

Changing Roles for the Global South in International Collaborative Learning

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Abstract: International collaboration is an important contributor to learning, innovation, and competence-building systems. International collaboration in research has been growing rapidly for several decades. The implications of these emerging patterns for developing countries are a matter for debate. New opportunities could be opening up for reciprocal learning involving researchers in the global South, through more equal research relationships and ones that go beyond historical colonial ties. This paper looks for signs of that new pattern in two specific energy-related fields, biofuels and neutron science. Literature-based data indicate that several developing countries are strong players in biofuels and that international collaboration is growing faster there than in neutron scattering. However, interview data suggest that several kinds of collaboration could be involved: career-oriented, project-oriented, and sponsor-initiated. Growth in the first or last would indicate continuing asymmetric relationships, while growth in the latter would indicate growing equality. Indicators of international collaboration are probably skewed towards project-based collaboration, which appears to be dominant in instrument-intensive fields like neutron scattering. But the interesting dynamics are probably happening in fields like biofuels, where global learning relationships could in fact be shifting.

Keywords: biofuels, international collaboration, neutron scattering, North-South relationships

JEL classifications: D83, P28, P48, Q16

1. Introduction

International collaboration is an important contributor to learning, innovation, and competence-building systems. Drawing on the “strength of weak ties” (Granovetter, 1973), actors in research systems can learn a disproportionate amount from contact with colleagues outside their own countries. Local colleagues tend to share many elements of a stock of knowledge, while more

distant colleagues are more likely to bring fresh information, because they are differently positioned in knowledge networks and approach questions from different cultural angles.

Even as technology becomes more and more research-intensive, international collaboration in research has been growing rapidly for several decades. The most recent data on international co-authorship of published research show that articles with two or more collaborating countries are the fastest growing segment of the world's scientific publications. The United States and European Union countries collaborate less internationally than would be expected based on their number of publications, but Asian countries collaborate more than would be expected, and a new intra-Asian zone of collaboration is emerging. Collaboration between Asian countries has increased in recent years even without the kind of encouragement the European Commission has provided in an attempt to build collaborations within that region (National Science Board, 2010).

Two decades ago, North-South collaboration in research was thought to represent knowledge flow from North to South. Patterns of co-authorship continued to reflect past colonial relationships (Luukkonen *et al.*, 1992). Recent analyses claim, however, that a collaborative network is emerging globally. While the number of countries publishing scientific papers has not grown much, the internal network structure of relationships among them tightened a great deal between 1990 and 2005 (Wagner and Leydesdorff, 2005). In 2005, the "core component" of the network included 66 countries, as compared with 37 in 1990. Within that core was a central group of fourteen most collaborative countries (Leydesdorff and Wagner, 2008).

The implications of these emerging patterns for developing countries are a matter for debate. On the one hand, Leydesdorff and Wagner claim that the basic network-building dynamic is "preferential attachment" – that is, researchers seek the most prominent collaborators they can find, to raise their own visibility (Wagner and Leydesdorff, 2005). This dynamic would seem to favour connections with scientists already established in the global North. On the other hand, they note that as the network grew, "influence and power were spread more widely among nations at the global level" (Leydesdorff and Wagner, 2008). The strength of weak ties could make collaboration with scientists in peripheral countries more attractive in general, and the actual location of relevant experience in particular areas of research could also tip opportunities towards researchers from the global South.

Under the latter scenario, new opportunities could be opening up for reciprocal learning involving researchers in the global South, through more equal research relationships and ones that go beyond historical colonial ties. This paper looks for signs of that new pattern in two specific energy-related fields, biofuels and neutron science. Biofuels presents an important

opportunity for the global North to learn from the global South, given the leadership of Brazil in ethanol innovation. Neutron scattering, in contrast, is a Big Science field with limited participation from developing countries.

Data for this paper are drawn from a project designed to explore the role international collaboration plays in creating US absorptive capacity. The larger project examines the effect of collaboration-oriented policy interventions, using two specific examples of interventions in 2007 – in biofuels, a collaborative agreement between the US and Brazil, and in neutron science, the opening of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. While the study was designed to gather information on learning in the United States, we will take a different angle in this paper, focusing on the data we have available on developing countries.

After placing our work in the literature on research collaboration, the second section of the paper reviews publication-based evidence and the third section presents results from interviews. In the concluding section, we review implications of these types of collaborations for understanding changes in the global network of international collaboration and learning. In brief, we find that in the field where several emerging economies had special expertise to offer, their international collaborations grew in the latter part of the period, both absolutely and in comparison with the other field. Our interview data suggest that it is crucial to distinguish collaborations aimed at professional advancement (“career-oriented”) from those based on complementary knowledge and resources (“project-oriented”) and those stimulated by funders (“sponsor-initiated”). The overall collaboration rate represents a mixture of these types, which have quite different implications for global learning.

2. Literature Review

The increase in international research collaboration has been noted by many scholars (Georghiou, 1998; Luukkonen *et al.*, 1992, 1993; Okubo *et al.*, 1992). Much of this work has used bibliometric methods of analysis to examine the forms and patterns of collaboration. The increased specialization and complexity of science, access to expensive instruments, growth of interdisciplinarity, and career advancement are some of the factors that are seen to drive collaboration. The perceived benefits of research collaboration range from the diffusion of information and access to knowledge and resources, to increased scientific productivity and innovative capacity (Galison and Helvy, 1992; Luukkonen *et al.*, 1992; Katz and Martin, 1997; Wagner, 2005; Schmoch and Schubert, 2008). On the other hand, the costs that research collaboration impose have detrimental effects on the same aspects of productivity and research quality (Katz and Hicks, 1997; Katz and Martin, 1997).

The motivation of individual scientists to collaborate on research is also a well-studied topic. Georghiou (1998: 620-621) differentiates motivation to collaborate internationally into direct and indirect motivations. The former category includes “access to complementary expertise knowledge or skills; access to unique sites, facilities or population groups; sharing costs and risk; and addressing transnational or global problems” while indirect motivations cover collaboration that is driven by external political, economic or strategic goals. Bozeman and Corley (2004) in their study of research collaboration among US scientists identify thirteen factors that drive collaboration preferences including reputation and work ethic of collaborator, previous collaboration, complementary skills and nationality of collaborator.

Fewer studies have focused on the motivations of scientists and researchers from developing or newly developed countries to enter into collaborative relationships with scientists from the North. The work in this area that focuses on developing countries mostly looks at how collaboration between the global North and the global South produces a slew of benefits for the latter, including capacity building. Building capacity is the proclaimed goal of the many policy tools that have been utilized to promote international collaboration in many of the countries in the South (see Basu and Aggarwal, 2001).

Despite the growth of interest in international research collaboration in recent decades there is a paucity of work that focuses on developing countries. Much of the research on international research collaboration between the global South and the global North utilizes Wallerstein’s world systems framework, visualizing the world as a system of cores and peripheries that are linked to each other by a network of unequal economic exchanges. North-South collaboration is viewed as a core-periphery relationship characterized by inequality in resources and capacity. Schott (1998) for example, has used the world system framework of core and periphery to understand the organization of world science while Hwang (2008) and Schubert and Sooryamoorthy (2010) have used it to analyze patterns of collaboration. Existence at the periphery results in a lack of access to resources, opportunities and information that can be surmounted by collaborating with scientists from the core or centre. The latter two works present a more complex nature of the relationships between the core and periphery, recognizing that these relationships are multifaceted, with the periphery being simultaneously a core for other peripheral areas.

The unequal distribution of scientific resources and knowledge plays a role in establishing collaborative relationships, but the dynamics cannot be reduced to a simple dichotomous relationship between the core and periphery. Wagner and Leydesdorff (2005) have provided a stronger theoretical foundation for conceiving the patterns. Their work uses the concept of self-organizing systems to characterize the collaborative dynamics. After considering theories that account for the structure of the network in terms of

centre-periphery relations, internal disciplinary differentiation and big science, Wagner and Leydesdorff conclude that the network is instead self-organizing, driven by “preferential attachment” or the self-interest of individual scientists and researchers.

3. Publication-based Evidence

Our research methodology combines bibliometric analysis, using co-authorship as a proxy measure of collaboration, along with interview data. The former provides an insight into whether rates of international collaboration are changing and the contribution of the South to these changing patterns. Interview data, on the other hand, allows us to analyze the substance of these changes permitting insights into trends, motivations and context. The most common form of data used to study international collaboration in research is co-authorships on published papers (Arunachalam and Doss, 2000; Arunachalam *et al.*, 1994; Derbyshire, 2007; Glänzel, 2001; Glänzel, *et al.*, 1999; Luukkonen *et al.*, 1992, 1993; Okubo *et al.*, 1992). Co-authorship is neither a simple measure of collaboration nor a comprehensive one (see discussion in Katz and Martin, 1997) but gives at least one angle of vision into the phenomenon.

The first stage of our research on biofuels and neutron science gathered and analyzed a publication data set for each field for the period 2003-2009. We developed a keyword strategy to retrieve articles in each area and analyzed the patterns of co-authorship in each. Because the study was designed to examine the effects of policy interventions in 2007, our data are divided into two periods: 2003-2006, *before* the intervention occurred, and 2007-2009, *after* the intervention.

Biofuels

The field of biofuels research was particularly lively during the period we studied. Petroleum prices went on a strong upward surge to a high in late 2008, before the economic collapse. Biofuels are a particularly attractive competitor against gasoline during times when oil prices are high, so the surge in research in the area during this time is not a surprise. Before the period we studied, Brazil had engaged in decades of improvement both in ethanol production and in developing a fleet of vehicles that could switch to ethanol use when conditions made it competitive. It was also not surprising, then, that it emerged as a strong international partner. China and India, however, also increased their collaboration.

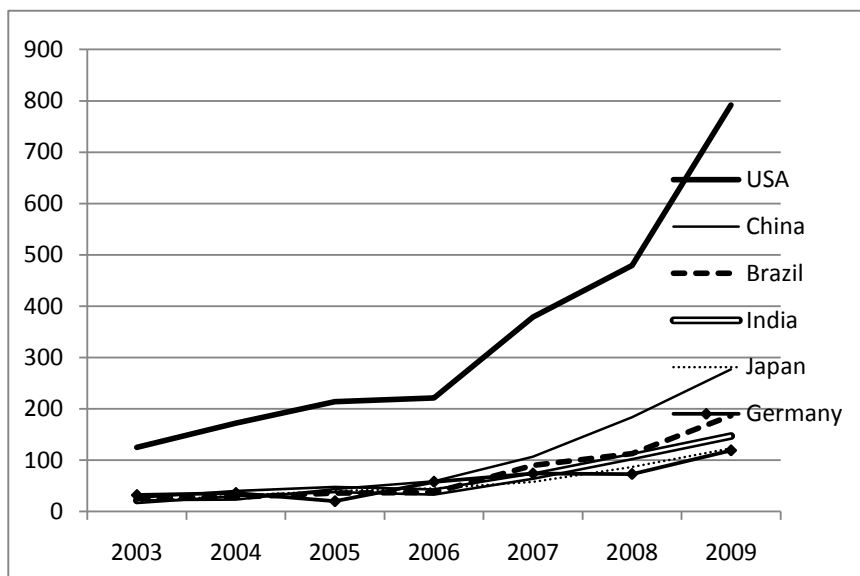
To identify publications on biofuels over this period, we developed a multi-stage search strategy based on literature and on consultation with

specialists in the field.¹ Publications in biofuels have grown nearly six-fold between 2003 and 2009, going from under 500 to nearly 3,000 articles published in journals and conference proceedings. International collaboration has followed the growing trend of publications, going from 13 per cent to 18 per cent of total publications in the field between 2003 and 2009.

Although the US was the leading producer of scientific publications in biofuels over this period, three BRIC countries were right behind: China, Brazil, and India. Since biofuels are made from agricultural products (corn, sugarcane, palm oil, etc.), countries with strong agricultural research traditions have an advantage in this field.

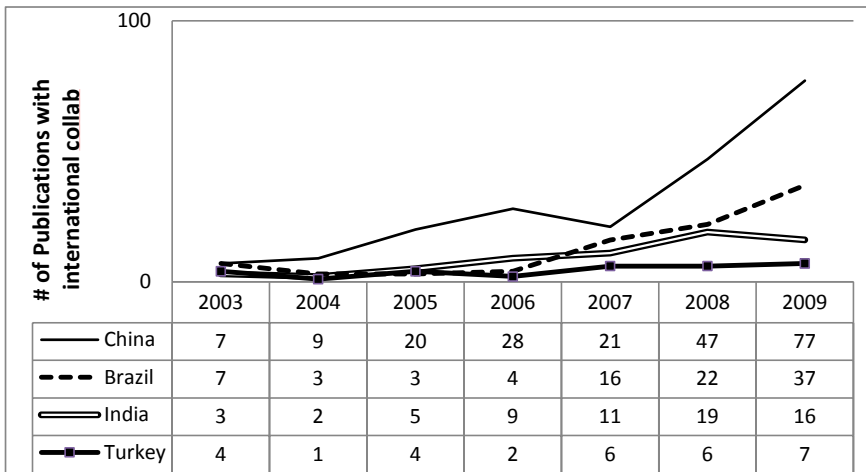
International collaboration is also growing very fast in these developing country biofuels contributors, especially in China (see Figure 1). This phenomenon could be the result of local or national strategies to learn from other countries through outward collaboration, or it could be due to inward preferential attachment, that is, scientists from other countries seeking collaborations in these developing countries because of their specialized expertise. By 2009, many of the institutions publishing the most in the field were from China, Brazil, and India, displacing Swedish and Danish research institutions at the top of the list (see Figures 2 and 3). Only U.S. institutions share the top of the list with institutions from those three developing countries.

Figure 1: Leading Countries in Biofuels Publications, 2003-2009



Source: Web of Science data, analyzed by authors.

Figure 2: Increase in International Collaborations Involving Four Leading Developing Countries, 2003-2009



Source: Web of Science data, analyzed by authors.

These top institutions were also collaborating more, particularly with the United States but also with Europe. Two Brazilian institutions appear in the later list (University of Sao Paulo and University of Campinas), reflecting the strong research activity of Brazilian institutions, particularly in ethanol research.

Table 1 shows details for the increase in collaboration for Brazil over the period. Publications and collaborations rose dramatically for Brazil in this area in the last three years of data, 2007-2009. Collaborations within the country rose even faster than international collaborations, although those with the United States stood out in their rate of increase. Assuming a one to two year time lag between doing research collaboratively and resulting publications appearing in a journal, the sharp upturn represents the period of renewed general interest in biofuels based on the surge in oil prices. Brazil's successful ethanol program was receiving international attention at this time, and its research enterprise could plausibly have been attracting collaborative partners from both South and North.

In sum, then, a few leading developing countries – commonly identified as emerging S&T contenders – increased their collaborative links with Northern researchers over the period of study. Prolific institutions in countries with strong agricultural research traditions could easily have been sought out by potential collaborators in the North. We return to the question of whether they were when we report interview results later in this paper.

Table 1: Highest Publishing Institutions in Biofuels, 2003-2006 vs. 2007-2009

2003-2006		2007-2009	
Institutions	Country	Institutions	Country
US Dep. of Agriculture (Agric. Research Service)	USA	US Dep. of Agriculture (Agric. Research Service)	USA
Lund University	Sweden	<i>Chinese Academy of Science (*)</i>	<i>China</i>
<i>Indian Institute of Technology</i>	<i>India</i>	University of Illinois	USA
Chalmers University of Technology	Sweden	<i>Tsing Hua University</i>	<i>China</i>
<i>University of Sao Paulo</i>	<i>Brazil</i>	<i>University of Sao Paulo</i>	<i>Brazil</i>
University of Illinois	USA	Iowa State University	USA
Swedish University of Agricultural Sciences	Sweden	<i>Indian Institute of Technology (*)</i>	<i>India</i>
Iowa State University	USA	<i>Scilla Sci</i>	<i>Turkey</i>
Technical University of Denmark	Denmark	<i>State University of Campinas</i>	<i>Brazil</i>

Note: * Institutions include many different organizations that were indexed under the same common name.

– Institutions in developing countries in italics.

Source: Web of Science data, analyzed by authors.

Neutron Scattering

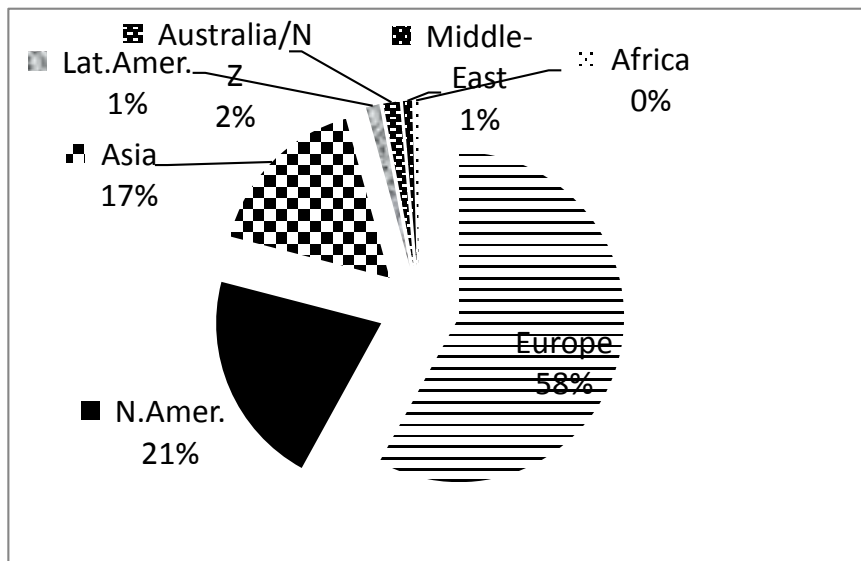
Neutron scattering is a Big Science field, completely dependent on very expensive sources of neutron beams, of which only a few operate in the world. The field is inherently international in that several countries invest in experimental equipment to be used in conjunction with the neutron source. These instruments are always built collaboratively between the source host country and another participant. Teams of researchers who use the facility typically include the permanent scientific staff of the host country as well as visiting experimentalists from other participating nations. Since this is an expensive field, the costs of entry are high for a national community. Once a country begins to participate, national science policies tend to maintain the investment through continuing participation in the construction and use of various facilities. Generations of graduate students are trained to work in them. The experimental results feed into many fields, including industrially relevant areas.

In the field of neutron scattering, following advice from a specialist from the Spallation Neutron Source at Oak Ridge National Laboratory, we constructed the bibliographic dataset by looking for articles containing the string “neutron scattering” in the title, abstract, or any keyword field. We found approximately 7,700 articles published in journals and indexed by SCI, Web of Science between 2003 and 2009, with the number of publications increasing nearly 50 per cent during this time period. As expected, neutron scattering is a more internationally collaborative field than biofuels during the period analyzed – 44 per cent of the articles were co-authored by authors from two or more countries. The share of articles co-authored internationally has remained in the range of 43 to 45 per cent and there is no clear upward trend.

In neutron scattering, the production of science is even more concentrated in North America and Europe than in biofuels. We found that between 2003 and 2009, 80 per cent of articles were published by scientists affiliated to European and American institutions (Figure 3). Asia, mainly led by Japan and China, has only 16 per cent participation in world publications. The United States is the leader in publications with 1974 articles published between 2003 and 2009. It is followed by France, Germany, Japan, and England.

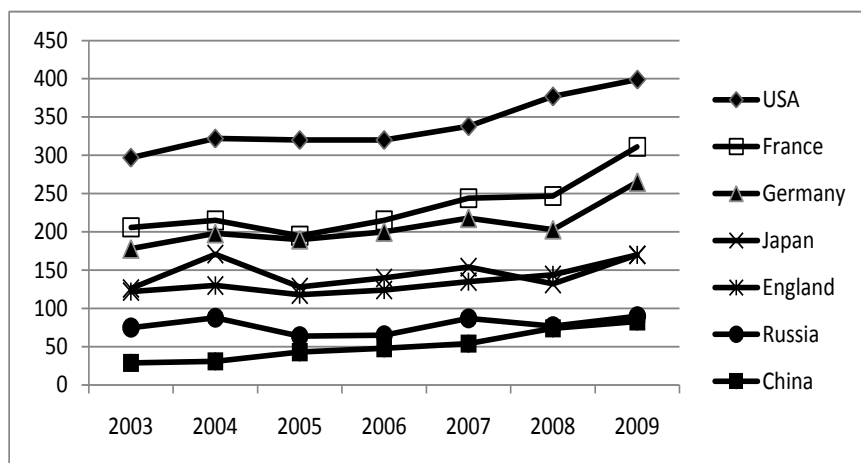
Figure 4 shows the evolution of publications by country during the period. The United States is the leader and growing faster than other countries, especially between 2006 and 2009. China has also shown steady growth since 2003. France is the second in publication and has gained ground when compared to Germany, England, and Japan. Russia is the sixth largest producer of articles with 456 published in the period.

Figure 3: Neutron Scattering – Publications by Region, 2003-2009



Source: Web of Science data, analyzed by authors.

Figure 4: Neutron Scattering – Number of Articles Published by Countries, 2003-2009



Source: Web of Science data, analyzed by authors.

In contrast to the pattern in biofuels, the main players in the science of neutron scattering remain mostly the same over the time period, indicating some barriers to entry in the field such as beam time and high cost. Oak Ridge National Laboratory has strengthened its position in the field, possibly as a result of investments in its new Spallation Neutron Source. The Bhabha Atomic Research Center rose in the ranks, giving one sign of India's strategic interest in neutron scattering (Table 2). The interest reflects a long-term investment in India in fields related to high energy physics, stretching back to the early years after independence.

In an analysis of the pattern of collaborative links in the two time periods, Cozzens and Berger (2009) found that a few more linkages go beyond European countries in the second period, but not many. A clear cluster of Asian institutions appears, with Japanese strength but also Chinese and Indian participation in the later period. The Bhabha Institute collaborates with European institutions, and the Chinese Academy of Sciences with US ones. In general, the collaborations show stability over time, with very few developing country participants, who find entry through Northern institutional collaborations.

4. Interview Data

Bibliometric analysis utilizing co-authorship as a measure of international collaborations is not without drawbacks. Many researchers have multiple institutional affiliations and in a time of greater international mobility of researchers, institutional affiliation and country of origin of the researchers (especially those from the global South) are often different. As a result, co-authorship is often only a partial measure of collaboration (Katz and Martin, 1997). Co-authorship as a measure does capture collaboration but "to learn more about the substance of collaboration we have to rely on complementary information" (Melin and Persson, 1996: 365). Kim (2006), in his case study of the physical sciences in Korea points out that context of the collaboration provides a more nuanced understanding of international collaboration than just co-authorship. Laudel (2002) reports that only half the collaborations reported in her study of German scientists resulted in publications. Interviews of researchers involved in international collaboration are thus invaluable in providing the context to collaboration.

In order to explore the nature of international collaborations in more depth, we interviewed researchers in our two focus fields. The interviews were based on a protocol that was developed to look at the patterns, perceived benefits and costs of international research collaboration. The section on benefits was informed by previous work done by Salter and Martin (2001). The biofuels interviews yielded much more insight on shifting global patterns

Table 2: Highest Publishing Institutions in Neutron Scattering, 2003-2006 vs. 2007-2009

2003-2006		2007-2009	
Institutions	Country	Institutions	Country
Inst. Max Von Laue Paul Langevin, Grenoble	France	Inst. Max Von Laue Paul Langevin, Grenoble	France
Natl. Inst. Stand & Technol, Gaithersburg, MD	USA	Natl. Inst. Stand & Technol, Gaithersburg, MD	USA
Rutherford Appleton Lab, ISIS, Oxon	UK	Oak Ridge Natl. Lab., Oak Ridge, TN	USA
CEA Saclay, CNRS, Gif Sur Yvette	France	<i>Bhabha Atomic Research Center, Mumbai</i>	<i>India</i>
Oak Ridge Natl Lab, Oak Ridge, TN	USA	Rutherford Appleton Lab, ISIS, Oxon	UK
University of Tokyo, Chiba	Japan	CEA Saclay, CNRS, Gif Sur Yvette	France
Russian Acad. Of Sci., Novosibirsk	Russia	Paul Scherrer Inst., Villigen	Switzerland
University of Maryland	USA	University of Maryland	USA
Hahn Meitner Inst. Berlin GmbH, Berlin	Germany	University of Tokyo, Chiba	Japan
Argonne Natl. Lab., Argonne, IL	USA	CNRS	France
Kyoto University	Japan	Argonne Natl. Lab., Argonne, IL	USA
Paul Scherrer Inst., Villigen	Switzerland	Tech University of Munich	Germany

Note: Institutions in developing countries in italics.

Source: Web of Science data, analyzed by authors.

than the neutron scattering interviews, at least directly. In this section, we first describe the biofuels interviews, then return to what the lessons learned there suggest about neutron scattering.

Biofuels

We selected people to interview based on the publication dataset described in Section two. In the 2003-2006 data, we located papers that represented collaborations listing one institutional address in the United States. From among those papers, we chose target areas in which to conduct interviews with the international partners, choosing Brazil, China, India, and selected countries in Europe. There were few enough researchers in each of these areas who had worked with US collaborators that we contacted all of them, along with their US partners. We supplemented this “original sample” with particularly prolific biofuels researchers in the same geographic areas, and talked with them about their international collaborations in general and a recent example in depth. The interviews with researchers in Brazil, China, and India were done in person and in Europe by telephone.

In all, we conducted 35 interviews in biofuels, with researchers from China, India, the United States, Brazil, Germany, Sweden, and Spain. There were 30 male researchers and five female, 15 from the global North and 20 from the global South. Eight were junior at the time of the collaboration we discussed with them.

Before we were able to make sense of differences between the North-North and North-South collaborations described by those we interviewed, we first needed to sort out several different types of collaborations. These were evident in the interview descriptions but not at all visible from the publications reporting on that work.² Using the interview data from this project, Thakur *et al.* (2011) have distinguished three types of collaborations.

- *Career-oriented collaborations*, initiated by graduate students or junior professionals to visit in the laboratories of more senior people in the field.
- *Research project-oriented collaborations*, with a primary focus on producing research, usually involving two senior researchers.
- *Sponsor-initiated collaborations*, in response to a government funding program or the request of a particular industrial sponsor.

One might think that researchers from the South were more prone to initiate career-oriented collaborations, but we did not find strong evidence of this pattern in our data. First, junior and senior researchers were about evenly split between North and South among those we interviewed, as shown in Table 3. Junior researchers both North and South sought opportunities to

Table 3: Summary of Biofuels Interviewees by Rank and Region

	North	South	Total
Senior	11	15	27
Junior	4	4	8
Total	15	20	35

Source: Authors.

work in the laboratories of more senior people in their fields. But there is a striking difference in the labs they visited – all of them were in the North. And junior researchers from the South were more likely than those from the North to emphasize the opportunities that the collaboration might provide in terms of access to lab resources, funding and so on. Another benefit reported by junior researchers from the South is the positive perception that their peers would have of them after collaborating internationally. Thus they attached a higher premium to international research collaboration than their colleagues from the North. Alternatively, junior researchers from the North often reported benefits in terms of career development more than access to resources.

Some examples of career-oriented collaborations involved senior researchers from the South who advanced their careers with a visit to the North. We had several examples of visits in the position of postdoctoral researcher, like a Brazilian interviewee who did postdoctoral training at a university in the United States. He reported that the professor he worked with was well known in the field and that this collaboration had a positive impact on his career in terms of international exposure to academia outside Brazil, his personal academic development and of course a publication. In a few cases the collaboration did not come in the form of a postdoc but still included a long-term stay at the senior partner's lab. For example, one interviewee from India reported that he was a professor in India and went to work with a more senior professor in the United States. As in the other cases, he also reported that the resulting publications were beneficial to his career back in India. In one case from China, there was no actual visit involved. Rather collaboration took place online and via telephone with work going on in two different labs. This kind of division of labour, however, was rare in our sample.

In two instances, senior researchers from the North felt that their partners from the South had benefited more. Regardless of origin, however, both senior and junior researchers viewed these collaborations as an opportunity to improve the latter's career, and this was the basis for initiating the partnership.

The *research project-oriented collaborations* allowed partners to identify common broad research agendas and pool complementary resources. Senior researchers collaborating in this mode were more likely to stay in touch with each other after the collaboration than was the case with the career-oriented partnerships. As with the career-oriented model, there were again several noticeable differences between researchers based on the North and those in the South. In most cases, both sets of researchers felt that their projects were successful. There were several commonly stated reasons for this success such as good timing, availability of funding and a recent general interest in that particular field. There were also two instances where the researcher from the South attributed much of that success to the partner from the North even if they were of similar rank. All the collaborations reported in our interviews that involved laboratory visits in the South were short-term, not long-term visits.

Several researchers mentioned language as being one of several potential challenges to engaging in international research collaboration. For the most part, the interviewees did not mention differences in culture as a challenge to collaboration. However, at least one researcher noted how the dynamics between North and South might influence perceptions. For example, he reported that on his first visit to Brazil he had to convince the staff that the Germans were not just there to take Brazilian resources or access cheaper human resources. Thus he felt that to overcome such fears/issues, one needs to build up a relationship with the potential partner prior to working with them.

The clearest differences between North-North and North-South collaborations appeared in the *sponsor-initiated collaborations*. North-South collaborations were more likely to get funding from industrial/corporate sources, or international donors. North-North collaborations were more likely to be funded by their universities or governments. This led to different types of partners in each group. In the North-South cases it was sometimes university-industry and in North-North it was university-university partnerships. We outline these sponsor-initiated collaborations as a third model because while they might support both career-oriented research and of course research projects, their *modus operandi* were different.

In one example from India, the interviewee noted that a large US automobile company provided the funding for joint work between their institution in India and their colleagues in the US. In this way the company acted as a funded agency for the project and regular monitored activities and outputs. In another example from China, an oil firm was the industry sponsor and played a key role in supporting the research project. In contrast, several interviewees from Germany and the United States pointed to their governments or universities as main sponsors for their research. The researchers viewed the involvement of the company in setting the research agenda positively, as a benefit of this kind of work.

Intellectual property rights also came up occasionally. In two cases researchers from the South mentioned it as an issue. For example, when dealing with foreign firms they noted that part of the research arrangement was that intellectual property generated in the course of the research would accrue to the sponsoring company. Although a common arrangement, they noted that this was one of the challenges in international research collaboration in general. This may point to one of the constraints of limited funding that is available to some researchers.

What do these subtle differences in the interview data suggest about changing global patterns of collaboration? On the one hand, they portray a flattening world for young researchers, who appear to be pursuing international collaboration opportunities from wherever they begin. On the other, they suggest continuing asymmetries in resources and learning, even in the project-oriented collaborations. And finally, they point to changing commercial conditions as an additional driving force in the international relationships – apparently another asymmetric factor, bringing business interests from the North into the collaboration picture.

Neutron Scattering

With these results from the biofuels area in mind, we turn briefly to the interview results in neutron scattering. Most of these interviews were done face to face, since we took advantage of visits of researchers to the Spallation Neutron Source at Oak Ridge National Laboratory, a few hours from us in Atlanta. Some were done by telephone, including interviews in French and Spanish with European researchers. Altogether, we talked with 21 researchers, all affiliated with research institutions in the North. Six were junior and 15 were senior comprising of 18 men and 3 women. All the collaborations they described were North-North. In the few instances in which we talked to a researcher who was originally from the global South, he or she was now affiliated with a university in the North and moved there as a student or post doc.

As in biofuels, the neutron scattering interviews allowed us to characterize the kinds of collaborations in ways that we could not perceive from publications. The neutron scattering collaborations were all of the project-oriented type. This was not a surprise, since neutron scattering is universally described as a field where international collaboration is intrinsic to the work, where people from different countries build experimental equipment and carry out experiments together as a matter of course. Junior researchers were automatically involved in the experiments, and institutional arrangements or national agreements provided the framework, but these features of the collaborations were driven by the work, rather than the other way around.

An example of the intrinsically collaborative nature of the field is the division of labour between the crystal grower and the “experimenter” or “neutron scatterer.” One researcher mentioned that complementary competencies link collaborative partners like the United States and Japan. The latter is known for their material sciences while the best instruments are in the United States. With regard to who initiates collaboration, one of the interviewees mentioned that it is the usually the “scatterer” who searches out the crystal grower. “Scatterers” need access to samples and “crystal growers” need access to beam time.

This interdependence drives co-authorship. As one interviewee described:

In NS you always need to have a local scientist who is responsible for the instrument. No user (visitor) can operate the instrument by himself. At the SNS, each instrument has two scientists responsible for its operation and maintenance. Therefore, if a scientist comes for an experiment, the scientist responsible for the instrument will automatically be co-author of the paper. If the scientist doing the experiment needs more than one instrument, both scientists responsible for the instruments will be co-authors as well.

The dominance of project-oriented collaboration in this instrument-intensive field is less interesting in and of itself than for what it implies for the distribution of collaboration types across science when it is compared with the results for biofuels. We turn to that comparison in the final section of the paper.

5. Conclusions

As we turn to discussing our findings, it is important to keep in mind that the collaborations described in our interviews took place after the 1990s, when Wagner and Leydesdorff claim that the global level of the international collaboration network formed, but before the spurt in publications and collaborations in biofuels that we observed in the publication data. In theory, the interviews thus could show some signs of an emerging pattern of more reciprocal collaborations, rather than South-North dependency, even without the influence of the changing environment of biofuels research.

Neutron scattering clearly does not show that change. In this field, we found the classic pattern of interdependence based on complementary skills in the experimental process. Collaboration levels are high, but if there is any growth in percentage collaboration, it is slow-moving. Players from the global North dominate, and those from the global South are making only modest inroads. When collaboration is measured across the sciences, fields like neutron scattering will have a strong influence on their findings because of the high absolute numbers of collaborations.

The classic pattern may therefore mask the action that is happening in fast-growing, industrially-relevant fields like biofuels. Most importantly, in this area, commercial interests and opportunities are overlaid on the classic pattern of collaboration for career advancement, and players from the South are both entering the field aggressively and being sought as collaborators by those from the North. Since the collaboration rates are low, such fields will be a smaller portion of collaboration counts than of publications generally. But because they represent what is changing in the system instead of what is remaining constant, they are particularly important to observe.

With regard to Wagner and Leydesdorff's theoretical assertions, it is clear from our interviews that collaboration in science is not a single, self-organizing system driven simply by preferential attachment. The career-oriented collaborations may fit that mold, but project-driven collaborations less so and sponsor-initiated collaborations less still, by definition. Overall collaboration rates are made up of some mix of the three types, which are likely to vary among fields of research as they did between the two fields we studied. Studying the mix will require different methods than the literature-based analysis that is so widely used now.

Is there any hint in our data that the growth in collaboration indicates a more equal, "flatter" world in science? No and yes. No in neutron scattering as every new instrument increases the gap between the top and the bottom of the capability ladder. But yes, because the culture of complementarity in such an area makes space for many kinds of skills. No in biofuels, because junior researchers still go predominantly to laboratories in the North for career advancement. But yes in biofuels, because the value of emerging economy research to global actors is clearly visible, and means that they are becoming sellers, not just buyers, in the global knowledge economy.

The implications for reciprocal patterns of learning in globalized science are clear. The historic scientific powers of the North can no longer assume that others will come to them to learn forever. They must begin to develop the habit of learning from the rest of the world. Dynamic areas like biofuels research are likely to be better classrooms for that educational process than more traditional international collaboration sites.

Notes

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1. The search strategy was:

1. TS=(hemicellulos* OR lignocellulos* OR biomass OR “forest residue*” OR “forest waste” OR “agricultur* waste” OR “agro waste” OR “crop residue*” OR “crop waste” OR bagasse OR “corn stover” OR “corn stalk*” OR switchgrass OR miscanthus OR poplar
2. TS=(sugarcane OR “sugar cane” OR energycane OR “energy cane” OR beet OR beets OR “sugar beets” OR sorghum OR corn OR maize OR cassava OR wheat)
3. TS=(ethanol OR bioethanol OR bio ethanol OR biobutanol OR biofuel* OR bio fuel* OR bio refinery OR biorefinery OR bio refineries OR biorefineries)
4. #2 OR #1
5. #4 AND #3
6. TS=(biodiesel OR bio diesel OR biofuel* OR bio-fuel* OR bio-gasoline) OR TS=(renewable SAME fuel*) OR TS=(synthetic SAME fuel*) OR TS=(energy SAME crop*) OR TS=((fischer - tropsch OR fischer tropsch) AND (biomass OR feedstock*))
7. #5 OR #6
8. TS=(medicine* OR medication OR medical OR pharmac* OR rat OR rats OR liver OR drug* OR blood OR plasma OR embryo OR cereal OR fruit OR fruits OR nutrition* OR wine* OR polymer OR membrane OR biopolymer* OR biomaterial* OR biofilm* OR film OR bioremediation OR coating OR extrusion OR extruder OR crustaceous OR crustacea)
9. #7 NOT #8
Timespan=2003-2006. Databases=SCI-EXPANDED, SSCI. Document type: (Article OR Abstract of Published Item OR Meeting Abstract OR Meeting Summary OR Meeting-Abstract OR Review).

2. Laudel (2002) also developed a thorough typology of types of collaboration, but based on the substantive content of the collaborative contributions rather than the larger social relations reflected in our types.

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