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WORLD-SYSTEM ANALYSIS 2.0

Globalized science in centers and peripheries

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Introduction

Science is being transformed by a series of technical and organizational changes that profoundly affect the terms of its production and use, thereby reconfiguring its role in contemporary societies. At the national level, these changes have particularly been analyzed in terms of 'modes' (Nowotny et al., 2001), of 'regimes of knowledge production' (Pestre, 2003; Van Oudheusden et al., 2015), of reconfiguration of the relationship between state, science and industry (Etzkowitz and Leydesdorff, 2000; Joerges and Shinn, 2001), of shifting governance and research evaluation (Mustar and Laredo, 2002), or of a renewed relationship between science and society, due to the increase in public controversies involving scientific and technical issues (Latour, 1999). Furthermore, the nature of the production of scientific knowledge is also subject to greater openness, for example to indigenous knowledge, patient associations (Callon and Rabeharisoa, 2003) or other kind of actors (Jasanoff, 2004, Collins and Evans, 2008).

At the international level, even if science always was an 'international enterprise' (Salomon, 2006) during recent decades it has become increasingly globalized and the reorganization of 'international science' presents a growing complex map. Indeed, some authors (Rosemann, 2014; Moya-Anegón et al., 2013; Grauwin et al., 2012; Veugelers, 2010) talk about a new multipolarity, particularly pointing at the decline of the formerly leading nations in the share of international scientific production (especially the US and Western Europe), and the emergence of new regions, like BRICs (Brazil, Russia, India, China). However, there exist until today very few studies focused on the consequences of these changes on less advanced (semi-peripheral) countries and on the relationships among knowledge production centers, with a critical perspective that takes into account the emerging complex dynamics. Therefore, our aim in this chapter is to suggest an analytical framework and to present empirical data on these dynamics, as well as on the consequences that 'globalization' has on the international organization of science, analyzing the complex relations between centers and peripheries (emphasizing the plural).

We consider, in fact, that a critical 'centers & peripheries' approach—as it were a world-system analysis 2.0—is more adequate than the currently used concepts like 'North and South', or 'developing countries', because they are not able to show the profound heterogeneities *within* each geographical context. Indeed, even when adopting the plural to designate 'peripheries', we can distinguish three kinds (presented as ideal types) of knowledge production dynamics among countries[1] usually described as 'developing':

a) traditional contexts where research activities are strongly rooted from (at least) the end of 19th century, with particular specialization patterns, a considerable number of scientists in most disciplinary fields (relatively weaker in 'high technological fields'), and often oriented to biomedical research. This is for instance the case in big Latin American countries such as Brazil, Argentina, Mexico, or Chile and in some Northern African countries such as Egypt, Algeria, Tunisia and Morocco;
b) 'non-traditional scientific countries', which have experienced a very significant and rapid growth during recent decades, as well as a strong presence of firms able to industrialize knowledge (examples include India, Korea, Singapore, or even South Africa – even though it may arguably be also a member of the first group); and
c) countries with weak scientific systems, very few scientists clustered in only a few disciplines, no important equipment, etc. like most African and small Latin American countries (see also chapters by Peloquin; Vessuri).

In the first part of this chapter, we illustrate the context of globalization and internationalization within which science is evolving. Taking stock of these transformations, we will take, as a starting point, the following questions:

- Does globalization imply that diverse regions conduct the same type of scientific activities and, therefore, that specialization patterns are going to disappear?
- Does it imply that knowledge is equally distributed and used in different contexts?

Our answer to both questions is negative, as elucidated in several examples. Considering that local frames and scientific specialization, as well as the important differences in the production, distribution and use of knowledge are still important within a globalized context, we can raise several questions: does the process of globalization have different impacts on scientific dynamics in these quite different contexts? And what kind of variables can explain these differences? Are the former 'centers' and 'peripheries' still pertinent to understanding today's scientific dynamics? To answer these questions, the second part of the chapter will analyze a case study from a semi-peripheral country, the development of agricultural biosciences and biotechnologies in Argentina, to show the various emerging alliances between new centers and peripheries *within and across* the country (Tyfield and Urry 2009). We conclude by arguing for the theoretical development of a world-system analysis 2.0 to better understand how exactly globalized science makes national action and policies more important but also more difficult as the disparities between scientific disciplines are exacerbated by international scientific cooperation and competition. Globalization and cosmopolitization thus are not reducing the importance of the nation-state.

The production of scientific knowledge: towards new centers and peripheries

Looking at the production of scientific knowledge from an international perspective, there is no doubt that we live in a changing world. But now that scientific production is no longer concentrated in a few 'developed' countries, which formerly dictated the terms of scientific agendas for the rest of the planet, in what direction(s) are these changes going? We answer this question in relation to the distribution of knowledge production and the emergence of 'mega international networks' (Kreimer, 2012).

In recent decades, the distribution of knowledge production on a global scale has begun to change in at least two ways. First, there is a clear shift from a world largely dominated by the more traditional countries, in which most production was concentrated, towards a multipolar, more complex world (Santander 2014; Grauwin et al., 2012; Veugelers, 2010). Second, a change has occurred in the very *modes* of production of knowledge, towards the elaboration of research results that are increasingly the product of international cooperation. However, we argue that this does not mean that so-called 'developing' countries participate in the same way as their 'developed' counterparts in the new organizations of scientific work, nor that collaboration happens on equal grounds (see also Pfotenhauer, this volume).

To understand these shifts, let's briefly step back a couple of decades to look at the articles then listed on Web of Science. During the period from 1993 to 1997, the United States accounted for some 37 percent of international production, while the European Union (then 15 countries) gathered about 35 percent. Japan, Canada, Russia, Australia and Switzerland accounted for 22 percent, so that altogether this group concentrated about 94 percent of total world scientific production (King, 2004, May, 1997). But that concentration was even more marked in terms of citations as an indirect but relevant indicator of the visibility and usefulness that communities of researchers accord the scientific production within their own field. Here, the United States produced more than half of the citations (52 percent), while Europe maintained the same share (35 percent), and all other countries were dramatically lower. Moreover, if one was taking the upper 1 percent of the most cited articles, the US had nearly two-thirds of the world's total (King, ibid.).

Table 29.1 Percent of world publications and citations in selected countries, 1993–1997

	1993–1997		
	% of World Publications	*% of World Citations*	*Dif. Pub-Cit*
United States	37.46	52.30	+14.84
EU 15	35.42	36.57	+1.15
United Kingdom	9.29	10.87	+1.58
Germany	8.05	8.63	+0.58
Japan	8.69	7.54	–1.15
France	6.11	6.37	+0.26
Canada	5.05	5.59	+0.54
Italy	3.67	3.71	+0.04
Switzerland	1.73	2.69	+0.96
Netherlands	2.51	3.22	+0.71
Australia	2.69	2.60	–0.09
Sweden	1.91	2.43	+0.52
Spain	2.37	1.96	–0.41
Belgium	1.20	1.39	+0.19
Russia	3.65	1.23	–2.42
China	2.06	0.95	–1.11
South Korea	0.81	0.44	–0.37
India	2.19	0.76	–1.43
Brazil	0.84	0.51	–0.33

Source: OECD: Main Science and Technology Indicators: www.oecd.org/sti/msti.htm

The situation has shifted today. Considering publications for the period 2010–2012 the US has dropped to less than a quarter of the total (24.3 percent), while some newcomers have clearly emerged. Several countries formerly considered as 'developing' markedly increased their share, most notably China (see chapters by Suttmeier; Xu and Ye), which gathered almost 11 percent of the world's scientific production during that period. Other cases in point are India and South Korea, scoring 3 percent and 4 percent each (see Figure 29.1). On the other hand, there was a slow decline in some traditionally strong countries like Japan—whose international share in knowledge production halved, as well as, for example, Canada or France, both of which reduced their share by more than a third (Levin, Jensen and Kreimer, 2016). Therefore, several authors speak of a new multipolar world of knowledge production (Veugelers, 2010, Grossetti et al, 2012), one that replaces the older picture of a world only dominated by one hegemonic actor (US) and accompanied by several 'leading figures' (Japan, Germany, United Kingdom). The same scholars also stress a decentralizing trend within each country, with a tendency towards greater distribution among cities (Grossetti et al, 2012).[2]

It is necessary to be careful when taking stock of these changes, especially when observing two considerations: first, it does not seem overstated to argue that the primary change is the increased participation of China in the production of international science, along with the not-yet-so significant emergence of other Asian countries, for instance South Korea. Indeed, if we set China aside, which was ranked 12th in 1987 and has risen to the second place in only twenty years (King, 2004, Levin et al. 2016), the rest of the top ten countries with the highest production remained unchanged. Second, these changes are very heterogeneous from one discipline to another. Using a novel methodology, Levin, Jensen and Kreimer[3] have shown that, while the overall participation of China in all disciplines reaches less than 11 percent, in the field of nanoscience and nanotechnology its global share climbs to almost 24 percent, turning it into the world's leader. Something similar can be noted in the case of engineering.[4] Nonetheless, as the second part of the chapter will show, in more historically established areas of research, such as the emblematic case of biomedical sciences or R&D related to the generation of new drugs and treatments, the long-term accumulation processes remain crucial and, consequently, 'traditional' countries largely remain firmly in the lead even though the emergence of new centers has to be acknowledged.

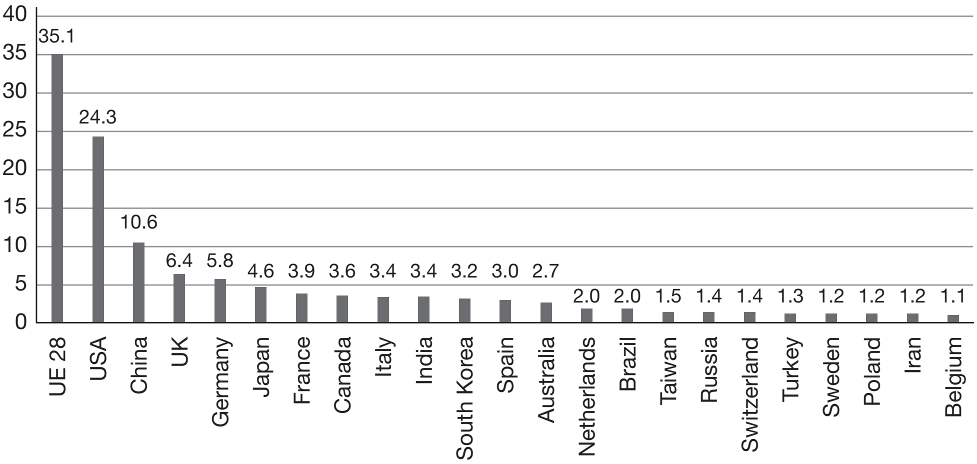

Figure 29.1 Percent of world publications, 2010–2012
Source: Levin, Jensen and Kreimer (2016)

On the other hand, the *scale* of the processes of knowledge production has evolved from national laboratories to the formation of increasingly large networks with participation of a greater number of groups from different countries. This has been clearly influenced by a new set of policies, such as those of the European Union (i.e. the successive Framework Programs, now Horizon 2020), which explicitly promoted these mechanisms, as a reaffirmation of their rivalry with the United States and other regions (CCE, 2007). Several authors (Cambrosio, Mogoutov, Keating, 2004; Adams, 2012 and 2013; Wagner, 2009) attest to the emergence of these networks, which implied a considerable mobilization of resources and an important change in the scale of research: in various fields, standards shifted from the 'group' as a unit of knowledge production to 'large networks' made up of different groups and operating in different national contexts.

These changes in both the modes and scales of knowledge production have different consequences for more advanced research systems and for 'non-hegemonic' ones (Losego and Arvanitis, 2008). Despite the optimistic arguments claiming that greater democratization and new opportunities for formerly excluded groups accompany these changes in processes of knowledge production (Wagner, 2009, Gaillard, 1998), it is important to pinpoint the emergence of a new configuration that has led to a 'new global division of scientific work' (Hwang, 2008, Kreimer and Levin, 2015, Kreimer, 2006). In such configuration, the elites belonging to countries with important scientific traditions, but which are relatively less developed[5] or 'non-hegemonic', are today actively involved, but their ability to influence the direction of research agendas and, above all, to industrialize the knowledge produced by these networks is still very limited. In recent research, Kreimer and Levin (2015) conducted a survey with almost 1,000 Latin American research leaders who had participated in European projects, and showed that more than a third affirmed that their activities mostly consisted of 'data collection', while another third of researchers stated they were limited to 'data processing'. Another 25 percent stated that they spent their time at 'technical work', and only 10 percent asserted that they took an active part in theoretical development or production.

To present a comprehensive view of current research practices, we need to add one additional piece: the crucial transformation catalyzed by the extension and massification of Information and Communication Technologies (ICTs), especially the Internet and the big databases available 'in a shared cloud'. This has led in several knowledge fields to the creation of 'virtual laboratories' where a great number of scientists from various contexts work together in projects that overcome traditional/national frontiers. International databases shared by a great number of scientists who are at the same time producers and users of data are the mark of a new era of research. However, the access to and application of data is not equally distributed around the world: even when there are not formal restrictions to access, the unequal cumulative capacities in different research groups tend to reproduce the old distinctions between 'centers' and 'peripheries'.

Therefore, the 'globalized science' in emerging countries seems to be working to strengthen knowledge-based industries mostly located in the more advanced countries, but this dynamic is not yet regulated by a new set of policies. To sum up our point so far, current shifts attest to the emergence of a relative multipolarity in terms of knowledge production, but we should be cautious and not take the emergence of multiple centers—and thus of multiple peripheries—as an equalizing trend since major differences and inequalities remain.

Globalized science's dynamics and the joint emergence of centers and peripheries: a case study in Argentina

In most peripheral contexts, a substantial part of knowledge is still being produced by public institutions, with very infrequent participation and relationships with the private/industrial sector – a marked difference to the 'global North' (see chapters by Edgerton; Pagano and Rossi; Lazonick et al.; Schiller and Yeo).[6] While the context of neoliberal science (Lave, Mirowski and Randalls, 2010) seems to push research towards industrial needs, at the same time we witness in many countries the (re)emergence of claims favoring a return of the state in a series of domains, including science. This is certainly the case in Argentina, where a long tradition of publicly funded biosciences and biotechnologies today struggles for survival under the new global international division of scientific labor described above.

This leads us to stress a current paradox: in spite of the large scientific community working in Argentina on molecular biology and agricultural biotechnology supported by public funds, scientists' participation in international scientific collaboration has decreased over the last decade (while agriculture decreased its relative relevance for European research collaboration policy with Latin America: see Kreimer and Levin, 2015). Instead, S&T collaborations tend to concentrate on biomedicine or traditional natural sciences (chemistry, physics). Furthermore, in biomedicine, there has been a shift from 'local' issues (e.g. tropical diseases) to 'global' ones (tuberculosis, vascular disease or leishmania).

How can we make sense of this paradox? Influential works in the political economy of science and technology address the unfolding of a 'globalized privatization regime' (Mirowski and Sent, 2008), characterized by, among other things, the privatization of publicly funded research, commercial agreements eluding national controls, and a general trend toward the commodification of scientific knowledge (Slaughter and Rhoades, 1996, Tyfield, 2012, Lave et al., 2010). Based on the case study of genetically modified (GM) soybean in Argentina (analyzed in greater details elsewhere, in Delvenne et al., 2013 and Delvenne and Vasen, 2013), we ask how such a regime has developed in Argentina. Can we point at trends that reflect the general pattern of commercialization of science, or do we see different dynamics, contradicting this general pattern to a certain extent? Are central (corporate and political) power and resources unevenly distributed at the expense of the periphery? To what extent has the peripheral character of Argentina influenced the process of biotechnology's expansion in this country?

Transgenic soy was introduced in Argentina in 1996 as part of the circulation of a global 'technological package', including GM soy and a herbicide whose toxic agent is glyphosate (both were initially produced by Monsanto, the multinational and quasi-hegemonic firm). However, the tremendous expansion of that global technological package coming 'from above' cannot be explained without mentioning its integration with developments coming 'from below', especially no-till farming techniques (see Goulet 2008). While no-till farming started with a group of tinkering farmers in the late 1980s, who were seeking productivity gains and concerned by soil's degradation, today, Argentina is the world's leading country in no-till farming techniques, with a rate of 92 percent of adopters. The key element is that the massive adoption of no-till farming techniques, the fast development of the national agro-industrial machinery industry to meet the needs of no-till farming (and today of precision agriculture) and the substantial adoption of GM soy *co-evolved* and *co-produced* new centers and peripheries.

In terms of these evolving centers and peripheries, two examples can be highlighted. First, in the late 1990s/early 2000s, GM soy seeds from Argentina (also called 'Maradona soy') were illegally imported in Paraguay and Southern Brazil without significant impediments. The illegal soybean was estimated to represent around 80 percent of the 2003 harvest in the Brazilian state of Rio Grande do Sul (Vara, 2005). This *de facto* situation forced Brazilian Vice-President José Alencar to sign in 2003 an exceptional decree that authorized farmers to plant GM soy, thereby opening the door to a 'transgenic South America' and turning the subcontinent into a global center of GM crop production and export.

Second, in spite of the apparent homogeneity of the national technological package (GM soy, herbicide, no-till farming), the latter doesn't 'work' and deliver its promises equally to small or large-scale farmers. The key to understanding this asymmetry is to consider GM technology as a variable configuration, rather than a stable object or a technique that can be applied in the same manner everywhere. Considering a specific technology as a configuration makes the intimate relationship between technology and its conditions of use and implementation visible. Arza and Van Zwanenberg (2013) make the strong and important claim that the characteristics of farmers' production systems, such as access to capital, agricultural machinery and local seed input markets, are not 'external factors' to an otherwise stable technology, but an inherent part of a technological configuration as it comes into being in concrete situations. Since to be profitable GM soy requires cultivation of large surfaces and the acquisition of expensive machinery, in many cases small and medium-scale farmers were unable to catch up with capitalization and land-scale demands, so they have opted out of production by leasing their land to larger farmers or investors, thus becoming 'rentiers' rejected at the periphery of agricultural production (Gras and Hernandez, 2014).

The seminal work of Kloppenburg (1988) has stressed how much efforts to control the seed have shaped the emergence of the agricultural biotechnology industry. In the case of Argentina, however, there was almost no room for the development of local knowledge associated with GM organisms. The development of the GM soy complex in Argentina has gone through a number of peculiar conditions that render it particularly useful for exploring the ambiguities, complexities and in-between situations that can take place when the globalized neoliberal privatization regime takes root in a semi-peripheral country.

In Argentina, due to contingent circumstances, one can speak of a technological package 'free of patents', embedded in a permissive IP regime (Filomeno, 2013) as well as in a relatively open, non-monopolistic market dominated by private companies and not limited to multinationals. First, the patent of glyphosate had expired in 1991. This has been important because, as Ablin and Paz (2000) note, in the 1980s glyphosate was more expensive in Latin American than in central countries (US$40 per liter), a situation which changed dramatically in the 1990s when the price dropped to US$10, and less than US$3 in 2001—less than one third of its price in the US. Second, a crucial explanatory element of GM soy's expansion has been that the transnational company Monsanto could not patent the event in Argentina, contrary to what happened in most other countries in the world. This has had huge effects on the cost of the GM soy seeds, which was lower than it would have been had the intellectual property (IP) regime been favorable to Monsanto's interests as has been the case elsewhere with stronger IP regimes.

Argentina's peripheral location therefore facilitated the emergence of different actors from those described in the seminal work of Mirowski and Sent, illustrating the specific configuration of this new phase of the commercialization of science. We especially note two groups of actors. The first group is made of actors that support public-private R&D partnership in biotechnology and claim the importance of a national strategic perspective, as epitomized by the recent alliance of CONICET (National S&T Council) and the company Bioceres for a drought-tolerant event.[7] Unlike NGOs, this group of actors accepts the general terms of an overall privatization regime, but attempts to incorporate perspectives that take advantage of the strategic situation of Argentina, a country that is the world's third largest exporter and producer (after the US and Brazil) of GM crops. At the same time, they acknowledge that the country's peripheral position has forced its companies to enter into alliances with multinational corporations in order to put their products on the market (cf. the example with the US firm Arcadia). As in the framework laid out above, these alliances most often result in situations in which public actors have only very limited influence to steer the industrialized knowledge produced toward social needs of local populations.

The second group is mainly composed of national NGOs (peasants' movements like MOCASE, Via Campesina, or Rural Reflection Group) and some scientists (e.g. CONICET's molecular biologist Andres Carrasco) who combine a critical look at biotechnology, emphasizing anti-imperialism, health impacts of herbicide spraying and food sovereignty. During some protest actions, they have been joined by international NGOs such as Greenpeace or Friends of the Earth. In the case of GM soy, the social activists and concerned stakeholders argue that the technological package (made of the GM seed, glyphosate-based herbicides and new farming techniques) dramatically affects public health and the environment. They are especially worried about the impacts of what has been coined as a 'soy-ization' or a 'Pampeanization' of Argentina.

The former term relates to a tendency observed during the last two decades, mainly in the Pampas (a very fertile area of Argentina historically devoted to agriculture), to grow soy instead of any other crop (or instead of cattle raising) because it is more profitable and easier to handle. This led to a lack of crop rotation and to an agriculture that is too intensive, as well as an overuse of agrochemicals and fertilizers, thus decreasing soil quality and increasing erosion. The latter term, 'Pampeanization', refers to the tendency to introduce agro-industrial crops such as soy in other provinces than the ones where such activities usually took place (the humid traditional zones for intensive agricultural production), such as Northern Argentina, which is characterized by extremely dry zones, like the province of Salta. This affects the soil's fertility and disrupts the ecosystems of those regions by displacing indigenous population and increasing deforestation. These conflicting debates and worldviews, we argue, are not context but instead an integral part of the neoliberal governance of globalized science and, as such, can be analyzed in terms of their resulting from, and indirect effects on, the commercialization of science. This point is made in Delvenne et al. (2013: 159), where the authors take a similar approach to Rebecca Lave's (2012) analysis of the different types of environmental knowledge held by extramural science producers (like indigenous people or amateur scientists). Lave argues that those are surprisingly central to neoliberalism, and that it is worth considering them as deeply interconnected in order to see the fine-grained picture of neoliberalism and its effects on knowledge production.

What is interesting to stress here about these two groups is that both have national development objectives of Argentina in their ideological roots, although their conceptions of 'development' are different (industrial development vs. protection of peasants' life and the environment). By contrast, the other actors of the transnational companies (Monsanto, Nidera, etc.) are key players in the global bioeconomy (Delvenne and Hendrickx, 2013), so they see Argentina as a market from which to extract profits rather than a country that should be developed. In this sense, the two local resisting groups mentioned above may share an anti-imperialist imaginary, although from different perspectives, while the transnational companies *represent* that very imperialism. However, a difference lies in the fact that the interests of local actors supporting R&D in biotechnology might overlap with transnational companies' agenda to require a stronger system of intellectual property rights (IPR) protection (this would not be true of national NGOs). So, there is an 'economic cluster', which aims at stimulating a certain pathway of development by turning agricultural biotechnologies into a central axis of the national economy.

To conclude this section, then, we return to our opening paradox. The emergence of new centres and peripheries through the dynamics just described helps us make sense of a situation in which the progression of the hegemonic model of neoliberal science has been dependent on seemingly non-archetypically neoliberal models. With this brief example, we have seen that it is not enough to postulate that the neoliberal globalized privatization regime will just unfold and progressively expand to more countries at the expense of most Southern actors at the periphery. Rather, combined with the commercialization of science, 'peripherality' creates protest, activism and the joint emergence of new centers and peripheries, including through essential antagonisms and tensions within 'Southern' countries. Thus, further research should devote time to address the joint and complex progression of both neoliberal science and its externalities in (semi-) peripheral countries. This can concern cases when scientific knowledge is prevented from circulation by institutionalized means of concentrating knowledge and capital (e.g. patents). But this is also particularly useful to make sense of cases like the one we sketched, in which incorporated scientific knowledge has traveled fast in 'free of patents' technological packages and reconfigured new centers and peripheries within, beyond and across one specific country.

Conclusion[8]

In this chapter we analyzed how the social, political and historical dynamics at play during the developmental, translation and transformation processes of science production are crucial to understanding what happens under conditions of globalized science. We suggest a research agenda building on a critical reexamination of both central and peripheral scientific and technological traditions and policy-oriented approaches. Under this analytical approach, descriptions of 'alternative modernities' and the recognition of hybridities, borderlands and in-between conditions (Anderson, 2002: 643) become important.[9] There is an increased recognition of the need to engage critically in the 'coloniality of power' (Quijano, 2000), but in a more complex and subtle way than the too simple alternative between an uncritical following of Western models on the 'development path', close to the well-known Basalla model (Basalla, 1969) and a purely ideological and totalizing critique of these models. This move implies delving into earlier debates engaging with, and critical of, the dominance of particular institutional models of science and science organization in order to investigate the relations between science and technology traditions in the centers and peripheries and 'study up' from the standpoint of non-OECD cultures (Harding, 2008: 225, Medina, 2011).[10]

To grasp the full texture of the global reconfigurations that we sketched in this chapter, we consider that world-system analysis (Wallerstein, 1974, 2004, 2006; Chase-Dunn and Hall, 1997; Hall 2000) provides an important lens that has been neglected by mainstream science policy and political economic studies of science. But we stress that it needs to be updated to a 2.0 version.

A world-system broadly refers to a matrix made of various institutions: nation-states, interstate system, corporations, social classes, households, kin, ethnic groups, etc. It relates to the international division of labor, which divides the world into core countries, semi-peripheral countries and peripheral countries. In the 1970s and 1980s, the simple message was that central countries focus on higher skill, capital-intensive production, and the rest of the world focuses on low-skill, labor-intensive production and extraction of raw materials, in ways that are mutually reinforcing. This keeps the 'rich' countries rich and the 'poor' countries under-developed, hence generating enduring and dynamically reproduced 'centers' and 'peripheries'.

In a nutshell, instead of nation-states as the basic unit of social analysis, (traditional) world-system analysis (WSA) stresses that world-systems should be the privileged unit of analysis. In today's multipolar world, we have shown that big countries like India, China, Brazil or Argentina show internal tensions and a blurring of the international division of labor: ICT, nanosciences or agricultural biotechnology introduce other patterns too. Nevertheless, even if some shifting occurs, the earlier pattern of international division of labor is not undermined and it continues constantly to reinforce the dominance of the core countries. So WSA 2.0 is a reason to scrutinize, in each particular case, how and where power relations are enacted and reinforced. But we do not take over a simplistic world-system view on hegemony and domination: to address and analyze the stakes in globalized science, one needs to take the co-production of multiple centers and peripheries into account.

As we noted, innovation institutions, frameworks, and policies have different effects *within* nations – and (so) nations still matter – as much as they do extend *beyond* and *across* nations. Instead of frictions (Tsing, 2005), we see loci of complex interplays and national–international relationships that are to be unfolded (MacLeod 1980). Thus, a WSA 2.0 analytic lens should not only be limited to the national level. A focus on particular institutions, disciplines or topics – like it was the case in the example we gave with biotechnologies and GM agriculture – promises particularly interesting findings from a comparative perspective. Indeed, on the one hand, the dynamics observed in one domain in a particular country can vary significantly with other domains in the same country. On the other hand, cross-country comparison of the dynamics related to a specific discipline or domain will show a still different interplay of various centers and peripheries.

In conclusion, we present the various tensions that stem from the emerging situation we have described briefly in this chapter:

Consider the countries of intermediate development, such as those from some Latin American countries, North Africa (and South Africa), and some less developed European countries (Greece, Portugal, Poland), which have solid traditions of research and which have known an increasing international visibility during recent decades. In these countries, most scientific activities continue to be managed by and from the state, with a very low share of R&D to companies, and very little interaction between research and production sectors. Thus, it remains illusory to imagine the application of models such as the National Innovation System or Triple Helix, which have been developed for OECD countries in which the respective shares of public and private research funding show the exact opposite situation. The latter must be taken into account both for analytical purposes and for policy making.

The increasing globalization of S&T activities makes international firms locate within and exploit the comparative advantages of developing countries. However, firms tend only to incorporate scientific and local knowledge to the extent that this is mediated by international scientific networks that include researchers from different regions, but are normally led by Western Europeans and/or North Americans. Indeed, scientists from (semi-) peripheral countries do not control the scientific agendas of the large research networks in which they participate, even though within such networks they collaborate closely with firms from the central countries. The 'optimist' cases of the 'Marburg project' (related to a tropical disease) in Gabon or a fisheries project in Uganda, both in Africa,[11] as presented by Wagner (2009), who emphasizes the benefit of 'open systems' for developing countries, refer to isolated situations and much less scientifically-developed countries, thus rendering it difficult to generalize as a structural trend. In addition, international firms continue to appropriate indigenous knowledge (such as the medicinal use of local plants) in order to industrialize it in central countries (see Hayden, 2003, for a brilliant analysis on Mexico), in spite of the recent efforts toward advanced regulations to curb this process of 'cognitive exploitation' of the peripheries (Kreimer and Zukerfeld, 2014).

In terms of multipolarity, what is observed in certain disciplinary or thematic areas – like the case of nanoscience illustrated in Figure 29.2 – is a realignment based on the historic domination of 'old leaders' like Western Europe and the United States, which share research and innovation agendas in multiple fields, with a particular strength in biomedical and pharmaceutical applications. On the other hand, a new axis led by China (and, to a lesser extent, by India) concentrates on industrial development and gives a strong weight to engineering. Lastly, a third axis gathers the former socialist countries (close to the Soviet Union), which put a strong emphasis on R&D in energy issues, physics and heavy industries. It is in this context that the less developed countries move around multiple centers. For example, in Latin America, while Mexico and Argentina are closer to an 'OECD model', Brazil seems to be moving towards the pole of expertise led by China.

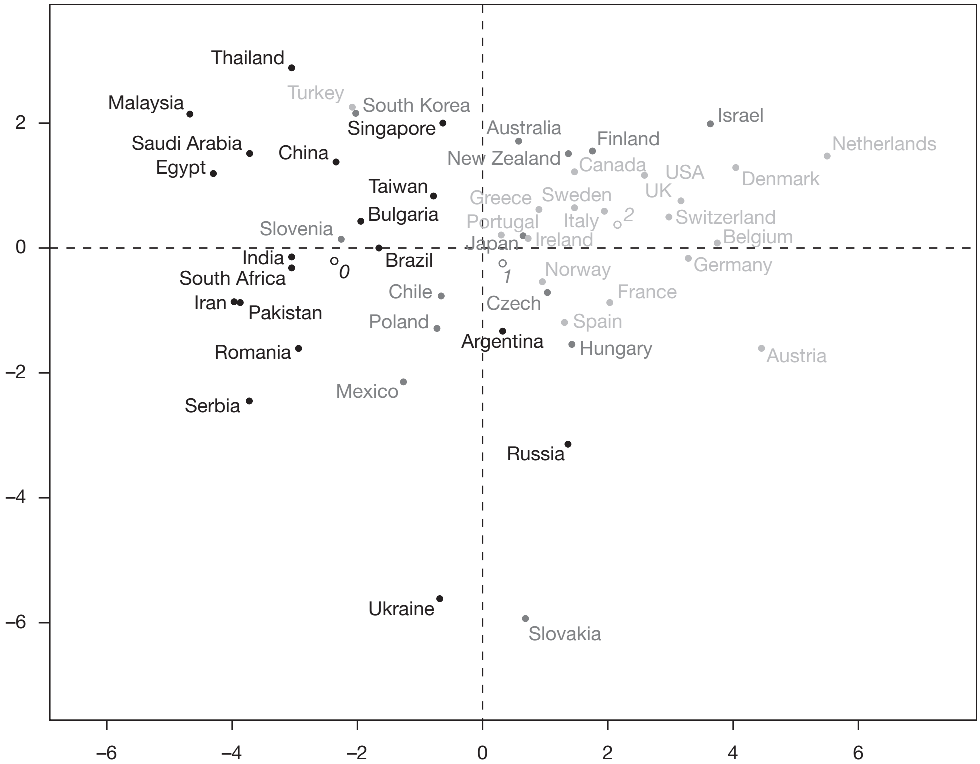

Figure 29.2 World distribution of nanoscience research, 2010–2012

Source: Levin et al. (2016)

Note: The vertical alignment means that countries in the upper part of the figure are relatively stronger in biomedical and pharmaceutical research, and those relatively stronger in high physics in the lower part. In the left are the countries with a relatively strong engineering research, and in the right, those which are relatively strong in basic research.

All these movements along the centers-peripheries axes create the illusion of a greater cosmopolitanism and openness, but we should note that, to date, globalized science's positive effects on the populations from the countries with low or intermediate development is very limited: multipolarity does not increase the chances of directing knowledge to local needs, it simply opens new windows of opportunity for more centers, at the expense of more peripheries.

Notes

1 Notwithstanding both the influence of globalization and the heterogeneities coexisting inside each country, the 'country' remains a crucial level of analysis, both considering national research systems and local research traditions (see e.g. Kreimer, 2010). To be sure, 'globalized' knowledge production dynamics have different effects *within*, *beyond* and *across* nations.

2 However, in the case of Latin America, and analyzing the participation of various cities in international programs, Kreimer and Levin (2015) have shown that, with the exception of Brazil (where programs are distributed in several cities, Sao Paulo, Rio de Janeiro, Campinas, Belo Horizonte, etc.), the bulk of activities remains concentrated in the capital city (Mexico, Buenos Aires, Santiago).

3 The authors have gathered all the nanoscience records from Web of Science (WoS) over three years (2010–2012), allowing for a more general study than previous work, focused in specific subfields. Instead of identifying the relevant subfields for research in nanosciences using standard, predefined

disciplinary categories such as the Journal Subject Categories (JSC) of the WoS, the approach defines subfields through a 'bottom-up' strategy that creates groups of articles that share many references and therefore are close in cognitive space.

4 Zhou and Leydesdorff (2006) had already made the same observations for the nano field, and Glänzel et al. (2008) for engineering.
5 Such as the most advanced countries in Latin America, North Africa and some Asian countries.
6 For instance, public funding for research in Mexico, Argentina and Brazil reaches more than two-thirds of the total R&D expenditures (RICYT, 2015), while it is around a half for intermediate-advanced countries (like Spain or Italy) and less than 30 percent for more scientifically advanced countries (the OECD average is around 28 percent, see OECD, 2016).
7 Arcadia Biosciences is an agricultural technology company focused on developing technologies and products that benefit the environment and human health. Bioceres is an agricultural investment and development company owned by more than 230 of South America's largest soybean growers. Together the two companies form Verdeca, a 50–50 joint venture.
8 The conclusion builds on and reinforces the research agenda sketched by Delvenne and Thoreau (2012), whose paper discusses the adequacy of the concept of 'National Innovation System' to non-OECD (Organization for Economic Cooperation and Development) countries, especially in Latin America where it is abundantly implemented and tends to be reified, which leads to a situation where relevant contextual elements tend to be ignored.
9 Post-colonial STS (PCSTS) has provided interesting insights to address these issues (see e.g. Anderson, 2002; Anderson and Adams, 2007; Harding, 2008; Harding, 2011; Hecht, 2011, Chakanetsa Mavhunga and Trischler, 2014). We want to stress, however, that to-date this subfield has yet mostly neglected the topic of political economy of science and the cultural hegemonism it potentially embeds. Furthermore, many PCSTS studies tend to reify the categories of 'Northern' and 'Southern' countries, whereas we suggest that we will gain analytical precision if we move away from concepts or 'North' and 'South' in order to adopt a 'centers and peripheries' perspective.
10 In an age in which localized political economies and prosperity are increasingly built upon innovation and 'cutting-edge' research, the political economy of *science* is a crucial but under-developed area of contemporary studies (see also Peloquin, this volume)
11 Wagner states, for instance, analyzing the Marburg project, that 'The resulting knowledge was distributed among the project members, as well as to collaborators in Gabon, Africa. In Africa, it could be used to solve or anticipate real problems' (2009). As we can see, there is an asymmetry: in this case, German (or Russian) researchers tackle a scientific problem and try to *offer* a solution to those affected in Gabon.

References

Ablin, E. and S. Paz (2000). *Productos transgénicos y exportaciones agr*ícolas: Reflexiones en torno de *un dilema argentino*. Buenos Aires: Cancillería Argentina.

Adams, J. (2012). 'Collaborations: The rise of research networks'. *Nature*, 490: 335–336.

Adams, J. (2013). 'Collaborations: The fourth age of research'. *Nature*, 497: 557–560.

Anderson, W. (2002). 'Postcolonial technoscience'. *Social Studies of Science*, 32: 643–658.

Anderson, W. and Adams, V. (2007). 'Pramoedya's chickens: Postcolonial studies of technoscience', in *Handbook of Science and Technology Studies*, 3rd ed., eds. Edward J. Hackett, Olga Amsterdamska, Michael Lynch, and Judy Wacjman, 181–204. Cambrige (MA): MIT Press.

Basalla, G. (1967). 'The spread of Western science. A three-stage model describes the introduction of modern science into any non-European nation'. *Science* 156 (3775): 611–22.

Callon, M. and Rabeharisoa, V. (2003). 'Research "in the wild" and the shaping of new social identities'. *Technology in Society* 25: 193–204.

Cambrosio, A., Keating, P. and Mogoutov, A. (2004). 'Mapping collaborative work and innovation in biomedicine: a computer-assisted analysis of antibody reagent workshops'. *Social Studies of Science* 34 (3): 325–364.

CCE (2007). Commission des Communautés Européennes. Livre vert. 'L'Espace européen de la recherche: nouvelles perspectives'. Brussels, le 4.4.2007. COM (2007) 161 final.

Chase-Dunn, C. and Hall, T. (1997). *Rise and Demise: Comparing World-Systems*. Boulder: Westview Press.

Chakanetsa Mavhunga, C. and H. Trischler (2014). *Energy (and) Colonialism, Energy (In)Dependence*. Rachel Cansel Center Perspectives.

Collins, H. and Evans, R. (2008). *Rethinking Expertise*. University of Chicago Press.

Dagnino, R. (2009). A construção do Espaço Ibero-americano do Conhecimento, os estudos sobre ciência, tecnologia e sociedade e a política científica e tecnológica. Rev. iberoam. cienc. tecnol. soc. v.4.

Delvenne, P. and Thoreau, F. (2012). 'Beyond the charmed circle of OECD. New Directions for Studies of National Innovation Systems'. *Minerva* 50–2: 205–219.

Delvenne, P. and Hendrickx, K. (2013). 'The multifaceted struggle for power in the bioeconomy'. *Technology in Society* 35(2): 75–8.

Delvenne, P. and Vasen, F. (2013). Lo que los Sistemas Nacionales de Innovación no miran. Una crítica constructiva de las políticas de ciencia y tecnología a partir del 'modelo de la soja transgénica'. In Tula Molina, Fernando; Vara, Ana Maria (eds.) *Riesgo, política y alternativas tecnológicas. Entre la regulación y la discusión pública*. Buenos Aires: Prometeo.

Delvenne, P., Vasen, F. and Vara, A.-M. (2013). 'The "soy-ization" of Argentina: dynamics of the "globalized" privatization regime in a peripheral context'. *Technology in Society* 35 (2): 153–162.

Etzkowitz H. and L. Leydesdorff, (2000). 'The dynamics of innovation: from national systems and "mode 2" to a triple helix of university-industry-government relations'. *Research Policy* 29: 109–23.

Filomeno, F. (2013). 'State capacity and intellectual property regimes: lessons from South American soybean agriculture'. *Technology in Society* 35 (2): 139–152.

Gaillard, J. F. (1998). 'Donors "models" for strengthening research capacity building in developing countries'. In M. J. Garrett and C. G. Granqvist (Eds.), *Basic Sciences and Development: Rethinking Donor Policy*, 81–126. Aldershot: Avebury Press.

Glänzel, W., K. Debackere, and M. Meyer (2008). 'Triad or Tetrad? On global changes in a dynamic world'. *Scientometrics* 74 (1).

Goulet, F. (2008). Des tensions épistémiques et professionnelles en agriculture. Dynamiques autour des techniques sans labour et de leur évaluation environnementale. *Revue d'Anthropologie des Connaissances* 2(4): 291–310.

Gras, C. and V. Hernandez (2014). 'Agribusiness and large-scale farming: capitalist globalisation in Argentine agriculture'. *Canadian Journal of Development Studies / Revue canadienne d'études du développement* 35 (3): 339–357.

Grauwin, S. et al. (2012). 'Complex systems science: Dreams of universality, interdisciplinarity reality'. *Journal of the American Society for Information Science and Technology* 63(7): 1327–1338.

Grossetti, M., Eckert, D., Gingras, Y., Jegou L., Lariviere V., and Milard B. (2012). 'The geographical deconcentration of scientific activities (1987–2007)'. 17th International Conference on Science and Technology Indicators (STI), 5–8 September, Montréal.

Hall, T. (2000). *A World-Systems Reader: New Perspectives on Gender, Urbanism, Cultures, Indigenous Peoples and Ecology*. London: Rowman and Littlefield.

Harding, S. (2011). *The Postcolonial Science and Technology Studies Reader*. Chapel Hill, Duke University Press.

Hayden, C. (2003). *When Nature Goes Public: The Making and Unmaking of Bioprospecting in Mexico*. Princeton: Princeton University Press.

Hecht, G. (2011). *Entangled Geographies. Empire and Technopolitics in the Global Cold War*. Cambridge: the MIT Press.

Hwang, K. (2008). 'International Collaboration in Multilayered Center-Periphery in the Globalization of Science and Technology'. *Science, Technology & Human Values*, January 33: 101–133.

Jasanoff, S. (2004). 'The idiom of co-production'. In: Jasanoff, S. *States of knowledge: the co-production of science and social order*. London, Routledge.

Joerges, B and Shinn, T. (2001). 'A Fresh look at instrumentation. An introduction'. In Joerges, B. and Shinn, T. *Instrumentation between Science, State and Industry. Sociology of the Sciences Yearbook Nr. 22*. Dordrecht, Kluwer Academic Publishers.

King, D.A. (2004). 'The scientific impact of nations'. *Nature* 430 (6997): 311–316.

Kloppenburg, R. (1988). *First the Seed: The Political Economy of Plant Biotechnology*. Madison: The University of Wisconsin Press.

Kreimer, Pablo (2006). ¿Dependientes o integrados? La ciencia latinoamericana y la división internacional del trabajo. *Nomadas*-CLACSO 24.

Kreimer, P. (2010). La recherche en Argentine: entre isolement et dépendance. *Cahiers de la recherche sur l'éducation et les savoirs* 9: 115–138.

Kreimer, P. (2012). Délocalisation des savoirs en Amérique latine: le rôle des réseaux scientifiques. *Pouvoirs Locaux* N° 94 III.

Kreimer, P. and Zukerfeld, M. (2014). La Explotación Cognitiva: Tensiones emergentes en la producción y uso social de conocimientos científicos, tradicionales, informacionales y laborales, in Kreimer, Vessuri et al: *Perspectivas Latinoamericanas en el estudio social de la ciencia y la tecnología*. México, Siglo XXI.

Kreimer, P. and Levin, L. (2013). 'Scientific cooperation between the European Union and Latin American countries: framework programmes 6 and 7', in J. Gaillard and R. Arvanitis, eds. *Research Collaborations between Europe and Latin America Mapping and Understanding Partnership*. Paris: Éditions des archives contemporaines: 79–104.

Latour, B. (1999). *Politiques de la Nature. Comment Faire Entrer les Sciences en Démocratie*, Paris, *La Découverte*.

Lave, R., Mirowski, P., and S. Randalls (2010). 'Introduction: STS and neoliberal science'. *Social Studies of Science* 40 (5): 659–675.

Lave, R. (2012). 'Neoliberalism and the production of environmental knowledge'. *Environement and Society* 3 (1).

Levin, L., Jensen, P., and Kreimer, P. (2016, forthcoming). 'Does size matter? The multipolar international landscape of nanoscience'. *PLOS One*.

Losego, P. and R. Arvanitis (2008). La science dans les pays non hégémoniques. *Revue d'anthropologie des connaissances*, 2 (3), 334–342.

MacLeod, R. (1980). 'On visiting the "moving metropolis": reflections on the architecture of imperial science'. *Historical Records of Australian Science* 5 (3): 1–16.

May, R.-M. (1997). 'The scientific wealth of nations'. *Science Technology & Society*, 275: 793–796.

Medina, E. (2011). *Cybernetic Revolutionaries. Technology and Politics in Allende's Chile*. Cambridge: The MIT Press.

Mirowski, P. and Sent, E.-M. (2008). 'The commercialization of science and the response of STS', in *Handbook of Science and Technology Studies*, 3rd edition, eds. Hackett, E. J. et al. Cambridge: The MIT Press, 635–689.

Moya-Anegón, F. and V. Herrero-Solana (2013). 'Worldwide topology of the scientific subject profile: a macro approach in the country level'. PLOS ONE, 8(12).

Mustar, P. and P. Larédo (2002). 'Innovation and research policy in France (1980–2000) or the disappearance of the Colbertist state'. *Research Policy* 31: 55–72.

Nowotny, H., Scott, P. and M. Gibbons (2001). *Re-Thinking Science*. Cambridge: Polity Press.

Pestre, D. (2003). 'Regimes of knowledge production in society: towards a more political and social reading'. *Minerva* 41 (3): 245–261.

Quijano, A. (2000). 'Coloniality of power and eurocentrism in Latin America'. *International Sociology* 15 (2): 215–232.

RICYT (2015). *El Estado de la ciencia. Principales indicadores de la ciencia. Iberaomericanos/Interamericanos*. Buenos Aires, RICYT.

Rosemann, A. (2014). 'Multipolar technoscience: clinical science collaborations in a changing world system'. Doctoral thesis (PhD): University of Sussex.

Salomon, J.-J. (2006). *Les Scientifiques. Entre Savoir et Pouvoir*. Paris: Albin Michel.

Santander, S. (2014). 'Competing Latin American regionalisms in a changing world', in M., Telò (Ed.), *European Union and New Regionalism*. London: Ashgate: 187–200.

Slaughter, S. and G. Rhoades (2004). *Academic Capitalism and the New Economy*. Baltimore: John Hopkins University Press.

Slaughter, S. and G. Rhoades (1996) 'The emergence of a competitiveness research and development policy coalition and the commercialization of academic science and technology', *Science, Technology, & Human Values*, 21 (3), 303-39

Tsing, A.-L. (2005). *Friction: An Ethnography of Global Connection*. Princeton: Princeton University Press.

Tyfield, D. (2012), *The Economics of Science: A Critical Realist Overview*. London: Routledge.

Tyfield, D. and J. Urry (2009). 'Cosmopolitan China? Lessons from international collaboration in low-carbon innovation'. *The British Journal of Sociology* 60 (4): 793–812.

Van Oudheusden, M., Charlier, N., Rosskamp, B., and P. Delvenne (2015). 'Broadening, deepening, and governing innovation: Flemish technology assessment in historical and socio-political perspective'. *Research Policy* 44 (10): 1877–1886.

Vara, A.-M. (2005). *Argentina, GM Nation. Chances and Choices in Uncertain Times. Country Case*. New York University Project on International GMO Regulatory Conflicts.

Veugelers, R. (2010). 'Towards a multipolar science world: trends and impact'. *Scientometrics* 82 (2): 439–456.

Wagner, C. (2009). *The New Invisible College: Science for Development*. Washington DC: Brookings Institution Press.

Wallerstein, I. (1974). *The Modern World-System. Volume 1. Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. Cambridge: Cambridge University Press.
Wallerstein, I. (2004). 'World-system analysis', in *Encyclopedia of Life Support Systems: Developed under the Auspices of the UNESCO*. George Modelski. Oxford: Eolss Publishers.
Wallerstein, I. (2006). *Comprendre le Monde. Introduction à l'Analyse des Systèmes-Monde*. Paris: La Découverte.
Zhou, P. and Leydesdorff, L. (2006). 'The emergence of China as a leading nation in science'. *Research Policy* 35 (1): 83–104.