Research Policy 43 (2014) 588–596

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Knowledge flows and bases in emerging economy innovation systems: Brazilian research 2005–2009

Branco Ponomariov[a,1], Hannes Toivanen[b,*]

[a] University of Texas at San Antonio, 501 Cesar Chavez Boulevard, San Antonio, TX 78207, USA
[b] VTT Technical Research Centre of Finland, P.O. Box 1000, 02044 VTT, Finland

ARTICLE INFO

Article history:
Received 24 April 2012
Received in revised form 22 August 2013
Accepted 4 September 2013
Available online 27 September 2013

Keywords:
Sources of knowledge
Research
National systems of innovation
National absorptive capacities
Emerging economies
Brazil

ABSTRACT

This article considers the role of domestic knowledge capabilities for developing countries and emerging economies, and in particular in the build-up of their national systems of innovation. Using bibliometric methods, we describe the geographic sources of knowledge and the users of Brazilian research in 2005–2009, and analyze the roles of domestic and foreign knowledge bases in it. Our results suggest that increasing reliance on domestic sources of knowledge is a feature of Brazil's improved science and technology capabilities. The ascendancy of Brazil's research informs us about the unfolding re-organization of global research, too, underlining nascent South-South knowledge flows, the prevailing relevance of EU research, and the relative decline of US research for Brazilian knowledge creation.

1. Introduction

A central theme in the analysis of emerging economies is the importance of cultivating enhanced domestic capacities in science, technology, and innovation. Many emerging economies, in efforts to transform their innovation systems from imitators to innovators, aim to build strong national knowledge bases for domestic and global innovation activities. Consequently, national systems of innovation in emerging economies are undergoing processes of expansion and transformation, as their capabilities are re-organized and objectives re-oriented, raising empirical and conceptual questions about the nature of this change and its global implications.

This paper proposes that the rise of an emerging economy's national system of innovation is accompanied by increasing reliance on and exploitation of locally generated scientific knowledge. Such trends, if detected, would be indicative of enhanced local capabilities and control of the scientific and technological agenda, as well as of shifts in global knowledge flows that reflect the relative ascent or decline of relevance of international knowledge hubs to the emerging economy. In an instrumental case, we investigate empirically changes in knowledge flows and bases of Brazilian research between 2005 and 2009 using data on Brazil's scientific publication output, and develop a perspective and a conceptual framework for scientific and technological research in emerging economy and developing country national systems of innovation.

The results cast light on the structural and dynamic features underpinning the growth and expansion of the Brazilian system of innovation, which envelops transformative processes reflexive of "development": the country's researchers are significantly and increasingly relying on domestic knowledge, suggesting an ongoing re-orientation of sources of knowledge and research agenda, as well as a system better positioned to serve the diverse needs of different Brazilian regions. Secondly, the ascendancy of Brazil's research informs us of the unfolding re-organization of global research, underlining nascent South-South knowledge flows, the prevailing relevance of EU research, and the relative decline of US research in Brazilian knowledge creation.

Conceptually, the paper suggests a method to investigate and assess how institutions of knowledge behave in the context of development – citation-based assessment of geographical sources of knowledge – and enhances our understanding of how scientific and technological research are elements for developing countries and emerging economies hoping to move toward a knowledge society, and what metrics are suitable to measure progress on that objective.

The next section introduces the conceptual framework, derived largely from the literature on national systems of innovation, and discusses in particular the role of domestic knowledge

* Corresponding author. Tel.: +358 40 186 3882; fax: +358 20 722 7604.
E-mail addresses: branco.ponomariov@utsa.edu (B. Ponomariov), hannes.toivanen@vtt.fi (H. Toivanen).
[1] Tel.: +1 210 458 2619; fax +1 210 458 2536x7604.

0048-7333/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.respol.2013.09.002

capabilities in the context of development. The third section details the materials and methods, whereas the fourth section presents and discusses the empirical findings about the sources and uses of Brazilian research. The final section invokes the conceptual and policy implications of the key empirical finding, namely that research and innovation in emerging economies are set to rely increasingly on domestic knowledge creation, and provides perspectives to reposition the role of scientific and technological research for contemporary development strategies.

2. Framework: the role of domestic research for a developing country's innovation systems

2.1. National innovation systems and developing countries

Co-evolutionary processes of organizations creating, acquiring, and implementing knowledge lie at the heart of the national systems of innovation framework (Nelson and Winter, 1982; Lundvall, 1992; Nelson, 1993; Edquist, 1997). Developmental stages of innovation systems range from catch-up to nascent to emerging to mature and, eventually, to decline, and are accompanied by certain types of structural, organizational, and dynamic features. Building and creating national systems of innovation – such as in the US, Japan, and the UK, to mention a few – has been an enduring theme in the field, and the literature on the newly industrializing countries is framed predominantly as a catch-up process (e.g. Nelson and Wright, 1992; Freeman and Soete, 1997; Kim, 1997; UNIDO, 2005; Fagerberg and Godinho, 2005; Lundvall, 2011).

The national systems of innovation framework emphasizes localized learning interactions as necessary for the build-up of critical capabilities throughout the innovation system (Lundvall, 1992; Bell and Albu, 1999; Metcalfe and Ramlogan, 2008; Lundvall et al., 2010; Kraemer-Mbula and Wamae, 2010). One of the key features of this literature for national development strategies is the emphasis on the critical importance of build-up of "national absorptive capabilities" (Criscuolo and Narula, 2008) in strategic areas of science and technology. In order to be able to apply existing knowledge and technologies acquired from elsewhere, not to mention to excel in research-based innovation, a country needs to create corresponding organizational capabilities, achieve quality and quantity thresholds in science and technology, foster knowledge diffusion between research and industry, and so forth (Mowery and Oxley, 1995; Kemeny, 2010; Fagerberg et al., 2010). Much of this continues to underpin policy prescription for emerging economies and developing countries, too, as put in a recent World Bank report on Brazil's innovation system (Rodriguez et al., 2008, p. 52).

The need to understand how domestic S&T capabilities evolve is becoming increasingly urgent, as recent evidence suggests that globalization actually enlarges technology gaps between the developed and the developing world, rather than reducing them (Castells, 1998; UNIDO, 2005; Kemeny, 2011). Worse yet, even countries demonstrating knowledge-based technological advancement may become more, not less, dependent on western economies (Shie and Meer, 2010) – the only difference being that the nature of dependency has shifted over time from financial toward technological dependence. High degrees of both technological and knowledge dependency (Abdullah, 1995; Boshoff, 2009) seem to be well established, and some are doubtful that technology gaps can ever be closed (Shie and Meer, 2010; Kemeny, 2011).

Many of these insights have resulted from studies investigating changes in knowledge and learning, and suggest that the dynamics of learning interaction, or institutions of knowledge, are subject to change, as countries advance. Analyzing the long-term competitiveness of 90 countries, Fagerberg et al. (2007) argued that it is specifically the co-occurrence of capabilities to create and exploit technologies (technology and capacity competitiveness) that sets apart developing countries that catch up with the global frontier.

For a casual observer of any emerging economy, excluding those propelled by simple exploitation of natural resources, such transitions are apparent. Given its global significance, China's attempts to shift its national innovation system toward endogenous innovation have attracted much attention, and also provide an important benchmark for our analysis of Brazil. Indeed, Gu and Lundvall (2006) cite weak absorptive capacities, including capacities in research, as one of the major obstacles to China moving to endogenous innovation. The growing emphasis on the arduous build-up of capacities in frontier research is recognized increasingly by others, as well as an enabler for China to put explicit emphasis on innovation in its STI-policies (Liu and White, 2001; Liu et al., 2011; Liu and Liu, 2011).

Recent literature on Brazil echoes the importance of university and other research for national and state innovation systems, but maintains that, perhaps uniquely, Brazil has a strong higher education and public research sector, comprising the majority of the national system of innovation. Capturing almost 40% of national R&D spending, higher education, universities, and public research institutes are the backbone institution of Brazilian knowledge, yet several analysts complain that they do not contribute sufficiently to technological capabilities of the private sector, and indeed fostering industry-academy links has become the key areas of contemporary Brazilian innovation policy (Avellar and Cardoso Boaventura Oliveira, 2009; Arbix et al., 2010; Rodriguez et al., 2008; Etzkowitz et al., 2005).

However, the argument that Brazilian research capacities contribute poorly to the country's innovation appear over-driven and seem to flow from a narrow focus on patenting and on only certain types of industry–academia linkages. Certainly, research fields such as clinical medicine, plant and animal science, agricultural sciences, and environment and ecology, which combined cover about 40% of Brazilian research in recent years (MCT, 2010), are research fields in which practical and industry relevance is more than plausible, given their importance to Brazilian society and industries.

Selected industries demonstrate that the Brazilian research sector has been instrumental in some of the country's most spectacular commercial successes, too, including such sectors as pulp and paper (Toivanen and Lima-Toivanen, 2009), bio-fuels (Lehtonen, 2011), aircraft (Argou Margues, 2004), and automobiles (Kesidou, 2004), as well as in other sectors, and universities contribute in multiple ways to medium- and low-technology firms as well (Rapini et al., 2009), suggesting that institutions of knowledge hold a critical role in the build-up of national innovation capabilities, when other supporting institutions and an enabling framework are being provided.

Brazilian federal and state-level STI policies balance the build-up of core capabilities in research with the needs to augment industry–academia linkages. The Action Plan for Science, Technology, and Innovation 2007–2010 aimed to "both broaden the national scientific base in terms of consolidating excellence in various areas of knowledge, as well as increasing the technological capacity of Brazilian firms to create, acquire and turn knowledge into innovations [...]" (MCT, 2007–2010). These objectives remain central to the current national science, technology, and innovation strategy (MCT, 2011; Arbix et al., 2011), although some observers (Stehnken, 2010; Koeller and Cassiolato, 2011) argue that governance challenges slow down the efficiency of the Brazilian innovation system and its transformation.

Accordingly, the central objective of this paper is to explore empirically the rate and direction of Brazil's improvement (if any) in local research capacity at the national level. Such analysis can provide initial evidence about the processes of national innovation system build-up, and its evolution in a country attempting to advance

toward the global knowledge and innovation frontiers. Aggregated science and technology statistics, typically invoked by observers of emerging economies, remain merely descriptive of developmental processes, and do not provide sufficient in-depth insight into how knowledge flows and bases are behaving as national systems of innovation take shape or take off. While still descriptive, this study focuses not only on scientific output growth, but also on the properties of the knowledge base underlying this output, and the organizational evolution of Brazil's innovation system.

2.2. Scientific research publications and emerging economies

A central objective for harnessing STI for development is to build sustainable local capacities in research, so that they are self-sustaining and capable of addressing local development challenges and enhancing local business and industry sectors. Developing regions – and Brazil in particular – are demonstrating impressive growth rates in research, measured as scientific publications (Alfaraz and Calviño, 2004; Pereira Friedrich and Dos Santos Rodrigues, 1998; Glänzel et al., 2006; Leite et al., 2011; Wainer et al., 2009; UNESCO, 2010). Brazil is a particularly interesting case, since its share of global scientific production is growing faster than the rest of Latin America (Glänzel et al., 2006), and its growth is happening at a rapid rate in excess of what can be explained by the (unstable) funding and growth in R&D personnel (Mugnaini, 2006; Helene and Ribeiro, 2011).

However, there is scant research to estimate the role of local capacities in this growth, other than descriptive recognition that the prominence of Brazilian research varies by field (Glänzel et al., 2006) or by the location of the researchers (Meneghini, 1992). In addition, the majority of bibliometric research on Brazil is limited to specific fields, disciplines, or collaboration (e.g. Meneghini, 1992; Wainer et al., 2009; Spagnolo, 1990; Schoeneck et al., 2011). In this paper, we propose that Brazil has improved its overall domestic research capacity and provide an illustrative descriptive analysis of bibliometric data in support of this proposition.

The issue of dependence is also significant in the context of science and innovation, as it addresses directly whether capabilities are domestic or reflect foreign dependencies (Abdullah, 1995; MacKinnon et al., 2002). Analysts of African research have demonstrated that it is heavily dependent on European and North American research: African countries contribute relatively little to each other's knowledge base as co-authors, and the overall research collaboration patterns appear uneven between Western and African researchers (Toivanen and Ponomariov, 2011; Jeenah and Pouris, 2008; Onyancha and Maluleka, 2011). The issue of dependency extends to whether local scientists simply follow research agendas set elsewhere, or engage in nationally relevant or locally developed research agendas, too (Mallick, 2009), and analysts of Latin America have arrived somewhat contrasting results. In the case of Colombia, trans-continental research collaboration increased significantly the productivity of research teams, but didn't affect how those teams contributed to local knowledge (Ordóñez-Matamoros, 2008; Ordóñez-Matamoros et al., 2010).

The growth of the Brazilian research and innovation system has been accompanied by its broader transformation (Leta and Chaimovich, 2002; Glänzel et al., 2006), and one would assume that changes also occur in the way knowledge is mobilized and utilized. Thus the growth in research output in itself is insufficient to infer the "health" of the Brazilian research system. The sources of research growth are important to understand from both a developmental and an S&T policy perspective. Specifically, does this growth in publications extend and build upon a domestic research capacity, or is it a derivation from externally produced knowledge? Is the domestic research capacity relevant nationally and internationally? To shed light on these questions, below we examine the origin of the knowledge bases of Brazilian papers, approximated as the national origin of the papers cited in the Brazilian research literature and the national origin of papers citing Brazilian research.

2.2.1. Cited and citing papers as descriptors of the Brazilian knowledge base

The central issue of this paper – examining the patterns in the research base and the impact of Brazilian research – relies on the operationalization of the knowledge base by means of the aggregate properties of cited and citing literature in Brazilian research. This approach is in line with currently accepted uses of citations, and due to the large number of observation and the level of aggregation, suffers little, if at all, from the commonly indicated shortcomings of citation analysis (Leydesdorff, 1998).

Scientific citations are made to acknowledge the various contributions of prior research to the citing paper. From a strictly technical point of view, citations are merely "two-dimensional displays of the linkages between document addresses" (Garfield, 1998, p. 70). As such, they have no inherent meaning. However, the act of citation has normative meaning in the conduct of science: all science advancements are to some extent based on prior research, and citations represent the payment of such "intellectual debts" (Small, 2004), and a primary measure for allocating credit for research achievements (Merton, 1973, 1988).

At the aggregate, citations establish direct empirical connections between research papers and the web of prior knowledge, and, indeed, the only tangible evidence that a paper has been "used" (Menard, 1971). The analytical advantage inherent in recording these attributions via citations is that they are directly apparent and allow technically easy large-scale analyses of knowledge flows for evaluation purposes (Moed, 2005).

The main sources of ambiguity in citation analysis are that citation is not just a professional, but also a social act, and that citations can be conceptualized as measures of multiple and diverse concepts such as scientific collaboration, scientific social networks, science quality and intellectual influence, field evolution, knowledge diffusion, and so on (Cole, 1970). In addition, citations are used at different aggregation levels, such as a paper, collection of papers, subject area or discipline, individual scientist, team, and so forth, with each level raising different conceptual issues regarding the validity and reliability of citation-based metrics (Leydesdorff, 1998).

There is considerable ambiguity regarding whether the meaning ascribed to citations per the traditional rational understanding of science (Cole, 1970) is sufficiently grounded in the peculiarities of actual "social uses" of citations (Krampen et al., 2007; Johnson and Oppenheim, 2007; Brooks, 1985; Rodríguez-Ruiz, 2009; MacRoberts and MacRoberts, 1989). However, such concerns are most likely overstated (Garfield, 1998) insofar as some of the problems are possible to address by means of statistical tools, while others are not universal, but contingent on the conceptualization of citations and the chosen unit of analysis. Overall, the conceptual ambiguities surrounding citation analysis are likely no more serious than those faced by any research relying on existing data: the main challenge is the operationalization (Babbie, 1995), a process chiefly contingent on the underlying theory.

For the present study, the ambiguity of citations as an indicator of dependence is minimal. Here, citations are understood as elementary signifiers of relevance, meaning that if a paper cites another paper for any reason, this by default makes the cited paper relevant to the citing paper (Garfield, 1998), while also providing evidence that the cited paper has been "used" in a way sufficient to warrant a citation (Cole, 1970). That there may be different degrees and substantive meaning or "relevance" and relative influence of the cited paper is secondary to our research question, which merely asks if a selected property of Brazilian national scientific output (specifically the geographical origin of the cited and citing

papers) shifts over time. The unit of analysis is the individual text, and the aggregation levels are nation and region, and a more narrowly operationalized version of the research question becomes "is the Brazilian research output increasingly dependent on the use of domestically produced knowledge, as evidenced by the increasing citations to (or "use of") domestic knowledge?" – meaning inward national or local citations.

According to this operationalization, if Brazilian research increasingly relies on domestic knowledge, then the share of Brazilian papers among all cited papers should increase as well. Accordingly, the proportion of Brazilian papers within the papers citing Brazilian papers should increase as well. Both measures capture different aspects of the concept of "reliance". The "cited" papers are the most straightforward measure of "relevance" of scientific research as outlined above, so they give a fairly direct picture of the proportion of domestic research in Brazilian production alongside other sources of knowledge. The relative size of the Brazilian set of papers citing Brazilian papers also signifies reliance on domestic research capacity, but it is a forward-looking measure. We expect both of these measures to trend upwards, although the interpretation of the latter is temporally limited: papers published in 2005–2009 simply have not had enough time to reach their full "citation potential", so the yearly numbers need to be interpreted cautiously.

Another general issue in bibliometric analysis is the coverage: only a small proportion of national output (about 4% for Brazil) is indexed in ISI or other key global databases (Wagner and Wong, 2012), and coverage is uneven depending on the field (Moed, 2005). The rate of under-representation is approximately the same across nations and geographical regions, making international comparisons in research linkages possible even with limited (and likely biased) coverage. The problem of under-representation of local and national coverage may work to the advantage of this study, and in particular the validity of any trends in research dependence, as the ISI data is likely to *under*-cover local and locally embedded scientific production. Thus, if any trends congruent with shifts toward such self-reliance are detected, they would likely signify actual trends, given that the coverage bias is likely to understate them.

3. Material and methods

The analysis utilizes publication data (Brazil-associated articles in scientific journals indexed by the Institute of Scientific Information – ISI in the Science Citation Index-Expanded/Web of Science database), retrieved at individual article level directly from Thomson Reuters and delivered with a cut-off date of May 2010. All subsequent analyses were performed by parsing and aggregating the individual article records at the desired aggregation level (e.g. Brazil overall), using, among other applications, VantagePoint™ software. Our analysis is limited to articles in order to focus exclusively on publications that manifest the creation of new knowledge and represent the end-point for research efforts.

We utilize three data sets: The core data set, the SOURCE dataset, is composed of the complete set of articles published between 2005 and 2009 (inclusive), where at least one of the authors had a Brazilian address, totaling 106,324 articles. To capture the characteristics of the knowledge bases of Brazilian research overall, we also obtained the full set of papers (the CITED data set) that have been cited by the SOURCE data set of Brazilian papers, totaling 1,692,221 records, as well as the full set of papers (CITING data set) that have awarded citations to Brazilian authored papers, totaling 235,579 papers. The articles across the three data sets were linked by means of their unique ISI article identifiers. If a cited or citing paper is not indexed by ISI, it will not appear in the CITED or CITING data – a systemic bias that is likely to undercount some Brazilian journals not covered by ISI, and discussed in detail below.

Table 1
ISI-indexed Brazilian research articles: growth 2005–2009.

Year	All articles	Controlled articles[a]	Growth all	Growth controlled
2005	14,408	14,405		
2006	16,560	16,411	14.9%	13.9%
2007	21,192	17,885	28.0%	9.0%
2008	26,151	20,080	23.4%	12.3%
2009	28,013	21,173	7.1%	5.4%
Total	106,324	89,954	94.4%	47.0%

Source: ISI-WOS.
[a] All articles from journals added to ISI index after 2005 removed.

The Brazilian data is affected by coverage error that had to be addressed before analysis. ISI dramatically expanded the coverage of Brazilian journals during the study period, thereby artificially inflating the growth rates in output. To distinguish real growth in articles, we have created a "Controlled articles" variable, which excludes any articles associated with journals added to ISI after 2005. As a result, the SOURCE data decreased in size by about 15%, to 89,954 articles (Table 1). Accordingly, articles associated with the same journals were removed from the CITED and CITING datasets (3383 and 10,326 records respectively). This eliminates the possibility that our results would reflect primarily changes in ISI's indexing of Brazilian journals, an inevitable outcome considering its expansion in Brazil. However, such a wholesale exclusion of Brazilian publications can also lead to punitive results by also excluding journals with a likely greater local relevance from the data.

That the ISI data set covers five years is a limitation of this study – ideally, a longer time period would be covered. Since the procurement of more detailed ISI data is impossible due to the financial limitations of the project, we supplement the analysis with aggregate data on Brazilian article output and citation from one additional source – the SCImago Journal & Country rank (SCImago, 2007)[2] services, which generates reports and rankings at different aggregation levels using data contained in the Scopus database. While not amenable to micro-level analysis, this data provides a useful counterfactual to our analysis of Brazilian citations and self-citations, the share of which is automatically computed in the SCImago country reports. The SCOPUS database has somewhat better coverage (~20%) than ISI (Falagas et al., 2008), hence the greater number of documents captured by the SCImago aggregation. While the aggregate SCOPUS data cannot be matched to the article-level analysis conducted on the basis of the ISI data, it provides a useful benchmark to assess the findings from the primary analysis against the share of self-citations (i.e. citations to other Brazil documents). Finally, considering that Brazilian knowledge production has really taken off in the early 2000s, perhaps subsequently crossing important system-level thresholds, a longer historical perspective would fail to cast light on country's recent developments.

Another challenge is that internationally co-authored articles include widely differing contributions from Brazil. Our data included articles with up to 816 authors and with more than 100 addressees, often from multiple countries. Without identifying the Brazilian share of authorship in an article, it is difficult to accurately estimate to what extent the knowledge flows it involves are really "Brazilian". Linking SOURCE papers with CITED and CITING papers

[2] There are two journal citation databases that specifically concentrate on Brazil and Latin America – Scielo (www.scielo.br) and Latindex (www.latindex.unam.mx). Both provide rudimentary journal, author, and article level citation reports, but unfortunately do not provide data in a format that would enable the distinction between citations and self-citations crucial for this project.

Table 2
Citations made by Brazilian research in 2005–2009 by geographical origin of cited papers: Brazil and major regions.

Rank[a]	Region	2005	2006	2007	2008	2009	Total	Change 2005–2009
1	North America	34.3%	33.1%	32.5%	31.8%	30.6%	762,543	−11.0%
2	EU-27	30.0%	29.9%	29.6%	29.4%	29.2%	699,532	−2.6%
3	Brazil	17.6%	18.0%	18.4%	18.6%	19.6%	440,272	11.2%
4	Asia	9.0%	9.4%	9.7%	10.2%	10.5%	234,048	17.2%
5	Europe (non-EU)	2.3%	2.3%	2.3%	2.2%	2.3%	53,908	−0.6%
6	Oceania	2.0%	2.2%	2.2%	2.2%	2.3%	52,453	14.1%
7	Middle East	1.5%	1.6%	1.8%	1.9%	2.0%	42,470	30.3%
8	South America	1.6%	1.6%	1.7%	1.8%	1.8%	40,634	9.7%
9	Central America and Caribbean	0.9%	0.9%	0.9%	0.9%	0.9%	21,458	0.5%
10	Africa	0.8%	0.9%	0.9%	0.9%	0.9%	21,038	17.0%
	Total	320,353	396,343	466,676	566,605	618,380	2,368,355	

Source: ISI-WOS.
Note: Citations are weighted with the share of Brazilian addressees in the citing paper.
[a] Rank by totals 2005–2009.

invokes the third challenge, as we try to measure the geographical location of articles cited and awarding citations. ISI does not include author-specific addressees, and provides address information only for institutional authors (research address). This practice consolidates all authors with a completely identical address into one, but distinguishes between any authors with any differing address information. While unsatisfactory in many respects, with ISI, institutional authorship is the best proxy to estimate the share of institutional authorship for any article (Gauffriau et al., 2008).

To estimate the share of Brazilian authorship for each individual article, we calculated the fraction of Brazilian addressees (BR-AUTH) from the total research addressees. Ranging from larger than 0 to 1, BR-AUTH is applied to estimate to what extent Brazilians are awarding or receiving citations. To analyze the geographical sources of knowledge, we added research addresses from the CITED data to each individual article in the SOURCE data, and to analyze utilization of Brazilian knowledge, we added research addresses from the SOURCE set to each individual article in the CITING data. As we linked individual SOURCE articles to CITED articles, the instances of institutional author countries of CITED article were multiplied by BR-AUTH. Countries awarding citations were estimated similarly with the CITING data. This enabled us to estimate more precisely the knowledge flows of the Brazilian research system than if we were applying a whole counting and blanked assumption that all articles include the same portion of Brazilian authors, a method almost inevitably leading to considerable noise in the results.

Furthermore, in order to emphasize changes in the knowledge capabilities of individual countries and major regions, we have limited the cited articles to papers published no earlier than 10 years before the publication of the paper citing it. Thus, our analysis includes for Brazilian papers published in 2005, all cited articles published in 1995–2005, and so forth. This limitation is done to remove some of the "noise" caused by possible ritualistic citations, as well as to focus analysis on knowledge flows between existing capabilities in different countries. In addition, the CITING data is necessarily truncated, insofar as the SOURCE papers have not had time to receive the actual number of citations they may realistically expect to receive, and thus the results need to be interpreted as tentative.

4. Results and discussion

4.1. Knowledge outflows – citations received by Brazilian articles

Brazil's research system has indeed expanded greatly over the last two decades. When Brazilian journals added in ISI in 2006–2009 are excluded (to control for coverage bias), the number of Brazilian articles between 2005 and 2009 increased by about 47%, with annual growth rates varying (Table 1). Here we examine from where Brazilian researchers tap knowledge, and whether we observe an increasing reliance on Brazilian capabilities.

4.1.1. Brazilian citations of Brazilian research

Citations made by Brazilian papers concentrate heavily on major global centers of scientific and technological research, as illustrated in Table 2. North America is by far the most important source of cited research literature for Brazilian research, accounting for 32% of articles cited by Brazilian research in 2005–2009. The European Union, defined as 27 countries here, is the second largest source of cited literature, accounting for 29%. Domestic researcher addresses account for 19% of citations made in Brazilian research in 2005–2009, and Asia, including India and China, accounts for almost 10%. The concentration of citations is even more evident at the country level, as illustrated in Table 3. Two countries are the origin of almost half of all research cited by Brazilian papers in 2005–2009, and the ten most important countries account for almost 80%.

Overall, Brazilian research appears to be simultaneously oriented toward established global research centers leading in research publishing volume and excellence, and toward building on domestic knowledge. Domestic citations notwithstanding, geographical proximity per se appears to be an insignificant factor: for example, Brazilian papers cite very little South American and Central American and Caribbean research, in spite of proximity.

Changes in geographical sources of knowledge, here defined as cited literature, are indicative of the relevance of a country's knowledge production for Brazil. Although the ranking of most important individual regions does not change between 2005 and 2009, major regions and countries demonstrate diverging paths, even over this relatively short period of time (Table 2 and Table 3).

A central observation is Brazil's increasing reliance on domestic sources of knowledge. Between 2005 and 2009, the number of cited Brazilian research addresses increases by 114%, totaling an increase of just over 11% in its share of citations made. Significantly, this represents the true rate of growth within the same set of journals, as any Brazilian journals added by ISI during the study period have been eliminated in order to avoid possible positive coverage bias.

Combined with the high growth in total research volume in Brazil, this increase in share of domestic citations demonstrates an increasing relevance and contribution to Brazilian knowledge production, especially in conjunction with the changing role of other nations' research.

Since the question of the possible increase in Brazilian reliance on domestic sources is central for this study, we compare the findings from our analysis to an aggregate report on Brazil's citations and self-citations generated by SCImago on the basis of the SCOPUS database. As Archambault et al. (2009) have noted, bibliometric

Table 3
Citations made by Brazilian research in 2005–2009 by origin of cited paper. Top 15 cited countries.

Rank[a]	Country	2005	2006	2007	2008	2009	Total	Change 2005–2009
1	USA	31.2%	30.2%	29.5%	28.8%	27.7%	691,561	−11.5%
2	Brazil	17.6%	18.0%	18.4%	18.7%	19.6%	440,272	11.2%
3	UK	6.1%	6.0%	6.0%	5.7%	5.5%	137,721	−9.8%
4	Germany	4.7%	4.6%	4.5%	4.4%	4.3%	106,011	−8.5%
5	Japan	4.7%	4.5%	4.4%	4.3%	4.1%	103,147	−12.5%
6	France	4.6%	4.4%	4.2%	4.2%	4.1%	101,277	−9.4%
7	Italy	3.7%	3.9%	3.7%	3.7%	3.7%	87,777	−0.5%
8	Canada	3.1%	3.0%	3.0%	3.0%	2.9%	70,983	−6.1%
9	Spain	2.3%	2.3%	2.4%	2.5%	2.5%	57,205	9.6%
10	Australia	1.7%	1.9%	1.9%	2.0%	2.0%	45,325	15.5%
11	Netherlands	1.8%	1.9%	1.8%	1.8%	1.8%	42,938	3.4%
12	China	1.2%	1.4%	1.7%	1.9%	2.2%	41,884	81.1%
13	Sweden	1.3%	1.4%	1.3%	1.3%	1.3%	30,651	−5.3%
14	India	1.0%	1.1%	1.1%	1.2%	1.3%	27,283	36.8%
15	Other	15.1%	15.5%	16.0%	16.6%	17.1%	384,319	13.4%
	Total	320,353	396,343	466,676	566,605	618,380	2,368,355	

Source: ISI-WOS.
Note: Citations are weighted with the share of Brazilian addressees in the citing paper.
[a] Rank by totals 2005–2009.

indicators and citation data are independent of ISI and SCOPUS indexing practices, and allow the comparison of data from both databases. The added advantage of the SCImago report is that it also enables an assessment of a longer time period than that made possible with the ISI data. SCImago utilizes a different methodology to compute citation rates, resulting in a share of citations to Brazil papers that is approximately double the rate calculated by us on the basis of ISI data. However, the primary comparison of interest is whether the trend of an increasing domestic share of citations detected in Table 3 is credible, and SCImago supports this proposition: the share of domestic citations in Brazilian papers grows from 31% in 1999 to 37% in 2009, while also exhibiting roughly stable year-on-year growth. Although in 4 of the 10 years in Table 4, there are small declines, the overal growth offsets such fluctuations and results in an overall 20% increase in the share of domestic citations over 10 years.

4.1.2. Brazilian citations of research in other regions and countries

In addition to the trends in Brazilian articles' citation of domestic research in 2005–2009, our data shows that major research regions and some leading countries appear to be on diverging paths as sources of knowledge for Brazilian research. The share of North America as a knowledge source for Brazil declines by almost 11%, whereas EU-27 declines moderately, only a little less than 3%, suggesting that Europe's role as a knowledge source for Brazil has remained almost unchanged in 2005–2009. In contrast, Asia gains 17% in the same period, highlighting the nascent nature of South-South relationships. These results contrast with other research that has argued that US research literature and patents are receiving citations at a higher rate than European ones, indicating that the quality – or relevance – of European research and technology trails that of American (Albarrán et al., 2010; Chang and Breitzman, 2009), and suggesting that Brazil may be forging its own global knowledge base.

At the country level, the disparities are even greater. The USA declines by more than 11%, and although it is able to maintain its position as the most important knowledge source for Brazil, the decline is also suggestive of a re-orientation of Brazilian research toward areas where US research is less prominent. European countries demonstrate diverging developments as well. The shares of major European knowledge sources, such as the UK (3rd most important source of citations 2005–2009), Germany (4th), and France (6th) have declined between 8 and 10%, whereas Italy (7th) has remained unchanged. Spain (9th) has gained almost 10%, and the Netherlands (11th) more than 3%.

China (12th) and India (14th) are posting impressive gains, more than 80% and 35%, respectively. Although several other Southern economies, such as Australia, South Korea, South Africa, and Argentina, are increasingly important sources of knowledge for Brazilian research, the phenomenon is unlikely to challenge Northern research countries' central position for a long time.

Such changes mirror in part the changed research capacities of countries, but cannot be simply derived from respectively increased or decreased shares of global research. Between 2002 and 2008, Brazil increased its share of global research publications from 0.8%

Table 4
SCImago report for Brazil. Citations and self-citations to Brazilian documents.

Year	Citable docs	Cites	Self cites	Cites per doc	Self cites per doc	Share of self-citations from total cites	Growth of share of self-citations
1999	12,304	165,217	51,029	13.43	4.15	30.9%	
2000	13,376	186,359	58,437	13.93	4.37	31.4%	1.5%
2001	13,917	174,977	57,740	12.57	4.15	33.0%	5.2%
2002	16,089	201,541	64,662	12.53	4.02	32.1%	−2.8%
2003	18,027	210,832	67,197	11.7	3.73	31.9%	−0.7%
2004	20,034	210,106	66,120	10.49	3.3	31.5%	−1.3%
2005	22,558	211,414	66,146	9.37	2.93	31.3%	−0.6%
2006	28,348	201,808	67,876	7.12	2.46	33.6%	7.5%
2007	31,162	177,163	62,112	5.69	1.99	35.1%	4.2%
2008	35,860	141,806	50,238	3.95	1.4	35.4%	1.0%
2009	41,334	92,402	34,280	2.24	0.83	37.1%	4.7%

Source: SCImago. (2007). SJR – SCImago Journal & Country Rank. Retrieved July 12th, 2012, from http://www.SCImagojr.com. Full country report: http://www.SCImagojr.com/countrysearch.php?country=BR&area=0.

Table 5
Citations received by Brazilian papers in 2005–2009 by origin of citing paper: Brazil and major regions.

Rank[a]	Region	2005	2006	2007	2008	2009	Total	Change 2005–2009
1	Brazil	34.3%	36.2%	35.9%	36.4%	40.5%	169,298	18.2%
2	EU-27	23.3%	23.1%	23.6%	23.5%	21.9%	110,779	−6.2%
3	North America	18.5%	17.6%	18.1%	17.6%	17.0%	85,667	−8.0%
4	Asia	12.8%	12.1%	11.6%	12.1%	11.0%	57,970	−13.9%
5	Middle East	2.9%	2.7%	2.6%	2.4%	2.3%	12,928	−21.5%
6	South America	2.4%	2.3%	2.5%	2.4%	2.3%	11,476	−3.5%
7	Europe (non-EU)	1.9%	1.8%	1.9%	1.8%	1.7%	8840	−8.1%
8	Oceania	1.8%	1.8%	1.7%	1.7%	1.8%	8411	−0.1%
9	Africa	1.2%	1.2%	1.2%	1.0%	0.8%	5558	−29.8%
10	Central America and Caribbean	1.1%	1.2%	1.0%	1.0%	0.7%	5042	−31.6%
	Total	168,699	142,418	102,316	52,689	9848	475,969	

Source: ISI-WOS.
[a] Rank by totals 2005–2009.

to 2.7%. The shares of the USA and the EU declined by 9% and 8%, respectively, whereas those of China and India increased by 104% and 42%, respectively (UNESCO, 2010).

Thus, the geographic origin of papers cited by Brazilian research in 2005–2009 demonstrates trends in the relevance of research for Brazilian knowledge production, summarized in the following observations: (1) Brazilian research is relying increasingly on the country's own knowledge base, suggesting that domestic capabilities are supportive of dynamics of research growth; (2) The relevance of European research has remained almost unchanged, although there appear to be diverging developments between leading and middle-range EU-research countries; (3) The relevance of the US has declined; (4) South-South knowledge linkages between Brazil and China, Australia, India, South Korea, Argentina, and South Africa have increased, although these linkages are still on a modest scale when compared to key relationships with the US and Europe.

4.2. Knowledge outflows – citations received by Brazilian articles

Considering that the papers under study (all those published between 2005 and 2009) are too recent to infer reliable citation patterns (especially for the most recent years), the purpose of this analysis is supplementary. Analysis of the geographical origin of papers *citing* Brazilian research allows us to highlight how regions differ as sources and users of knowledge for Brazilian research. This casts light on the locations in which Brazilian research is demonstrating relevance and is a significant source of knowledge. In substantial ways, this analysis mirrors and augments our analysis of sources of knowledge, and provides another perspective on our claims about Brazil building increasingly on domestic knowledge capacities and the diverging relevance of major global regions.

The analysis provided here should be treated only as an indicative and auxiliary analysis to the previous section. Because citation data is set to change in time, and its proper use would require systematic treatment of citation windows, our analysis must be interpreted carefully and only in connection with citations made. We have included all citations received by Brazilian papers by mid-2010, and look only at the regional level of citations received.

A comparison of regions and countries as sources and utilizers of knowledge allows us to examine their balance of knowledge flows with Brazil, an analysis that reveals highly contrasting profiles and trends. Overall, these diverging roles of regions and countries as sources of knowledge and as users of Brazilian knowledge fall roughly along a South-South and South-North divide, though again with big variations among individual countries. EU-27 and North America have a significantly higher share as sources of knowledge than as users, whereas the reverse is true of Asia, and of emerging economies and developing countries in general.

The share of EU-27 in citations made to Brazilian research is only three-quarters of its role as a source for Brazilian research, and the respective relation to North America is about half. With such a significant difference, one is bound to contemplate that these regions have a more significant role as a source of knowledge than as users of Brazilian research. In the case of Brazil, the balance of knowledge flows is inverted. It features almost twice as much as a user of knowledge than as a source. This feature is shared by Asia, whose share as a user exceeds that as a source by about one third.

These trends, summarized in Table 5, in combination suggest that the rate of domestic and foreign citations changes unequally: the rate of domestic citation expands fast enough to reduce the share of foreign citations.

In summary, when we contrast the role of regions as sources and users of Brazilian knowledge, important global differences emerge. Traditional global science hubs, North America and EU-27, have pronounced roles as users of Brazilian knowledge, whereas Brazilians themselves, and other emerging economies and developing countries, proliferate as users of Brazilian knowledge. Such knowledge flow balances suggest that the emerging economy innovation systems in Brazil and Asia may have unique complementarities, or are at least in the process of establishing these, and that their mutual knowledge relationships differ from those between emerging economies and rich countries. While an assessment of this phenomenon is beyond this paper, it has significant analogies with the evolution of the Brazilian innovation system analyzed here, as it demonstrates increasing reliance on other southern emerging economies as sources of knowledge.

5. Conclusions

We have argued that institutions of knowledge in emerging economies reflect their enhanced capacities in science, technology, and innovation, and that such changes are unfolding on a scale of global significance. Going beyond aggregate growth or organizational change of fast-growing emerging economies, we investigated with bibliometric methods the location of sources of knowledge and users of Brazilian research in 2005–2009.

Our central results suggest that when creating new knowledge, Brazil's researchers are increasingly relying on domestic sources of knowledge. Secondly, the ascendancy of Brazil's research informs us of the unfolding re-organization of global research, underlining nascent South-South knowledge flows, the prevailing relevance of EU research, and the relative decline of US research in relation to Brazilian knowledge production. Finally, an analysis of the in- and outflows of knowledge demonstrated that advanced economies have a primary role as sources of knowledge for Brazil, whereas Brazil and other emerging economy regions seem to prioritize the use of Brazilian knowledge.

Naturally, additional comparative research is necessary to confirm how sources of knowledge matter for developing countries' efforts to build national systems of innovation. In addition, it is quite likely the knowledge flows vary greatly between research fields, something our national analysis is not able to detail here. Whereas our study has analyzed a relatively short period, longer historical analyses are necessary to confirm how institutions of knowledge behave in different types of developing countries.

Despite these limitations and the need for further research, our results carry some implications for contemporary strategies of development, which often emphasize "quick wins" achievable through North-South technology and knowledge transfer, and downplay the potential of research in poor countries. The way Brazil's knowledge flows and bases appear to be re-grouped once it is about to gain global prominence in science, technology, and innovation after decades of determined build-up, seems to emanate from a deeper need to ensure that research is relevant to Brazilian challenges. If, as we suggest, domestic and South-South research capacities play an increasing role in developing country and emerging economy innovation systems as they gain momentum, this raises the broader question about the political economy of knowledge within the global research system. Thus, the issue of dependency, a perpetual theme in developmental literature, also needs to be taken seriously and perhaps re-evaluated by development practitioners and policy-makers advocating innovation-led development.

Acknowledgements

This paper has been prepared with financial support from Tekes – the Finnish Funding Agency for Technology and Innovation, for the project "Smart Globalization: Evolving relationships between emerging economies and high-tech regions". An early version of this paper was presented at the Atlanta Conference on Science and Technology in September 2011, and a revised version in a seminar at the University of São Paulo, Institute for Advanced Studies Observatory for Innovation and Competitiveness, on 14th December 2011. We are also grateful for the criticism and suggestions made by three anonymous referees and the editors. All the usual disclaimers apply.

References

Abdullah, S., 1995. Scientific and technical information: impetus for development in Southeast Asia. International Forum on Information and Documentation 20, 3–13.
Albarrán, P., Crespo, J.A., Ortũno, I., Ruiz-Castillo, R., 2010. A comparison of the scientific performance of the U.S. and the European Union at the turn of the 21st century. Scientometrics 85, 329–344.
Alfaraz, P., Calviño, A., 2004. Bibliometric study on food science and technology: scientific production in Iberian-American countries (1991–2000). Scientometrics 61, 89–102.
Arbix, G., Salerno, M.S., Toledo, D., Miranda, Z., dos Reis Alvarez, R. (Eds.), 2010. Inovação. Estratégias de sete países. Agência Brasileira de Desenvolvimento Industrial, Brasília.
Arbix, G., De Negri, J., de Negri, F., 2011. Um banco da inovação para elevar a competitivade da economia. In: dos Reis Velloso, J.P. (Ed.), China, Índia e Brasil: O país na competiçao do século. José Olympio Editora, Rio de Janeiro, pp. 137–152.
Archambault, É., Cambell, D., Gingras, Y., Larivière, V., 2009. Comparing bibliometric statistics obtained from the web of science and scopus. Journal of the American Society for Information Science and Technology 60, 1320–1326.
Argou Margues, R., 2004. Evolution of the civil aircraft manufacturing system of innovation: a case study in Brazil. In: Mani, S., Romijn, H. (Eds.), Innovation, Learning and Technological Dynamism of Developing Countries. United Nations University, Hong Kong, pp. 77–106.
Avellar, A.P., Cardoso Boaventura Oliveira, F., 2009. Evolução dos Indicatores de Ciência. In: Vilela Vieira, F. (Ed.), Economia e Desenvolvimento em Países Emergentes. Brasil, Rússia, Índia e China. Alińea, Campinas-SP, pp. 161–184.
Babbie, E.R., 1995. The Practice of Social Research, 7th ed. Wadsworth Pub. Co., Belmont.
Bell, M., Albu, M., 1999. Knowledge systems and technological dynamism in industrial clusters in developing countries. World Development 27, 1715–1734.
Boshoff, N., 2009. Neo-colonialism and research collaboration in Central Africa. Scientometrics 81, 413–434.
Brooks, T.A., 1985. Private acts and public objects: an investigation of citer motivations. Journal of the American Society for Information Science 36, 223–229.
Castells, M., 1998. End of Millennium. Blackwell Publishers, Oxford.
Chang, C.K.N., Breitzman, A., 2009. Using patents prospectively to identify emerging, high-impact technological clusters. Research Evaluation 18, 357–364.
Cole, J.R., 1970. Patterns of intellectual influence in scientific research. Sociology of Education 43, 377–403.
Criscuolo, P., Narula, R., 2008. A novel approach to national technological accumulation and absorptive capacity: aggregating Cohen and Levinthal. The European Journal of Development Research 20, 56–73.
Edquist, C., 1997. Systems of Innovation: Technologies, Institutions and Organizations. Pinter, London.
Etzkowitz, H., Carvalho de Mello, J.M., Almeida, M., 2005. Towards meta-innovation in Brazil: the evolution of the incubator and the emergence of a triple helix. Research Policy 34, 411–424.
Fagerberg, J., Godinho, M.M., 2005. Innovation and catch-up. In: Fagerberg, J., Mowery, D.C., Nelson, R.R. (Eds.), Oxford Handbook of Innovation. Oxford University Press, Oxford, pp. 514–542.
Fagerberg, J., Shrolec, M., Knell, M., 2007. The competitiveness of nations. Why some countries prosper while others fall behind. World Development 35, 1595–1620.
Fagerberg, J., Srholec, M., Verspagen, B., 2010. Innovation and Economic Development. In: Hall, B., Rosenberg, N. (Eds.), Handbook of the Economics of Innovation, vol. II. North Holland, Amsterdam, pp. 833–872.
Falagas, M.E., Pitsouni, E.I., Malietzis, G.A., Pappas, G., 2008. Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. The FASEB Journal 22, 338–342.
Freeman, C., Soete, L., 1997. Economics of Industrial Innovation, 3rd ed. MIT Press, London.
Garfield, E., 1998. Random thoughts on citationology its theory and practice. Scientometrics 43, 69–76.
Gauffriau, M., Larsen, P.O., Maye, I., Roulin-Perriard, A., Von Ins, M., 2008. Comparisons of results of publication counting using different methods. Scientome 77, 147–176.
Glänzel, W., Leta, J., Thijs, B., 2006. Science in Brazil. Part 1: A macro-level comparative study. Scientometrics 67, 67–86.
Gu, S., Lundvall, B.-Å., 2006. China's innovation system and the move towards harmonious growth and endogenous innovation. Innovation, Management Policy & Practice 8, 1–26.
Helene, A.F., Ribeiro, P.D., 2011. Brazilian scientific production, financial support, established investigators and doctoral graduates. Scientometrics 89, 677–686.
Jeenah, M., Pouris, A., 2008. South African research in the context of Africa and globally. South African Journal of Science 104, 351–354.
Johnson, B., Oppenheim, C., 2007. How socially connected are citers to those that they cite? Journal of Documentation 63, 609–637.
Kemeny, T., 2010. Does foreign direct investment drive technological upgrading? World Development 38, 1543–1554.
Kemeny, T., 2011. Are international technology gaps growing or shrinking in the age of globalization? Journal of Economic Geography 11, 1–35.
Kesidou, E., 2004. The political economy of technology policy: the automotive sector in Brazil (1950–2000). In: Mani, S., Romijnm, H. (Eds.), Innovation, Learning and Technological Dynamism of Developing Countries. United Nations University, Hong Kong, pp. 107–134.
Kim, L., 1997. Imitation to Innovation. The Dynamics of Korean Technological Learning. Harvard Business School Press, Cambridge, MA.
Koeller, P., Cassiolato, J.E., 2011. Achievements and shortcomings of Brazil's innovation policies. In: Lundvall, B.-Å. (Ed.), BRICS and Development Alternatives: Innovation Systems and Policies. Anthem Press, London, pp. 133–162.
Kraemer-Mbula, E., Wamae, W. (Eds.), 2010. Innovation and the Development Agenda. OECD, Paris.
Krampen, G., Becker, R., Wahner, U., Montada, L., 2007. On the validity of citation counting in science evaluation: content analyses of references and citations in psychological publications. Scientometrics 71, 191–202.
Lehtonen, M., 2011. Social sustainability of the Brazilian bioethanol: power relations in a centre-periphery perspective. Biomass and Bioenergy 35, 2425–2434.
Leite, P., Mugnaini, R., Leta, J., 2011. A new indicator for international visibility: exploring Brazilian scientific community. Scientometrics 88, 311–319.
Leta, J., Chaimovich, H., 2002. Recognition and international collaboration: the Brazilian case. Scientometrics 53, 325–335.
Leydesdorff, L., 1998. Theories of citation? Scientometrics 43, 5–25.
Liu, X., Liu, J., 2011. Science and technology and innovation policy in China. In: Lundvall, B.-Å. (Ed.), BRICS and Development Alternatives: Innovation Systems and Policies. Anthem Press, London, pp. 133–162.
Liu, F.-C., Simon, D.F., Sun, Y.-T., Cao, C., 2011. China's innovation policies: evolution, institutional structure, and trajectory. Research Policy 40, 917–931.
Liu, X., White, S., 2001. Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30, 1091–1114.
Lundvall, B.-Å. (Ed.), 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter, London.
Lundvall, B.-Å., Vang, J., Joseph, K.J., Chaminade, C., 2010. Innovation systems research and developing countries. In: Lundvall, B.-Å., Vang, J., Joseph, K.J., Chaminade, C. (Eds.), Handbook of Innovation Systems in Developing Countries. Building Domestic Capabilities in a Global Setting. Edward Elgar, Cheltenham, pp. 1–32.

Lundvall, B.-Å. (Ed.), 2011. BRICS and Development Alternatives: Innovation Systems and Policies. Anthem Press, London.
MacKinnon, D., Cumbers, A., Chapman, K., 2002. Learning, innovation and regional development: a critical appraisal of recent debates. Progress in Human Geography 26, 293–311.
MacRoberts, M.H., MacRoberts, B.R., 1989. Problems of citation analysis: a critical review. Journal of the American Society for Information Science 40, 342–349.
Mallick, S., 2009. The intellectual property rights regime and the changing structure of scientific research in India: lessons from the developing world. Perspectives on Global Development and Technology 8, 628–654.
Menard, H.W., 1971. Science: Growth and Change. Harvard University Press, Cambridge, MA.
Meneghini, R., 1992. Brazilian production in biochemistry. The question of international versus domestic publication. Scientometrics 23, 21–30.
Merton, R.K., 1973. The Sociology of Science: Theoretical and Empirical Investigations. University of Chicago Press, Chicago.
Merton, R.K., 1988. The Matthew Effect in science. II: Cumulative advantage and the symbolism of intellectual property. Isis 79, 606–623.
Metcalfe, S., Ramlogan, R., 2008. Innovation systems and the competitive process in developing economies. The Quarterly Review of Economics and Finance 48, 433–446.
Ministério da Ciência e Tecnologia, 2007–2010. Plano de ação em ciência 2007–2010. Documento síntese. Ministério da Ciência e Technologia, Brasília.
Ministério da Ciência e Technologia, 2010. Plano de ação em ciência, Technologia e inovaçao. Principais resultados e avanços 2007–2010. Ministério da Ciência e Technologia, Brasília.
Ministério da Ciência e Technologia, 2011. Ação de C, T&I, http://www.mct.gov.br/index.php/content/view/73409.html (accessed 05.01.12).
Moed, H.F., 2005. Citation Analysis in Research Evaluation. Springer, Dordrecht.
Mowery, D.C., Oxley, J.E., 1995. Inward technology transfer and competitiveness: the role of national innovation systems. Cambridge Journal of Economics 19, 67–93.
Mugnaini, R., 2006. Caminhos para adequação da avaliação da produção científica Brasileira: impacto nacional versus international. Unpublished Ph.D. Dissertation. Universidade de São Paulo, São Paulo.
Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. Belknap Press, Cambridge, MA.
Nelson, R.R. (Ed.), 1993. National Innovation Systems: A Comparative Analysis. Oxford University Press, New York.
Nelson, R.R., Wright, G., 1992. The rise and fall of American technological leadership: the postwar era in historical perspective. Journal of Economic Literature 30, 1931–1964.
Onyancha, O.B., Maluleka, R.R., 2011. Knowledge production through collaborative research in Sub-Saharan Africa: how much do countries contribute to each other's knowledge output and citation impact? Scientometrics 87, 315–336.
Ordóñez-Matamoros, H.G., 2008. International research collaboration, research team performance, and scientific and; technological capabilities in colombia – a bottom-up perspective. Unpublished Ph.D. Dissertation. Georgia Institute of Technology, Atlanta, GA.
Ordóñez-Matamoros, H.G., Cozzens, S.E., Garcia, M., 2010. International co-authorship and research team performance in Colombia. Review of Policy Research 27, 415–431.
Pereira Friedrich, M.P., Dos Santos Rodrigues, P., 1998. Looking at science in Brazilian universities: the case of the instituto de Biofísica Carlos Chagas Filho. Scientometrics 42, 247–258.
Rapini, M.S., Albuquerque, E., Vilela Chave, C., Alves Silva, L., de Souza, S.G.A., Righi, H.M., Cruz, W.M.S., 2009. University–industry interactions in an immature system of innovation: evidence from Minas Gerais, Brazil. Science and Public Policy 36, 373–386.
Rodriguez, A., Dahlman, C., Salmi, J., 2008. Knowledge and Innovation for Competitiveness in Brazil. World Bank, Washington, DC.
Rodríguez-Ruiz, Ó., 2009. The citation indexes and the quantification of knowledge. Journal of Educational Administration 47, 250–266.
SCImago, 2007. SJR – SCImago Journal & Country Rank. Retrieved July 12th, 2012 from http://www.SCImagojr.com
Shie, V., Meer, C., 2010. The rise of knowledge in dependency theory: the experience of India and Taiwan. Review of Radical Political Economics 42, 81–99.
Schoeneck, D.J., Porter, A.L., Kostoff, R.N., Berger, E.M., 2011. Assessment of Brazil's research literature. Technology Analysis & Strategic Management 23, 601–621.
Small, H., 2004. On the shoulders of Robert Merton: towards a normative theory of citation. Scientometrics 60, 71–79.
Spagnolo, F., 1990. Brazilian scientists' publications and mainstream science: some policy implications. The case of chemical and electrical engineering. Scientometrics 18, 205–218.
Stehnken, T., 2010. The Politics of Interaction in Innovation Systems: Evidence from Brazilian Multi-Level-Governance Structures. Nomos Verlag, Baden-Baden.
Toivanen, H., Ponomariov, B., 2011. Regional aspects of the African innovation system: bibliometric analysis of research collaboration patterns 2005–2009. Scientometrics 88, 471–493.
Toivanen, H., Lima-Toivanen, M.B., 2009. Learning, innovation and public policy: the emergence of Brazilian pulp and paper industry. In: Malerba, F., Manil, S. (Eds.), Sectoral Systems of Innovation in Developing Countries: Actors, Structure and Evolution. Edward Elgar, Cheltenham, pp. 99–127.
UNESCO, 2010. UNESCO Science Report. The Current Status of Science Around the World. UNESCO, Paris.
UNIDO, 2005. Industrial Development Report 2005. Capability Building for Catching-Up. Historical, Empirical and Policy Dimensions. UNIDO, Vienna.
Wagner, C., Wong, S., 2012. Unseen science? Representation of BRICs in global science. Scientometrics 90, 1001–1013.
Wainer, J., Xavier, E., Bezerra, F., 2009. Scientific production in computer science: a comparative study of Brazil and other countries. Scientometrics 81, 535–547.