside of our data range, however. In fact, holding the other variables constant, the probability of collaborating increases with every

additional product but once the team reaches a total of 132 products the probability starts to fall at an increasing rate.

Hence, the model analyzed predicted collaboration for 543 of the teams, of which 386 did collaborate and 157 did not. It predicted that 1346 did not collaborate, but 350 actually did.

The sensitivity of the model is 52.5%: it correctly predicted 386 of the 736 who collaborated. Also, the model is quite specific: 86.4% of those who did not collaborate were not predicted to collaborate (996/1153); 66.9% of those who were predicted to collaborate actually did collaborate, and 74.6% of those who were predicted not to collaborate did actually not collaborate.

More importantly, the model correctly classified 73.2% (386+996/1889), an improvement of about 12% compared to the null model (1153/1889=61.04%). By converting this to an adjusted count R2, we see that the number of errors in prediction drops from 736 to 507 (350+157), a decline of 31.1%.

In sum, based on the results obtained, team size, team age, team composition, leadership, productivity, discipline, institution of affiliation, and geographical location seem to affect the probability of collaborating internationally. In contrast, the sector where the team works is not significantly associated with the collaborative behavior. No significant curvilinear effects were found.

6. The Choice of Collaboration Modalities

Based on the population data and using the full model with the sector variables included, the choice of hosting foreign funding depends mostly on the team's size, the

number of PhDs, the characteristics of the team leader, the activities performed, the scientific discipline, and the size of the city where the team is located (see Table 4).

The choice of working with foreign funding depends on all the factors considered except team size and the size of the city where the team is located. This finding is confirmed by a Wald Test of the joint effects of the location variables.

More precisely, larger teams tend to host more foreign researchers than smaller teams of similar characteristics, but the size of the teams does not seem to affect the probability of working with foreign funding. Older teams tend to prefer working with foreign funding than younger teams, but team age is not associated with the choice of hosting foreign researchers. The number of PhDs is positively associated with both types of collaboration. Teams led by researchers able to write well in a second language or that studied overseas are more likely to collaborate internationally both through hosting foreign researchers and working with foreign funding than comparable teams. The number of projects active and the number of bibliographic products a team has is associated with the probability of working with foreign funding, but it is not significantly associated with hosting foreign researchers.

Teams working in the medical sciences, or in the engineering, are less likely to host foreign researchers than comparable teams working in the natural sciences. Teams working in the humanities are less likely to work with foreign funding than similar teams working in the natural sciences.

Teams working in the government sector or in the NGOs' sector are more likely to work with foreign funding than comparable teams affiliated with the academic sector. However, the sector where the team works does not seem to be associated with the

probability of hosting foreign researchers. Teams affiliated with large institutions are more likely to work with foreign funding than comparable teams affiliated with small and mid size institutions, but the size of the home institution does not seem to be significantly associated with the probability of hosting foreign researchers.

Finally, the size of the city where the team is located also seems to affect the choice of hosting foreign researcher as opposed to the choice of working with foreign funding. In fact, teams located in mid-size cities are less likely to host foreign researchers than comparable teams located in large cities.

Table 4: Factors Explaining the Choice of Hosting Foreign Researchers and of Working with Foreign Funding

Variable	Foreign Researchers	Foreign Funding
Team Size in 2003	0.048**	-0.008
	(3.67)	(0.59)
Team Age in 2003	0.006	0.028*
	(0.50)	(2.42)
Total PhDs in 2003	0.187**	0.164**
	(5.08)	(4.29)
Leader Writes Oth Langua	0.467**	0.467**
	(3.46)	(3.39)
Leader Studied Overseas	0.342**	0.395**
	(2.67)	(3.00)
Tot. Proj. in 2003	-0.018	0.065**
	(1.64)	(5.10)
Tot. Bib. Prods. by 2003	0.000	0.011**
	(0.29)	(5.64)
Agrosciences	-0.482	-0.241
	(1.68)	(0.87)
Medical Sciences	-0.787**	0.028
	(3.46)	(0.13)
Social Sciences	-0.411*	-0.191
	(1.98)	(0.91)

Cont'd

Table 4 *Cont'd*

Variable	Foreign Researchers	Foreign Funding
Leader Studied Overseas	0.342**	0.395**
	(2.67)	(3.00)
Tot. Proj. in 2003	-0.018	0.065**
	(1.64)	(5.10)
Tot. Bib. Prods. by 2003	0.000	0.011**
	(0.29)	(5.64)
Agrosciences	-0.482	-0.241
	(1.68)	(0.87)
Medical Sciences	-0.787**	0.028
	(3.46)	(0.13)
Social Sciences	-0.411*	-0.191
	(1.98)	(0.91)
Humanities	0.076	-0.436*
	(0.46)	(2.36)
Engineering	-0.711**	-0.258
	(3.28)	(1.24)
Other Sciences	-0.286	0.332
	(0.91)	(1.06)
Business Sector	0.182	0.344
	(0.48)	(0.83)
Government	-0.324	0.645*
	(0.90)	(2.01)
Other Sector	-0.104	1.687**
	(0.23)	(3.77)
Mid. Home Inst.	-0.263	-0.445**
	(1.82)	(3.04)
Small Home Inst.	-0.080	-0.762**
	(0.37)	(3.05)
Small City	-1.865	-0.162
	(1.82)	(0.28)
Midsize City	-0.391*	-0.022
	(2.34)	(0.14)
Constant	-1.958**	-2.427**
	(9.29)	(10.98)
Observations	1889	1889

Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%

The analysis of the factors affecting the choice of co-authoring with partners located overseas is done using the sample. In this case, the internal characteristics of the teams are excluded as they were observed after the co-authorship took place.

Hence, as shown in Table 5, teams working in the agricultural sciences or the engineering appear less likely to co-author with colleagues located overseas than comparable teams working in the natural sciences. Interestingly, teams working in the academic sector are less likely to co-author with colleagues located in foreign countries than comparable teams working in the business sector or in the government sector. This may suggest an important level of endogamy characteristic of the Colombian academic sector. Finally, teams affiliated with large institutions are more likely to co-author with partners located overseas than comparable teams affiliated with the small and midsize institutions. No significant effect of location is found. This is confirmed by a Wald Test of the joint effect of these variables not shown here.

Table 5: Factors Explaining the Choice of Co-authoring with Partners Located Overseas

Variable	Int. Co-Authorship in 2001-2
Agrosciences	-1.050**
	(2.69)
Medical Sciences	-0.322
	(1.25)
Engineering	-0.679**
	(2.59)
Other Sciences	-1.464
	(1.93)
Business Sector	2.325**
	(3.78)
Government	2.154**
	(4.66)
Other Sector	2.366*
	(2.40)

Cont'd

Table 5 ***Cont'd***

Variable	Int. Co-Authorship in 2001-2
Mid. Home Inst.	-0.921**
	(3.82)
Small Home Inst.	-2.917**
	(5.19)
Small City	-0.468
	(0.59)
Midsize City	-0.403
	(1.54)
Constant	-0.392*
	(2.49)
Observations	672

Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%

7. The Choice of Partner

Based on the population data, and as shown in Table 6, all the factors considered, except team size and team location, significantly affect team choice of collaborating with partners from the north. In contrast, the choice of collaborating with partners from the south seems to be associated with team size, the number of PhDs, the extent to which the team leader writes well in a second language, and team productivity only. The z-tests of the effects of individual variables and the Wald Tests of joint effects of the categorical variables confirm these findings.

Table 6: Factors Explaining the Choice of Collaborating with Partners from Northern and Southern Countries

Variable	Int. Res. w/ North	Int. Res. w/ South
Team Size in 2003	0.013	0.028*
	(0.94)	(2.04)
Team Age in 2003	0.037**	-0.004
	(3.13)	(0.34)
Total PhDs in 2003	0.267**	0.091*
	(6.54)	(2.40)
Leader Writes Oth Langua	0.338**	0.493**
	(2.63)	(3.25)
Leader Studied Overseas	0.483**	0.096
	(3.90)	(0.68)
Tot. Proj. in 2003	0.068**	0.002
	(5.18)	(0.18)
Tot. Bib. Prods. by 2003	0.007**	0.008**
	(3.50)	(4.72)
Agrosciences	-0.567*	0.010
	(2.08)	(0.03)
Medical Sciences	-0.419*	-0.380
	(2.03)	(1.58)
Social Sciences	-0.376	-0.139
	(1.89)	(0.61)
Humanities	-0.220	-0.069
	(1.31)	(0.36)
Engineering	-0.797**	-0.288
	(3.84)	(1.24)
Other Sciences	0.010	0.071
	(0.03)	(0.21)
Business Sector	0.270	0.288
	(0.71)	(0.70)
Government	0.307	-0.048
	(0.99)	(0.13)
Other Sector	1.051*	0.265
	(2.46)	(0.56)
Mid. Home Inst.	-0.436**	-0.164
	(3.15)	(1.02)
Small Home Inst.	-0.400	-0.235
	(1.85)	(0.92)
Small City	-0.653	-1.379
	(1.15)	(1.34)

Cont'd

Table 6 ***Cont'd***

Variable	Int. Res. w/ North	Int. Res. w/ South
Midsize City	-0.260	-0.141
	(1.69)	(0.79)
Constant	-2.146**	-2.435**
	(10.20)	(10.42)
Observations	1889	1889

Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%

8. The Choice of Combining Collaborative Activity and Partner

Based on the population data, and as shown in Table 7, the choice of hosting foreign researchers from the North depends mostly on the size of the team, the number of doctorates the team has, the characteristics of the leader, whether the team works in the natural science as opposed to working in the agricultural sciences, the medical sciences, the social sciences or in the engineering; whether it is affiliated with a large institution and whether it is located in a big city. The choice of hosting researchers from the South also depends on the size of the team, the number of PhDs it has, whether the team leader writes well in a second language, or whether it works in the natural sciences as opposed to working in the medical science. Receiving funding from the northern countries is associated with team age, the number of doctorates the team has, the characteristics of the team's leader characteristics, the dynamism of the team, the sector, and the size of the home institution. Finally, the choice of working with projects funded by southern countries is associated with how productive the team is, and whether it works in the multidisciplinary sciences as opposed to working in the natural sciences only.

More precisely, and as discussed before, team size positively affects the choice of hosting foreign researchers. However, it is slightly more important for explaining the choice of hosting researchers from the south than for explaining the choice of hosting researchers from the north. The difference of the effects of each variable can be seen by comparing the z-statistics in each model.

The opposite is true regarding the effects of having PhDs in teams. As the number of PhD holder increases, the probability of hosting foreign researchers increases, but it raises more for hosting researchers from the north than for hosting foreign researchers from the south, holding the other variables constant.

Teams led by someone who writes well a second language positively affects the probability of hosting foreign researchers, but it increases it more for hosting researchers from the south than from the north, holding the other variables constant.

Teams led by someone who studied overseas appear more likely to host foreign researchers than teams not led by someone who studied overseas, but this is mostly because this factor affects the choice of hosting researchers from the north and not from the south.

Teams working in the natural sciences are more likely to host foreign researchers than comparable teams working in the medical sciences, the social sciences and the engineering. However, this is mostly due to its higher probability of engaging researchers from the north than for its probability of engaging researchers from the south, which is not statistically significant. By contrast, the odds of hosting foreign researchers are higher among the teams working in the natural sciences than among the teams working in the medical science. These differences are statistically significant regarding both types of

partners. In this case, the difference in the odds is also higher regarding the choice of hosting researchers from the north than of hosting foreign researchers from the south.

Finally, the higher probability of hosting foreign researchers among teams affiliated with big institutions or located in large cities compared to that of teams affiliated with mid-size institutions or being located in mid-size cities responds mostly to the higher probabilities of the former types of teams to host researchers from the north.

As for the factors affecting the choice of working with foreign funding is concerned, team age appears to affect positively the choice of working with foreign funding, but it affects more the choice of working with funding from the north than of working with funding from the south, holding the other variables constant.

By contrast, although the effects of having PhDs in teams positively affects the choice of working with foreign funding, it seems to affect positively more the choice of funding from the north than from the south, holding the other variables constant.

The extent to which a team has a leader who is able to write well in a second language or studied overseas in the past is more important for explaining the choice of working with foreign funding from the north than for explaining the choice of working with funding from the south (whose effects are not statistically significant).

The number of projects active a team has is important for explaining the choice of foreign funding. However, the effect is greater for explaining the choice of working with funding from the north. In contrast, the number of S&T products a team has is more important for explaining the choice of funding from the south than from the north, although it is also important for explaining the choice of receiving funding from the north.

Teams working in the other sciences or in the multidisciplinary sciences are more likely to work with projects funded by southern countries than teams working in the natural sciences. They are also more likely to work with funding from the south than with funding from the north.

Teams affiliated with the NGOs' are more likely to work with foreign funding than comparable teams affiliated with the academy, mostly because the former are more likely to work with funding from the north.

Finally, teams affiliated with large institutions are more likely to work with foreign funding than comparable teams affiliated with small and midsize institutions. However, the main difference is due to their likelihood of working with funding from northern countries.

No significant effects were found regarding the location variables on the probability of working with funding of any origin.

Table 7: Factors Explaining the Choice of Different Combinations of Partners and Types of Collaboration

Variable	Researchers from North	Researchers from South	Funding from North	Funding from South
Team Size in 2003	0.040**	0.046**	-0.007	-0.021
	(2.72)	(3.12)	(0.50)	(1.01)
Team Age in 2003	0.017	-0.025	0.030*	0.018
	(1.35)	(1.56)	(2.52)	(1.21)
Total PhDs in 2003	0.206**	0.099*	0.191**	-0.011
	(5.08)	(2.33)	(4.93)	(0.24)
Leader Writes Oth Langua	0.386*	0.520**	0.467**	0.313
	(2.30)	(2.91)	(3.27)	(1.33)
Leader Studied Overseas	0.375*	0.146	0.445**	0.146
	(2.37)	(0.88)	(3.27)	(0.67)

Cont'd

Table 7 ***Cont'd***

Variable	Researchers from North	Researchers from South	Funding from North	Funding from South
Tot. Proj. in 2003	-0.010	-0.015	0.066**	0.026
	(0.77)	(1.06)	(5.14)	(1.86)
Tot. Bib. Prods. by 2003	-0.001	0.002	0.009**	0.011**
	(0.43)	(1.24)	(4.94)	(5.52)
Agrosciences	-0.875*	-0.285	-0.235	0.127
	(2.30)	(0.80)	(0.82)	(0.29)
Medical Sciences	-0.889**	-0.771**	0.052	0.168
	(3.24)	(2.58)	(0.24)	(0.51)
Social Sciences	-0.542*	-0.397	-0.150	0.164
	(2.11)	(1.49)	(0.69)	(0.47)
Humanities	0.087	-0.103	-0.355	-0.461
	(0.45)	(0.48)	(1.87)	(1.36)
Engineering	-1.266**	-0.353	-0.246	-0.225
	(4.16)	(1.35)	(1.15)	(0.62)
Other Sciences	-0.079	-0.647	0.272	0.897*
	(0.23)	(1.44)	(0.84)	(2.20)
Business Sector	0.268	0.330	0.263	0.572
	(0.59)	(0.69)	(0.62)	(0.90)
Government	-0.103	-0.406	0.623	0.722
	(0.24)	(0.84)	(1.91)	(1.45)
Other Sector	0.251	-0.229	1.761**	1.245
	(0.51)	(0.37)	(3.92)	(1.90)
Mid. Home Inst.	-0.460*	-0.072	-0.447**	-0.463
	(2.53)	(0.39)	(2.94)	(1.77)
Small Home Inst.	-0.092	-0.118	-0.656*	-0.810
	(0.34)	(0.41)	(2.57)	(1.80)
Small City	-1.231		-0.009	-0.073
	(1.19)		(0.02)	(0.07)
Midsize City	-0.519*	-0.200	-0.088	0.049
	(2.34)	(0.96)	(0.52)	(0.18)
Constant	-2.499**	-2.541**	-2.648**	-3.492**
	(9.89)	(9.43)	(11.55)	(10.16)
Observations	1889	1856	1889	1889

Absolute value of z statistics in parentheses
* Significant at 5%; ** significant at 1%

9. Conclusions and Policy Implications

Table 8 summarizes the findings on the effects of the variables studied on the collaborative behavior in Colombia. It shows the positive, the negative or the non-effects (at he 0.05 level) of each variable on the type of collaboration studied, the type of partner involved, and the preference for a specific combination of collaborative activity and partner's origin. In particular, it shows that the number of doctorates a team has and the characteristics of its leader are the variables with the stronger explanatory power on team's decision to collaborate internationally all types and origins considered.

Table 8: Summary Table: Determinants of International Research Collaboration in Colombia

Variable	IRC	Type of Collaboration			Type of Partner		Type of Collaboration and Partner			
		Foreign Researchers	Foreign Funding	Co-Authorship	North	South	Researchers from North	Researchers from South	Funding from North	Funding form South
Team size in 2003	+	+	No Sig	?	No Sig	+	+	+	No Sig	No Sig
Team Age in 2003	+	No Sig	+	?	+	No Sig	No Sig	No Sig	+	No Sig
Total PhDs in 2003	+	+	+	?	+	+	+	+	+	No Sig
Leader Writes in Other Lang.	+	+	+	?	+	+	+	+	+	No Sig
Leader Studied Overseas	+	+	+	?	+	No Sig	+	No Sig	+	No Sig
Tot. Proj. in 2003	+	No Sig	+	?	+	No Sig	No Sig	No Sig	+	No Sig
Tot. Bib. Prod by 2003	+	No Sig	+	?	+	+	No Sig	No Sig	+	+
Agro sciences	No Sig	No Sig	No Sig	-	-	No Sig	-	No Sig	No Sig	No Sig
Medical Sciences	-	-	No Sig	No Sig	-	No Sig	-	-	No Sig	No Sig
Social Sciences	-	-	No Sig	?	No Sig	No Sig	-	No Sig	No Sig	No Sig
Humanities	No Sig	No Sig	-	?	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig
Engineering	-	-	No Sig	-	-	No Sig	-	No Sig	No Sig	No Sig
Other Sciences	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	+
Business Sector	No Sig	No Sig	No Sig	+	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig
Government	No Sig	No Sig	+	+	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig
Other Sector	No Sig	No Sig	+	+	+	No Sig	No Sig	No Sig	+	No Sig
Small Home Inst.	No Sig	No Sig	-	-	No Sig	No Sig	No Sig	No Sig	-	No Sig
Mid. Home Inst.	-	No Sig	-	-	-	No Sig	-	No Sig	-	No Sig
Small City	-	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig	No Sig
Midsize City	No Sig	-	No Sig	No Sig	No Sig	No Sig	-	No Sig	No Sig	No Sig

The understanding of the determinants of international research collaboration and of the different ways it is conceived as well as of the choice of partners helps to better design public policies oriented at exploiting the benefits derived from collaborating internationally or at reducing the negative effects that may result from it.

To be continued…

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