Intersectoral flows of technological knowledge in emerging countries: an input-output analysis

Eduardo Gonçalves and Amir Borges Ferreira Neto

ABSTRACT

In this paper, we aim to assess the production, use and diffusion of technology in the production structure in emerging countries, such as Brazil, China, the Russian Federation and South Africa, through the analysis of: (i) users and producers of technology; (ii) research and development (R&D) content in each group of sectors, and (iii) technical knowledge flows between these groups. We use input-output matrices combined with sectoral R&D statistics to achieve our objectives. Our major findings point to significant differences among the emerging countries and also between developing and developed countries, including differences in sectoral hierarchy in terms of production and use of technological knowledge, and differences in the direction of main technological flows among sectors.

KEYWORDS

Technology, research and development, technology transfer, production, developing countries, Brazil, Russia, China, South Africa

JEL CLASSIFICATION

O57, O30, R15

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I
Introduction

According to Lundvall (2011), Brazil, China, India, the Russian Federation and South Africa play a major role on the international scene that goes beyond their territorial boundaries, population contingents and total outputs. Part of their importance is associated with changes in their national innovation systems in recent years, which have led them to become knowledge producers alongside Europe, Japan and the United States of America.

However, which of these countries are best characterized as knowledge producers? And which economic sectors are best qualified to generate and diffuse technological knowledge? Although these countries share features typical of emerging countries that have undergone late industrialization processes —including import substitution, varying degrees of economic opening and technological dependence in technology-intensive sectors— there might be differences among them in the process of sectoral technological accumulation.

In this paper we analyse the intensity of use and production of technological knowledge, and the intersectoral knowledge flow in Brazil, China, the Russian Federation and South Africa. More specifically, we try to answer the following questions: (i) what are the main sectoral differences in terms of production and use of technological knowledge? (ii) How do our findings relate to those of other studies on developed countries? (iii) Is there homogeneity in this particular group of emerging countries in terms of sectoral hierarchy and technological knowledge flows?

The productivity of a sector in a given economy depends on its own efforts in R&D, but also on the efforts of its trading partners, as such interrelations occur. For this reason Schmookler (1966), for example, associates technological performance improvements in one sector with innovative efforts coming from the other sectors in an economy. Hence, the technical knowledge produced in a given sector is not constrained by its own R&D expenses, since intersectoral purchases and sales allow sectors to incorporate knowledge embodied in inputs and capital goods.

Although trading of final goods, capital goods and intermediate inputs may be a channel through which spillovers occur (Macdissi and Negassi, 2002), the mere acquisition of technology cannot enhance the innovative capacity of an importing country. That country will need a concomitant local R&D effort in order to benefit from the import of technology. Local effort develops absorption capacity and allows technological learning, which enables the catch-up process (Fu, Pietrobelli and Soete, 2011; Li, 2011; Viotti, 2002). In order to analyse emerging countries, we therefore needed a methodology that would weight the importance of the various sectors in an economy in terms of production of technological knowledge in relation to the use of technological knowledge from domestic and foreign sources.

Hence, in methodological terms, we follow the tradition introduced by Scherer (1982); Papaconstantinou, Sakurai and Wyckoff (1998); Wolff (1997); Van Meijl (1997); Sakurai, Papaconstantinou and Ioannidis (1997); Vuori (1997); Verspagen (1997), and, especially, Hauknes and Knell (2009), whose work combines input-output matrices and R&D data, allowing us to measure product-embodied R&D diffusion from domestic and foreign sources.

We use input-output matrices for Brazil, China, the Russian Federation and South Africa (data were from 2005 for Brazil and South Africa and from 2000 for China and the Russian Federation). For China, the Russian Federation and South Africa, we use input-output matrices from the Organization for Economic Cooperation and Development (OECD) and R&D data from the Analytical Business Enterprise Research and Development (ANBERD) database, while for Brazil we use data from the technological innovation survey (PINTEC), conducted by the Brazilian Institute of Geography and Statistics (IBGE).

In addition to the Introduction, this paper comprises five sections. Section II presents an empirical and theoretical review of the literature. Section III provides a brief discussion on the national innovation systems in the selected countries. In section IV we present information on the databases used, and in section V we describe all the methodologies used and their results. Section VI presents our conclusions.

II
Theoretical background

Mansfield (1971) emphasizes the importance of external sources of knowledge, ideas and innovations, affirming that their main external source is the flow of technology from one sector to another. Pavitt (1984) notes an empirical regularity that made it possible to construct a taxonomy confirming the existence of such intersectoral flows of technology and knowledge. Robson, Townsend and Pavitt (1988) also find sectoral differences deriving from the production and use of innovations. In view of the different patterns of sectoral innovation, Malerba (2004) proposes the existence of a sectoral system of innovation encompassing the variety of specific knowledge bases, technologies, production processes and many others aspects that characterize all economic sectors.

Pavitt's taxonomy (1984) points to similarities and differences among sectors with regard to the sources, nature and impacts of innovations. The taxonomy comprises three groups of sectors: (i) supplier-dominated sectors; (ii) production-intensive sectors (which in turn can be broken down into scale-intensive firms and specialized suppliers), and (iii) science-based sectors. These three sectors show different innovation patterns, depending on their technology sources (which include R&D laboratories, among others), user requirements (price, performance and reliability) and property rights (trade secrecy, patents, natural and lengthy technical lags, and other, non-technical means).

Firms belonging to supplier-dominated sectors (such as textiles, lumber, wood and paper products, printing and publishing, construction and services) provide small contributions to their product and process technologies, but most of their technological innovations come from equipment and materials suppliers. In scale-intensive sectors, such as automotive and steel industries, process innovation is important and its sources are both internal (R&D and learning by doing) and external (producers of equipment). Specialized-suppliers, such as equipment producers, also have both internal and external sources of technology. Tacit knowledge and knowledge gained from the experience of more skilled workers can be cited as examples of internal sources, while user-producer interaction is an example of an external source. Science-based sectors, such as pharmaceuticals and electronics, are characterized by high rates of product and process innovations, R&D expenditure and scientific research carried out in universities and government institutions.

Innovation pattern differences and technological interdependence only become visible when we study input-output relationships in the economy. The advantages of using input-output matrices to study innovation benefits can be seen in the work of Rosenberg (1982), who emphasizes the need to consider inter-industry relationships in order to measure the benefits of technological innovation to society. According to this author, transferring technological change from one sector to another through sales of intermediate goods has significant implications for the understanding of productivity growth.

Bell and Pavitt (1993) state that, as far as developing countries are concerned, linkages between users and producers are sometimes weak or absent, which has negative repercussions on the possibilities for technological diffusion and capital stock efficiency.

In some developing countries, the expansion of capital goods industry and scale-intensive sectors was not accompanied by the development of sectors producing instrumentation and specialized and complex machinery or science-intensive sectors. Thus, these sectors are underrepresented in such economies, setting the stage for the historical process of technological dependence and the need to import technical processes. The industrialization process in emerging countries showed sectoral weakness, creating gaps in technological matrices, especially in technology diffusion sectors, such as the capital goods industry. This has historically weakened their national capacity to create new products and processes.

The technological activity of developing or late-industrializing countries is generally limited to adapting products and processes to the local conditions or improving them. More complex activities, such as developing new products and processes and conducting basic research, are less common in such countries (Fransman, 1985).

This difference in technological qualification is related to the historical routes taken in the industrialization processes of economies, which in turn create structural differences between economies considered to be developing and those considered to be developed. One reason can be traced to import substitution policies that, according to Ranis (1984), produced losses in terms of local technological activities, owing to the focus on "getting things done" and obtaining technologies available on the world market, especially in combination with policies allowing the free entry of capital goods.

The consequences of an industrialization process that fails to internalize the capital goods segment can be evaluated based on Rosenberg (1976), who highlights the essential role played by the machine-tools sector as both producer and disseminator of new skills and techniques in the economy, in response to specific customer orders.

Some developing economies succeeded in the process of catching up with the technological frontier. Japan is considered the most successful example (Fransman, 1985). Other countries adopted industrialization models that emphasized building the absorption capacity of domestic firms. Using an active learning strategy to assimilate sources of technological information from foreign industries, such as capital goods imports, technological licensing and foreign direct investment (FDI), economies such as that of the Republic of Korea acquired the ability to copy and, later on, make incremental innovations in various consumer and capital goods (Viotti, 2002).

The examples from Asia, in particular the countries known as the "Asian tigers," showed that a successful industrialization and catch-up process involved more than absorbing embodied technology in capital goods, as it required the acquisition of complementary skills and the facilitation of linkages and spillovers between economic sectors (Van Dijk and Szirmai, 2006).

According to Bell and Pavitt (1993), developed countries differ from developing countries, and developing countries differ from each other, in terms of technological accumulation for three reasons: (i) depth and intensity of intra-firm technological accumulation; (ii) institutional infrastructure related to education and training institutions and to greater investment in human capital by some firms, and (iii) complementarities between the import of technology and local technology accumulation, where the acquisition of foreign technology (through FDI, joint ventures, licensing) has been complemented by domestic R&D efforts to build technological absorption capacity.

The particularities of technological accumulation in emerging countries that did not follow the same trajectory as Asian economies such as Japan, the Republic of Korea and Taiwan Province of China, produced economies with the following characteristics:

(i) A low proportion of R&D expenditure devoted to technological effort, not only in the economy as a whole, but also in the more technology-intensive sectors (medium-high and high technology).
(ii) High expenditure on technology embodied in inputs, machinery and equipment —largely imported from countries on the technological frontier and from other emerging countries— as a proportion of the total amount spent on innovation.

The modest weight of R&D expenditure in the economic structure of developing countries is related to low representation of the most intensive R&D sectors, such as science-based sectors. Thus, we wish to confirm the following hypotheses: first, Brazil, China, the Russian Federation and South Africa do not present a sectoral hierarchy similar to that found in developing countries in terms of their capacity for technological production. Based on differences in terms of sectoral weight in the input-output structure of each economy, we can formulate a second hypothesis to test: the direction of technological knowledge flows will be different between groups of sectors. For example, high-technology (science-based) sectors may emerge as net receivers of technological flows, whereas sectors considered as intermediate in terms of the use and diffusion of technological knowledge, such as specialized suppliers and scale-intensive sectors (Hauknes and Knell, 2009), may take on the role of net suppliers of technology. The direction of such flows within each group of sectors will also depend on the characteristics of each country, given the heterogeneity of their industrial and technological trajectories.

III

General features of production and innovation systems in emerging countries

National innovation systems should not be understood only as an innovative process stemming from R&D, but also as a manifestation of several different dimensions that encompass production structures, human capital, and financial and credit systems, among others (Cassiolato and Lastres, 2011). Hence, the relative position of each national innovation system reflects a different set of historical conditions in each country.[1]

Although there is some heterogeneity with regard to political systems, economic policies and structural features, some common characteristics and tendencies can be distinguished among the countries selected for study (Brazil, China, the Russian Federation and South Africa):

(i) All four countries implemented import substitution policies and had economic opening strategies, albeit to differing degrees (UNIDO, 2012).

(ii) Energy resources have accounted for a high proportion of the total production of all four countries. While China has been excelling in the renewable energy field (wind energy), Brazil has great potential in hydroelectric power. The contribution of natural resources to economic development has been of great importance in these countries, especially Brazil and South Africa. Thus, technological accumulation in emerging countries can be related to energy sectors, where such sectors account for a significant share of the economic structure. We therefore need to examine whether all four countries exhibit the same pattern of technological opportunity (this is our third hypothesis). According to Cassiolato and Lastres (2011) and Cassiolato and Vitorino (2011), the greatest technological opportunities and constraints for Brazil and South Africa lie in sectors related to the environment.

(iii) With regard to technology, growth in R&D expenditure in some of the countries analysed, especially China, has exceeded the average increase in middle-income countries. On the other hand, the slow growth of R&D expenditure in Brazil, the Russian Federation and South Africa is an important difference among the selected countries and shows that the technology gap is still large when compared with the United States. Patent indicators grew in China, but have been falling since 2000 in Brazil, the Russian Federation and South Africa. Naudé, Szirmai and Lavopa (2013) conclude that, in general, technological progress has been more promising in China than in Brazil, the Russian Federation and South Africa, and highlight the fact that the economies of the Russian Federation and South Africa are dominated by natural resources extraction and traditional services.

Despite the similarities described above, some economic differences are apparent with regard to the availability of skilled labour, the weight of various economic sectors in the production structure and the role of each group of sectors, in terms of intensity of technological knowledge, in the industrial and technological dynamics in each country. These differences will be addressed in the sections that follow.

[1] Details on the historical trajectories of each country's national innovation system can be found in Gokhberg and others (2011) for the Russian Federation, in Liu and Liu (2011) for China, in Kruss and Lorentzen (2011) for South Africa, and in Koeller and Cassiolato (2011) for Brazil.

IV
Databases

We used two different types of information in this study: (i) OECD input-output matrices containing data on 48 sectors[2] for Brazil, China, the Russian Federation[3] and South Africa, and (ii) R&D data from OECD contained in the ANBERD database.[4] Owing to features of the two databases, for Brazil and South Africa we used data from 2005, while for China and the Russian Federation[5] we used data from 2000, as input-output and R&D data were not available for 2005. Nevertheless, the comparison among the countries is still valid, especially as R&D spending in Brazil and South Africa in 2005 is similar to that in China and the Russian Federation in 2000 (see annex figure A.1).

To make up for the lack of information on R&D in Brazil in ANBERD, we used data from PINTEC, a triennial survey carried out by IBGE. PINTEC follows the same criteria as ANBERD, which makes it possible to use the two databases concomitantly. They were reconciled in accordance with the International Standard Industrial Classification of All Economic Activities, Rev. 3 (ISIC Rev. 3).

We aggregated the 48 sectors into the eight groups comprising the new classification by Hauknes and Knell (2009), based on Pavitt's taxonomy (1984). Pavitt's taxonomy divides industries into four groups: (i) science-based sectors that depend heavily on R&D activities and technological learning; (ii) specialized-suppliers that require specific skills and are able to adapt their products to their consumers' needs; (iii) scale-intensive sectors that rely heavily on cost reduction and product improvement through engineering practices, and (iv) supplier-dominated sectors that make incremental improvements and adaptations to new technologies from upstream suppliers.

Hauknes and Knell (2009) broke down the "supplier-dominated" group into two subgroups: energy-producing and traditional sectors. They also classified materials separately and identified two kinds of services: knowledge-intensive business services (KIBS) and other services. Thus, we have eight groups: (i) energy; (ii) traditional; (iii) materials; (iv) scale-intensive; (v) specialized supplier; (vi) science-based; (vii) services, and (viii) KIBS.

[2] See table A.1 in the annex.

[3] Owing to various constraints, data from the pharmaceutical industry in the Russia Federation were aggregated with data from the chemical industry. Hence, we disaggregated the data using as a proxy the mean of the share of the pharmaceutical industry in the chemical industry in Brazil (15%) and China (16%). For countries on the technological frontier in which the same constraint applied, we used value added to disaggregate the two industries.

[4] ANBERD is a databank developed to provide (information) analysts with understandable and internationally comparable data on industrial R&D expenditure, including a corresponding time series.

[5] Despite the availability of input-output data for India, this country could not be included in the analysis, as R&D data on sectoral expenditure comparable with data from ANBERD were not available.

V
Methodological considerations and results

The input-output matrix describes the intersectoral flows in a national, regional or global economy. The main objective of such a matrix is to analyse the industrial interdependence in a specific economy (Miller and Blair, 2009). Applied in our context, this methodological approach allows us to make explicit some features of a national innovation system, as it stresses sectoral interdependence with regard to productive and technological knowledge flows.

By allowing us to analyse intersectoral flows, an input-output matrix becomes a way of measuring technical knowledge spillovers present in industrial sectors. Knowledge spillovers may be defined as externalities arising from an agent's investment in R&D that makes another agent's innovative effort easier (Breschi and Lissoni, 2001). Generally speaking, input-output matrices capture a kind of spillover called rent spillovers (Griliches, 1979). Following the literature, we therefore assume that investments in R&D are embodied in purchased inputs, using sales of intermediate inputs as a weighting factor to measure the intersectoral spillover (Terleckyj, 1974; Wolff, 1997; Wolff and Nadiri, 1993).

1. Input-output matrix

An input-output matrix is an attempt to apply the neoclassic model of general equilibrium. Hence, we propose an input-output matrix describing the monetary flows of an economy:

$$Z + f = x \qquad (1)$$

where Z is a matrix that represents intermediate consumption, f is the vector of final demand and x is the vector of gross output. Transforming vector x into a diagonal matrix, gives us x^D. Thus, matrix A of technical coefficients can be defined as:

$$A = Z\left(x^D\right)^{-1} \qquad (2)$$

Each element of A is defined as $a_{ij} = z_{ij}/x_j$, which corresponds to the proportion of input that industry j needs from industry i to produce US$ 1 of product.

Using (2) to solve (1), we get:

$$AX + f = x \qquad (3)$$

and, after some algebraic manipulations, we get:

$$X = Bf \qquad (4)$$

where B is the so-called Leontief inverse matrix, defined as $B = (I - A)^{-1}$. The elements b_{ij} of matrix B may be understood as the direct and indirect requirements of industry j for meeting one unit of output growth in industry i.

This approach is limited by the fact that technological changes are exogenous to the economic system, as technology is represented by technical coefficients of the input-output matrix. However, the analysis we present refers only to a single period of time and focuses on the production structure and input flows from different sectors in the economy. Therefore, the methodology used here is appropriate to this kind of analysis.

2. Embodied R&D and flows

As far as innovative activities are concerned, the stock of productive knowledge of industry j comprises direct R&D expenses and also those incorporated in purchased domestic inputs, goods and services resulting from domestic investment, imported intermediate inputs and goods and services resulting from imported investment.

Hauknes and Knell (2009) present calculations that allow us to measure product-embodied R&D diffusion. They divide the intensity of total R&D content in industry j $\left(s_j^x\right)$ into six components: own R&D $\left(r_j^d\right)$; intensity of R&D embodied in domestic inputs $\left(t_j^d\right)$; intensity of R&D embodied in foreign inputs $\left(t_j^m\right)$; R&D embodied in purchased domestic capital goods $\left(t_j^{dc}\right)$; and R&D embodied in purchased foreign capital goods $\left(t_j^{mc}\right)$. Mathematically, we get:[6]

$$s_j^x = r_j^d + t_j^d + t_j^m + t_j^{dc} + t_j^{mc} \qquad (5)$$

where

$$r_j^d = tx_j^d \quad if\ i = j \qquad (6)$$

$$t_j^d = \sum\nolimits_{i, i \neq j}\left[r_i\left(b_{ij}/b_{jj}\right)\right] \qquad (7)$$

$$s_j^d = r_j^d + t_j^d = \sum\nolimits_i\left[r_i\left(b_{ij}/b_{jj}\right)\right] \qquad (8)$$

$$t_j^m = \sum\nolimits_i\left(R_i^F m_{ij}\right) \qquad (9)$$

where $\left(t_j^m\right)$ is the expenditure of R&D embodied in imported inputs, R_i^F is the technological frontier, defined as the average R&D intensity of the United States and some countries of Europe,[7] and m_{ij} are the elements of matrix M of imported coefficients of all foreign sectors i for the domestic sector j.

$$t_j^{dc} = \sum\nolimits_i\left\{r_i\left[\sum\nolimits_k\left(b_{ik}I_{kj}^d\right)\right]\right\} \qquad (10)$$

$$t_j^{mc} = \sum\nolimits_i\left(R_i^F I_{ij}^m\right) \qquad (11)$$

where I_{kj}^d and I_{ij}^m are constructed by dividing the vector of gross fixed capital formation (FBCF) by the vector of gross output. For the former we used data from the

[6] $Tx = r^D O = [tx_{ij}]$, where $O = B(B^D)^{-1}$, B^D is a matrix with the diagonal elements of B, and r^D is the matrix of vector r diagonalized, where $r_i = R_i / x_i$, and R_i is R&D expenditure of industry i. Tx will thus measure total embodied R&D, or the technology intensity of industry j relative to total output of this industry. For more details, see Hauknes and Knell (2009).

[7] Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland.

domestic matrix and for the latter, data from the foreign inputs matrix.

Regarding flows, let Z^t be the total intermediate consumption matrix, now also taking imports into account. A^t will be considered the technical coefficient matrix and B^t Leontief's inverse matrix, defined as $B^t = \left(I - A^t\right)^{-1} = \left[b^t_{ij}\right]$. Matrix L of elements l_{ij} is to measure the amplitude of the aggregate linkage between industries i and j, so that:

$$l_{ij} = b^t_{ij} \Big/ \left(b^t_{ii} b^t_{jj} - b^t_{ij} b^t_{ji}\right) \quad (12)$$

It is worth noting that, at this point, matrix B^t does not change into matrix O since, though making sense from a mathematical viewpoint, matrix O does not make economic sense, as pointed out by Hauknes and Knell (2009). From equation (12) it is possible to calculate the technological flow from i to j as:

$$f^j_i = \left(r_i l_{ij} x_j\right) \Big/ \left(r_j x_j\right) \quad (13)$$

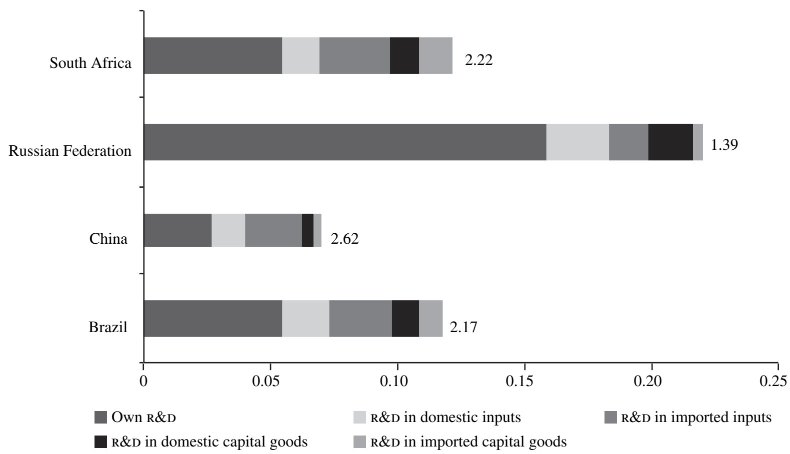
Following the methodology described above, it is possible to break down the technological intensity into five components, as described in equation (5). The result can be seen in figure 1 below, which shows the total technological intensity for each country and also the technology multiplier, defined as the ratio between total technological intensity and R&D intensity:

$$MTEC = \sum\nolimits_j s^x_j \Big/ \sum\nolimits_j r_j \quad (14)$$

This equation should be interpreted as follows: if the technology multiplier is equal to one, the industry is a pure technology producer. However, if the technology multiplier approaches infinity, the industry is a pure technology user. As for magnitude, the technology multipliers can be interpreted as follows: knowledge-producing countries exhibit a low multiplier, while knowledge-using countries exhibit a high multiplier.

FIGURE 1

Selected countries: technology multiplier components



Source: Prepared by the authors.

Note: For Brazil and South Africa data are for 2005, while for China and the Russian Federation data are for 2000.

Generally speaking, the absolute values of the multipliers are higher than those presented by Hauknes and Knell (2009) for OECD countries, which is consistent with the role played by each set of countries in terms of their proximity to the technology frontier. Using that criterion, China would be the highest user of foreign technical knowledge. However, as our data for China are for the year 2000, its technology multiplier can be expected to have decreased in recent years, as the ratio of R&D expenditure to gross domestic product (GDP) between 2000 and 2009 almost doubled, rising from 0.90% to 1.70%. At the same time, Brazil, the Russian

Federation and South Africa showed a more modest evolution in terms of R&D expenditure during the 2000s (see annex figure A.1(a)), which could prolong their status as technology users.

The Russian Federation shows the lowest absolute value for the technology multiplier, reflecting the country's historical conditions, in which large investments were made in constructing science and technology systems and developing high-technology sectors, such as electronics, for military use. Several authors, such as UNIDO (2012) and Gokhberg and others (2011), have highlighted the importance of the former Soviet Union to current Russian innovation capacity, despite the country's low investment in R&D in relation to other emerging countries in the 2000s.

For all of the countries, except China, own R&D exceeds 40% of total technology intensity. R&D in foreign capital goods represents 8% of technology intensity in Brazil and 11% in South Africa, but only 5% in China and 2% in the Russian Federation. Conversely, the percentage participation of domestic components is, strikingly, over 60% for all countries. South Africa and China recorded the highest multipliers, although their domestic components proportion is the lowest: 66% and 63% respectively. The Russian Federation, on the other hand, shows the highest proportion (91%) and the lowest multiplier.

Hauknes and Knell (2009) developed the methodology used in this paper but studied only developed countries (France, Germany, Norway, Sweden and the United States) in 2000. For that purpose, the authors used OECD input-output tables and the ANBERD R&D data.

When comparing the composition of these countries' technology multipliers with that of the developed countries studied by Hauknes and Knell (2009), we can see that, in both cases, own R&D is the most important multiplier component. On the other hand, technology dependence is evident, particularly for Brazil, China, and South Africa, when the share of R&D embodied in imported capital goods is, on average, much smaller in developed countries than in emerging countries. Although the R&D embodied in inputs and capital goods is a way to assess the R&D produced at the technological frontier, the low level of internal R&D can jeopardize effective technological learning, as discussed in section II.

Table 1 disaggregates the information contained in figure 1 by sector. The results are also derived from equation (5). In line with figure 1, table 1 confirms that own R&D is the most important component in most sectors, except when the multiplier shows a high magnitude. Own R&D is less expressive in cases such as services in Brazil and China or in traditional sectors in China, the Russian Federation and South Africa. A similar pattern among the emerging countries is that traditional and service sectors show lower own R&D intensity in general. In Brazil and the Russian Federation, KIBS sectors are among those with the highest own R&D intensity.

Based on the hypotheses put forward in sections II and III, we would expect that in some sectors, even those that are science-based, the absolute value of the technology multiplier would be higher than in other economic sectors of emerging countries, owing to external absorption of knowledge resulting from R&D.

In China and the Russian Federation, the science-based and KIBS sectors show, in general, the lowest values relative to other sectors, indicating that they are producers of technological knowledge, based on the value of the technology multiplier by sector (see table 1). In Brazil, however, the science-based sectors are more users than producers of knowledge and are in a worse situation than most other sectors. This reveals weaknesses in the pharmaceuticals and electronics sectors, in line with the weight of imports in those fields, as can be seen in the third and fifth columns of table 1, where the figures for foreign R&D in inputs and capital goods are higher for the science-based sector, and in annex table A.3, where imports account for 32% of the gross output of the sector in 2005.

In sectors with lower total technology intensity, we found the same pattern as for the OECD countries studied by Hauknes and Knell (2009). However, a striking difference between OECD and emerging countries is the great relative distance between leading sectors in own R&D (which are always science-based) and the other sectors in the taxonomy. Furthermore, the R&D intensity of specialized suppliers, scale-intensive industries and KIBS is in-between that of science-based sectors and of traditional and service sectors in the developed countries.

In general, these differences between emerging and developed countries are evidence of the scant presence of science-based sectors in the industrial structure of emerging countries. These sectors in emerging countries are ill-equipped to carry out their own R&D, and the absolute value of the multipliers reflects this.

In contrast to developed countries, in some cases, science-based sectors in emerging countries have higher multipliers compared with energy, traditional and materials sectors, except in China and the Russian Federation. Thus, in terms of technological knowledge production, taking into consideration the absolute value of the technology multiplier, we can affirm that there is no sectoral hierarchy similar to that observed in developing countries. In the emerging countries, science-based sectors show higher R&D dependence on input and capital goods suppliers, both domestic and foreign, than science-based sectors in developed countries, as is evident when table 1 is compared with the results from Hauknes and Knell (2009). This holds true especially in Brazil and South Africa, while in China and the Russian Federation the status of the science-based sector is similar to that of its counterparts in developed countries, with a lower absolute value for the technology multiplier.

TABLE 1

Selected emerging countries: total R&D content and technology multiplier by sector

		Own R&D	R&D in domestic inputs	R&D in imported inputs	R&D in domestic capital goods	R&D in imported capital goods	Total embodied R&D	Technology multiplier
Brazil	1. Energy	0.0030	0.0015	0.0007	0.0003	0.0000	0.0056	1.88
	2. Traditional	0.0008	0.0020	0.0001	0.0003	0.0000	0.0032	3.86
	3. Materials	0.0023	0.0031	0.0020	0.0004	0.0000	0.0079	3.41
	4. Scale-intensive	0.0095	0.0019	0.0040	0.0025	0.0011	0.0190	2.01
	5. Specialized-supplier	0.0076	0.0039	0.0014	0.0026	0.0038	0.0194	2.55
	6. Science-based	0.0106	0.0034	0.0157	0.0034	0.0042	0.0373	3.52
	7. Services	0.0003	0.0017	0.0006	0.0001	0.0000	0.0026	10.11
	8. KIBS	0.0202	0.0007	0.0006	0.0011	0.0001	0.0227	1.12
China	1. Energy	0.0011	0.0011	0.0002	0.0001	0.0000	0.0026	2.29
	2. Traditional	0.0005	0.0015	0.0003	0.0002	0.0000	0.0026	4.85
	3. Materials	0.0021	0.0014	0.0014	0.0004	0.0000	0.0054	2.52
	4. Scale-intensive	0.0038	0.0015	0.0021	0.0008	0.0004	0.0085	2.27
	5. Specialized-supplier	0.0042	0.0020	0.0132	0.0011	0.0009	0.0214	5.14
	6. Science-based	0.0125	0.0023	0.0049	0.0012	0.0020	0.0228	1.83
	7. Services	0.0003	0.0017	0.0002	0.0000	0.0000	0.0022	7.88
	8. KIBS	0.0021	0.0021	0.0000	0.0001	0.0000	0.0043	2.02
Russian Federation	1. Energy	0.0002	0.0032	0.0007	0.0000	0.0000	0.0040	20.67
	2. Traditional	0.0003	0.0019	0.0015	0.0001	0.0000	0.0037	14.47
	3. Materials	0.0008	0.0019	0.0018	0.0001	0.0000	0.0045	5.70
	4. Scale-intensive	0.0395	0.0025	0.0064	0.0007	0.0002	0.0493	1.25
	5. Specialized-supplier	0.0061	0.0040	0.0031	0.0017	0.0021	0.0169	2.75
	6. Science-based	0.0289	0.0072	0.0007	0.0001	0.0000	0.0371	1.28
	7. Services	0.0015	0.0023	0.0013	0.0002	0.0000	0.0053	3.47
	8. KIBS	0.0811	0.0016	0.0001	0.0149	0.0021	0.0997	1.23
South Africa	1. Energy	0.0053	0.0013	0.0013	0.0007	0.0001	0.0086	1.64
	2. Traditional	0.0006	0.0019	0.0009	0.0002	0.0000	0.0036	5.94
	3. Materials	0.0027	0.0015	0.0037	0.0008	0.0005	0.0092	3.35
	4. Scale-intensive	0.0049	0.0018	0.0035	0.0011	0.0010	0.0124	2.51
	5. Specialized-supplier	0.0056	0.0027	0.0040	0.0012	0.0011	0.0146	2.61
	6. Science-based	0.0316	0.0022	0.0137	0.0067	0.0103	0.0645	2.04
	7. Services	0.0023	0.0007	0.0006	0.0007	0.0000	0.0044	1.89
	8. KIBS	0.0017	0.0019	0.0003	0.0001	0.0000	0.0041	2.43

Source: Prepared by the authors.

The structure of the Russian Federation is more similar to that of more developed countries, as science-based sectors, KIBS and scale-intensive sectors are considered technology producers and technology multipliers have the lowest values. The legacy of the former Soviet Union explains these indicators. However, the ratio of R&D expenditure to GDP has been declining since 2003, which could jeopardize the country's status as a knowledge producer in these sectors (see annex figure A.1).

Table 2 shows intersectoral knowledge flows. Hauknes and Knell (2009) created their matrix of flows using the variational principle in disaggregated intermediate input-output flows. However, as our matrix was already disaggregated into eight technological groups, we used the net flow as a reference. Hence, if the value is equal to zero, there is a bidirectional flow. If the value is negative, the flow is strictly from the sector in the column to the sector in the row; whereas, if the value is positive the inverse is true: the flow is strictly from the sector in the row to the sector in the column. Some patterns emerge from these findings, such as the flow from the energy sector to the traditional sector, except in the case of the Russian Federation, where it is bidirectional.

TABLE 2

Selected emerging countries: intersectoral net flows, weighted by R&D

		1. Energy	2. Traditional	3. Materials	4. Scale-intensive	5. Specialized-supplier	6. Science-based	7. Services
Brazil	1. Energy							
	2. Traditional	-0.2						
	3. Materials	-0.1	0.2					
	4. Scale-intensive	0.1	0.8	0.5				
	5. Specialized-supplier	0.0	0.1	0.0	-0.2			
	6. Science-based	0.0	0.1	0.0	-0.1	0.0		
	7. Services	-0.5	-0.1	-0.1	-0.8	-0.2	-0.2	
	8. KIBS	0.3	0.6	0.3	0.1	0.1	0.1	3.7
China	1. Energy							
	2. Traditional	-0.2						
	3. Materials	0.1	0.4					
	4. Scale-intensive	0.1	0.6	0.1				
	5. Specialized-supplier	0.2	0.4	0.0	0.0			
	6. Science-based	0.1	0.3	0.0	0.0	0.0		
	7. Services	-0.3	-0.2	-0.5	-0.8	-0.9	-1.7	
	8. KIBS	0.0	0.1	-0.1	-0.1	-0.1	-0.3	0.3
Russian Federation	1. Energy							
	2. Traditional	0.0						
	3. Materials	0.0	0.2					
	4. Scale-intensive	1.8	2.3	0.5				
	5. Specialized-supplier	0.5	0.7	0.1	-0.1			
	6. Science-based	0.3	0.4	0.1	-0.1	0.0		
	7. Services	1.3	0.7	0.2	-0.3	-0.1	0.0	
	8. KIBS	9.6	2.0	0.9	0.0	0.3	0.0	0.8
South Africa	1. Energy							
	2. Traditional	-0.8						
	3. Materials	-0.1	0.4					
	4. Scale-intensive	-0.1	0.1	0.0				
	5. Specialized-supplier	-0.1	0.1	-0.1	0.0			
	6. Science-based	0.0	0.1	0.0	0.0	0.0		
	7. Services	0.0	0.8	0.1	0.0	0.1	0.0	
	8. KIBS	-0.1	0.1	0.0	0.0	0.0	-0.1	-0.5

Source: Prepared by the authors.

The KIBS group comprises services that are science- and technology-intensive, such as informatics, R&D and other business services. In Brazil and the Russian Federation, there is a flow from this sector to the others. In China and South Africa, such flows are, in general, inverted, which indicates lower technological capacity than other sectors in the production structure.

While the science-based sectors flows are predominantly in the expected direction (positive), there are also numerous bidirectional flows, indicating that other sectors are also suppliers of technological knowledge to the science-based sectors. This finding differs from the situation in developed countries, where positive flows prevail, as science-based sectors are primarily suppliers of technological knowledge (Hauknes and Knell, 2009).

Specialized supplier's flows go towards more basic sectors (energy, traditional and materials) in China and the Russian Federation. In Brazil and South Africa the flow is from specialized suppliers to traditional sectors, while the flow to energy and materials is bidirectional in Brazil and inversed in South Africa.

On the other hand, in Brazil, China and the Russian Federation, the direction of technological flows between specialized suppliers and scale-intensive sectors appears to be inverted, as those sectors provide the technology used by the suppliers. This flow direction is the same as in Germany and the United States, as observed by Hauknes and Knell (2009).

The scale-intensive sectors are the chemical, metallurgy, shipbuilding, and car, aircraft and railway rolling-stock manufacturing industries. With regard to gross output, these sectors have a 9.8%, a 3% and an 11% share, in Brazil, the Russian Federation and China, respectively, while specialized suppliers have a share of 3% in Brazil, 9% in the Russian Federation and 10% in China. This indicates that these sectors do not account for a large proportion of production in these emerging countries compared with other sectors (annex table A.3).

However, the same cannot be said when the share of R&D in each sector relative to total R&D expenditure is analysed. For this ratio, the scale-intensive sectors are very important in terms of innovation and investment, accounting for 31% of R&D in Brazil, 23% in the Russian Federation and 20% in China. On the other hand, specialized suppliers account for 7% of R&D in Brazil, 11% in the Russian Federation and 19% in China. Added together, the two groups make up more than one third of R&D in each country.

Although there is, in general, some heterogeneity in the direction of technological knowledge flows among the emerging countries, the following similarities can be identified:

(i) Sectors considered intermediate in the use and diffusion of technological knowledge (specialized suppliers and scale-intensive sectors) play a very important role in the production of this knowledge in developed countries. In developing countries, these sectors sometimes overtake those considered to be high-technology sectors, when the technology multipliers are considered. This situation reflects the history of industrialization and technological dependence in developing countries.

(ii) The energy sector in Brazil, China and South Africa is more a producer than a user of knowledge, based on the technology multiplier and the direction of flows. In the Russian Federation, while the sector accounts for a higher share of production, it is more a user than a producer of technological knowledge (12% of gross output and 0.7% of R&D expenditure). This finding confirms that Brazil, China and South Africa have a technological opportunity with regard to the energy sector.

(iii) The science-based sector has high multipliers and does not follow the sectoral hierarchy of developed countries, particularly in Brazil and South Africa. With regard to the direction of technology flows, according to Pavitt (1984) the expected direction is observed in some cases, but the most common pattern is bidirectional flows. This finding contrasts with what Hauknes and Knell (2009) observed in developed countries, where the science-based sector is primarily a technology supplier. This reflects the technological dependence of emerging countries.

(iv) KIBS behave as expected in Brazil and the Russian Federation, that is, as technology suppliers, but behave differently in China and South Africa. Despite the significant growth in the tertiary sector in South Africa since 1994, the country's level of education is still low, which negatively affects the performance of sectors such as KIBS (UNIDO, 2012). In China, on the other hand, industrial development deepened in the 2000s, favouring the growth of the capital goods sector. Both cases differ from Brazil, where, although the industrialization process did not culminate in the full development of the capital goods sector, there was some development of modern and knowledge-intensive services to support industries.

VI
Conclusions

Given the increasing relative importance of some emerging countries, including Brazil, China, the Russian Federation and South Africa, in technology production and diffusion, we sought to contribute empirically to the discussion on this matter, as the comparative literature on these countries' national innovation systems is scarce. Therefore, we calculated different indicators, such as technology multipliers, total R&D content and technological knowledge flows. For that purpose, we used input-output matrices for Brazil, China, the Russian Federation and South Africa, and aggregated the sectors based on the taxonomy of Pavitt (1984) extended by Hauknes and Knell (2009).

Overall, our main findings pointed to disparities among the so-called BRICS countries (Brazil, the Russian Federation, India, China and South Africa).[8] In terms of total R&D content, technology multiplier and technological flows, the Russian Federation is closest to the results of developed countries, based on indicators from the year 2000. However, these indicators may worsen as a result of weak R&D expenditure during the 2000s.

Although net technological flows reveal some heterogeneity among developing countries, some common ground can be found. Our methodology allowed us to compare the direction of flows of these countries with those of developed countries, which revealed few similarities.

We were able to test all of our hypotheses, and had to reject the hypothesis that the sectoral hierarchy would be similar to that in developed countries. The hypothesis that technological flows in the emerging countries analysed would behave differently in the science-based, scale-intensive and specialized-supplier sectors was partially refuted, as the science-based sector is not a diffuser of technology to the economy. Moreover, in some cases, scale-intensive and specialized-supplier sectors assume a more important position in the sectoral hierarchy or in the direction of technological flows. Lastly, with regard to the hypothesis of technological opportunity, we can affirm that the emerging countries do not all show the same pattern, although there are some similarities, for example in the energy sectors in Brazil, China and South Africa.

Flows in sectors that are net receivers of technology, such as the traditional, materials and service sectors, behave similarly to those in developed countries. In sectors such as KIBS, the flow moves in the expected direction, but these sectors are heterogeneous across the four countries analysed. In Brazil and the Russian Federation, these sectors are net suppliers of technology, but this is not the case in China and South Africa, a finding that is explained by differences in the industrialization trajectories of each economy. The energy sector in emerging countries is very different from that in developed countries, as it is a supplier of technology in Brazil, China and South Africa.

The differences among the set of countries analysed support the view that the BRICS countries do not exhibit the homogeneity normally expected of a bloc of countries, particularly with regard to indicators of technology flow and sectoral capacity for production and use of technology.

Lastly, Hauknes and Knell (2009) point out that specialized-supplier and scale-intensive (medium-high and medium-low tech) industries are the most important industries for economic growth, and that high-tech services are important as they interconnect industry groups. On the basis of total embodied R&D and net flows, we can affirm that medium-tech sectors are relatively less important in Brazil and South Africa than in China and the Russian Federation. At the same time, KIBS appear to be more important in Brazil and the Russian Federation than in China and South Africa. Thus, we conclude that the Russian Federation is best positioned to achieve greater economic growth as a result of technological development, followed by China, Brazil and South Africa, in that order.

A future extension of this paper might evaluate the temporal dimension of the indicators of production and use of technological knowledge and of intersectoral flows, in order to take into account structural changes in the technology dynamics of emerging countries. Such an undertaking would depend on the availability and comparability of input-output and R&D data for all four countries (Brazil, China, the Russian Federation and South Africa). Another possible extension arises from the limitations of this paper, which only evaluates local technological efforts and diffusion of embodied technology by means of R&D expenditure. Other kinds of innovative expenditures (such as the purchase of machinery, training of workers, industrial projects, licensing and know-how acquisition) might be used, if such data were available.

[8] Some studies, such as that of Armijo (2007), argue that this acronym is not a good way to group these countries as an analytical category. Our findings corroborate that study from a technological perspective.

ANNEX

TABLE A.1

Reconciliation of input-output matrix and suggested classification

Input-output according to OECD	Classification
1. Agriculture, hunting, forestry and fishing	2
2. Mining and quarrying (energy)	1
3. Mining and quarrying (non-energy)	3
4. Food products, beverages and tobacco	2
5. Textiles, textile products, leather and footwear	2
6. Wood and products of wood and cork	2
7. Pulp, paper, paper products, printing and publishing	2
8. Coke, refined petroleum products and nuclear fuel	1
9. Chemicals, excluding pharmaceuticals	4
10. Pharmaceuticals	6
11. Rubber and plastics products	3
12. Other non-metallic mineral products	3
13. Iron and steel	3
14. Non-ferrous metals	3
15. Fabricated metal products, except machinery and equipment	4
16. Machinery and equipment, NEC	5
17. Office, accounting and computing machinery	6
18. Electrical machinery and apparatus, NEC	5
19. Radio, television and communication equipment	6
20. Precision and optical medical instruments	6
21. Motor vehicles, trailers and semi-trailers	4
22. Building and repairing of ships and boats	2
23. Aircraft and spacecraft	2
24. Railroad and transport equipment, NEC	2
25. Manufacturing, NEC, recycling (including furniture)	2
26. Production, collection and distribution of electricity	1
27. Manufacture of gas, distribution of gaseous fuels through mains	1
28. Steam and hot water supply	1
29. Collection, purification and distribution of water	3
30. Construction	2
31. Wholesale and retail trade, repairs	7
32. Hotels and restaurants	7
33. Land transport, transport via pipelines	7
34. Water transport	7
35. Air transport	7
36. Supporting and auxiliary transport activities, activities of travel agencies	7
37. Post and telecommunications	7
38. Finance and insurance	7
39. Real estate activities	7
40. Renting of machinery and equipment	7
41. Computer and related activities	8
42. Research and development (R&D)	8
43. Other business activities	8
44. Public administration and defence, compulsory social security	7
45. Education	7
46. Health and social services	7
47. Other community, social and personal services	7
48. Private households with employed persons, extra-territorial organizations and bodies	7

Source: Adapted from J. Hauknes and M. Knell, "Embodied knowledge and sectoral linkages: an input–output approach to the interaction of high- and low-tech industries", *Research Policy*, vol. 38, No. 3, Amsterdam, Elsevier, 2009.

Note: OECD: Organization for Economic Cooperation and Development.
NEC: Not elsewhere classified.

TABLE A.2

Harmonization between the Analytical Business Enterprise Research and Development database (ANBERD) and the Technology Innovation Survey (PINTEC), suggested classification

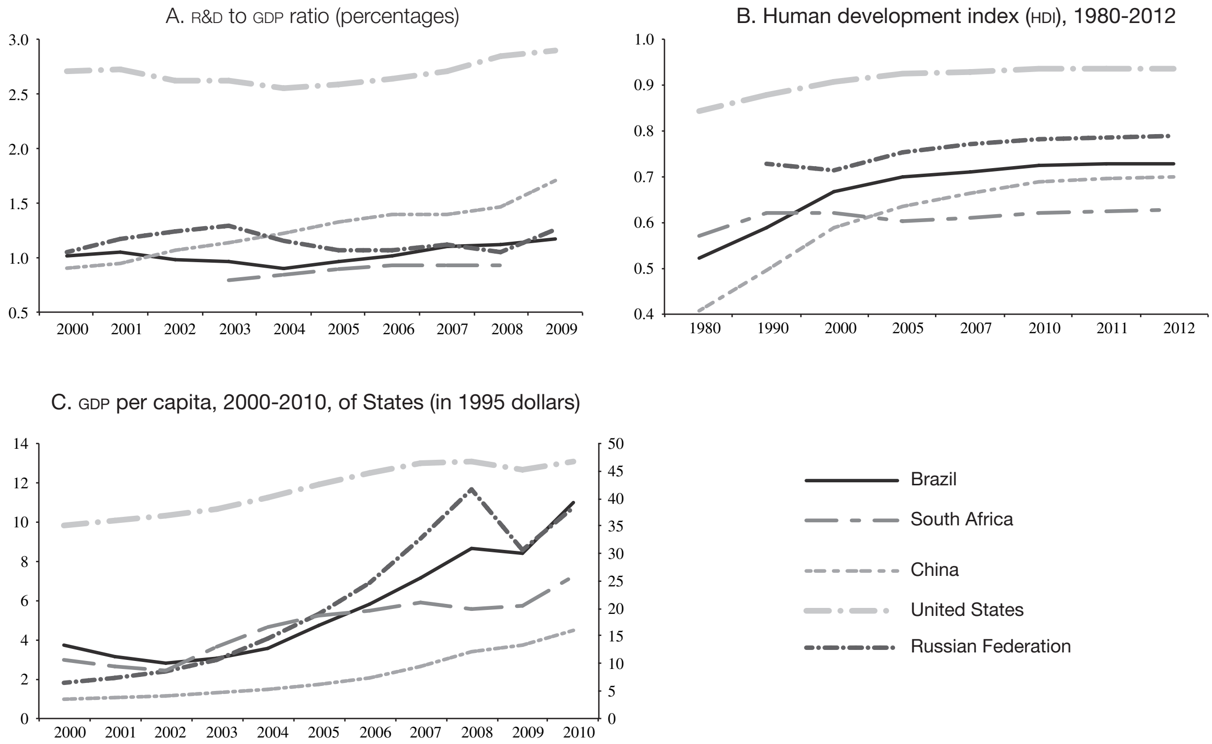
Classification (by sectors)	ANBERD	PINTEC (NACE 1.0)
1. Energy	23, 40	23
2. Traditional	15-22, 36-37, 45	15-22, 36-37
3. Materials	25-27, 41	25-27
4. Scale-intensive	24 (except 24, 23), 28, 34-35	24 (except 24.5), 28, 34, 35
5. Specialized-supplier	29, 31	29, 31
6. Science-based	24, 23, 30, 33	24.5, 30, 32, 33
7. Services	50-52, 55, 60-67, 70-71, 75-99	61
8. Knowledge-intensive business services (KIBS)	72-74	72-74

Source: Prepared by the authors.

Note: NACE: National Classification of Economic Activities (version 1.0). The numbers in the ANBERD and PINTEC columns correspond to their numbers in that database and survey.

FIGURE A.1

Selected countries: descriptive data



Source: Prepared by the authors.

Note: In figure (c), the values for the United States are on the right-hand scale and all values are expressed in thousands of dollars, at constant prices, deflated by the implicit price deflator of United States GDP.
R&D: Research and development; GDP: Gross domestic product.

TABLE A.3

Selected countries: share of gross output of each sector, imports as a percentage of total gross output and imports as a percentage of gross output by sector
(Percentages)

	Brazil			Russian Federation		
	Share of gross output	Imports/total gross output	Imports/sector gross output	Share of gross output	Imports/total gross output	Imports/sector gross output
1. Energy	9.4	1.0	10.2	12.0	0.5	4.1
2. Traditional	21.2	0.5	2.3	25.0	4.2	16.9
3. Materials	5.8	0.5	8.3	8.8	1.0	11.7
4. Scale-intensive	9.8	1.4	13.8	3.0	0.8	26.7
5. Specialized-supplier	3.1	0.7	20.8	9.4	3.1	32.9
6. Science-based	3.2	1.0	32.1	0.3	0.1	26.7
7. Services	43.8	0.9	2.1	39.7	1.0	2.6
8. KIBS	3.7	0.3	7.5	1.8	0.1	5.4
	China			**South Africa**		
	Share of gross output	Imports/total gross output	Imports/sector gross output	Share of gross output	Imports/total gross output	Imports/sector gross output
1. Energy	8.3	0.6	7.5	10.8	1.5	14.2
2. Traditional	33.0	1.2	3.6	17.7	1.5	8.5
3. Materials	11.2	0.9	7.9	14.5	3.6	25.2
4. Scale-intensive	11.1	1.3	11.8	6.4	2.3	36.2
5. Specialized-supplier	10.2	1.9	18.4	1.1	0.3	26.7
6. Science-based	5.0	0.9	17.2	1.3	1.0	74.3
7. Services	17.5	0.2	1.3	44.3	1.1	2.5
8. KIBS	3.7	0.0	0.0	3.9	0.3	7.4

Source: Prepared by the authors.

Note: Calculations based on input-output matrices. The share of gross output represents the gross output of each sector divided by the sum of gross output of all sectors. The imports to total gross output ratio is imports from the sector divided by the sum of gross output of all sectors. The imports to sector gross output ratio is imports from the sector divided by the gross output of the sector.

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