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Explanatory notes

- Three dots (...) indicate that data are not available or are not separately reported.
- A dash (-) indicates that the amount is nil or negligible.
- A full stop (.) is used to indicate decimals.
- The word “dollars” refers to United States dollars, unless otherwise specified.
- A slash (/) between years (e.g. 2013/2014) indicates a 12-month period falling between the two years.
- Individual figures and percentages in tables may not always add up to the corresponding total because of rounding.

Technological change and employment in Latin America: opportunities and challenges

Jürgen Weller

Abstract

The debate about what kind of impact current technological changes will have on employment is marked by a high degree of uncertainty, as is clear from the existence of widely differing estimates of the possible extent of job destruction. This article looks at various contributions to the analysis of how labour markets may be restructured and different projections of job destruction, job creation and changes in the nature of employment. A comparative consideration of the available evidence for developed countries and for the Latin American and Caribbean region based on a conditioned contextual approach leads to the conclusion that the impact of new technologies in the region will be shaped in part by the structure of production and of the labour market, the development of infrastructure and the relevant capacities of different sorts. Challenges in two areas of key importance in realizing the potential of new technologies to contribute to a sustainable development process and greater equality are then examined: workforce skills and competencies, and the regulation of labour relations.

Keywords

Employment, labour market, technological change, automation, unemployment, job creation, employment forecasting, labour relations, manpower, employment statistics, Latin America

JEL classification

J23, J24, O33

Author

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I. Introduction

The technological changes taking place today and those that are likely to occur in the near future are influencing a wide range of production activities and are opening up enormous opportunities for furthering development and attaining greater well-being, but they are also posing challenges and threats, especially in the area of employment. This combination of opportunities and challenges gives rise to a great deal of uncertainty which is, in turn, being reflected in widely divergent estimates of the possible extent of job destruction.

There is no doubt whatsoever that these technological changes will have a powerful impact on job destruction and creation and on future job profiles and the types of job skills that will be required. Employment relationships will also be altered as modifications in production processes drive the emergence of new modes of organization in both wage employment and emerging modalities of work.

The magnitude of these challenges is reflected, for example, in the oft-cited estimate that 65% of the children who are starting school now will have types of jobs and functions that do not even exist today (McLeod and Fisch, cited in World Economic Forum, 2016, p. 3). This underscores the challenges facing the region's education and vocational training systems.

While technological change is not the only process that will influence employment in the future, all of these elements will have a huge impact on the well-being of workers and society as a whole and on the associated distribution of benefits and costs.

In this article, the ways in which ongoing or future technological changes may influence labour markets will be explored from a conditioned contextual perspective, which posits that their impact will depend in large part on the decisions made by the actors concerned, although the range within which corresponding actions can be taken is determined by the characteristics of the technologies in question. This approach differs from the compensatory school of thought, which holds that the operation of the market will result in the creation of new jobs that will make up for the initial round of job destruction, and from the deterministic line of thought, which asserts that the impact on employment of technological change is solely determined by the characteristics of the technologies in question.

The following section sets out a number of general considerations regrading the impact of technological change on employment, while the third section reviews the recent literature on the subject. The fourth section covers job creation and destruction projections at the global level and specific projections for Latin America. The fifth section takes a closer look at two key areas for public policies aimed at influencing the employment impact of technological change: the regulation of new types of employment relationships; and skills-building and the development of areas of competence. The main conclusions drawn from this analysis are presented in the final section.

II. General considerations

Owing to the potential of technological changes to provide substitutes for human labour, such changes usually spark concerns about the emergence of a technology-driven surge in unemployment, on the one hand, and, on the other, expectations of improvements in the quality of life thanks to steep reductions in the amount of time people spend at work (Mokyr, Vickers and Ziebarth, 2015). As for the first aspect, Tarabusi (1997) differentiates among three types of unemployment on the basis of its causes and duration: short spells of unemployment caused by incremental technological changes at the company level; medium-term unemployment resulting from a major change at the sectoral level; and long-term unemployment brought about by a technical/economic paradigm shift in the economy as a whole. With regard to the second aspect, it suffices to recall the optimism expressed by Keynes, who, although he warned about the threat of technology-based unemployment, welcomed the technological changes of his time for their long-term impact on the quality of life of future generations.[1]

Technological change played a pivotal role in the development of capitalism in the nineteenth and twentieth centuries, mainly by spurring strong productivity gains thanks, for example, to the increasingly widespread use of electric and steam energy and the combustion engine, the various new machines that were being introduced in the textile industry and the appearance of the assembly line. As markets became more and more integrated, these increases in productivity (and, as a result, in competitiveness) created incentives for the introduction of these new technologies and —with the exception of certain specific niche markets— made it impossible for producers to remain competitive if they continued to use the older technologies. These technological advances consequently led to the elimination of jobs in occupations linked to production processes that were becoming obsolete.

These technologies did not only take the place of older ones that had been used to make the same products, however; they also opened the way for the appearance of a vast array of new products both by altering production and distribution processes and by bringing about changes in the way households were run (Gordon, 2016). As all this was taking place, a large number of new jobs were created that made up for the job losses caused by labour-saving technologies, and the earlier concerns that technological change would result in rampant unemployment were therefore not borne out in aggregate terms. In addition, thanks to social and political struggles, a number of positive changes were made in working conditions, such as the shortening of the workday and wage increases, which were facilitated by new productivity gains.[2]

The technological changes taking place now revolve around developments in such areas as quantum computing, the Internet of Things, cloud interconnectivity, robotics, big data, self-driving vehicles and artificial intelligence (ECLAC, 2017). This study will focus specifically on the sweeping changes brought about by information and communications technologies (ICTs) and the cognitive sciences and their related technologies, which, by bringing about the "universalization of the digital economy", have had the greatest impact up until now and are expected to continue to do so in the new future (ECLAC, 2016, pp. 60–62).

Current developments are not confined to specific sectors but instead are having an impact on all branches of activity, which are becoming increasingly integrated as the dividing lines between them become more and more blurred. The demarcation between the secondary and tertiary sectors is becoming fainter and fainter; for example, goods producers are finding that they have to incorporate services into their offerings, and in the case of ICTs, the production of hardware and software is becoming increasingly integrated.

The impact of new technologies on production processes is brought about by "the creation of digital goods and services, the addition of value by incorporating digital features into goods and services that in principle are not digital; and the development of production, exchange and consumption platforms" (ECLAC, 2016, p. 59). Schwab (2016) asserts that there are at least three reasons why today's transformations do not simply represent a prolongation of the third industrial revolution: their

[1] Keynes saw the grand task of the future to be learning how to use free time wisely in order to lead a good life: "For many ages to come the old Adam will be so strong in us that everybody will need to do some work if he is to be contented. We shall do more things for ourselves than is usual with the rich to-day, only too glad to have small duties and tasks and routines. Three-hour shifts or a fifteen-hour week may put off the problem for a great while. For three hours a day is quite enough to satisfy the old Adam in most of us!" (Keynes, 1930, quoted in Mokyr, Vickers and Ziebarth, 2015, p. 41).

[2] In a number of European countries, these technological changes coincided with a steep increase in the population (owing to the combination of high birth rates with a sharp decrease in mortality rates, especially infant mortality), which spurred mass emigration, especially to the Americas, in the nineteenth century and the first half of the twentieth. Without this "escape valve", the social and labour situation in many European countries would have become much more difficult than it did, which would have surely hampered the economic, social and political development of these countries.

velocity, scope and impact on production, management and governance systems. He goes on to maintain that the (in part as yet potential) breadth and depth of these changes thus herald the arrival of a fourth technological revolution.

What lessons can we learn from past experiences about the impact of technological change on the labour market? What approach should be used in analysing the possible impact of new technologies on the quality of employment and the quantity of jobs? Tarabusi (1997) identified three such approaches:

(i) The compensatory line of thinking posits that, in undistorted markets, the efficiency gains generated by technical changes translate into a stronger demand for consumer goods (because they become less expensive) and for capital goods (which are needed to incorporate those same technical changes), which, in turn, reduces unit wage costs and generates a greater demand for labour. The market therefore automatically compensates for the job losses caused by technical change.

(ii) The deterministic school of thought theorizes that technologies have intrinsic characteristics that will determine their impact and that there is no real scope for influencing the resulting job destruction or the job qualifications or skills for which they will create a demand.

(iii) The contextual line of reasoning is based on the idea that new technologies' quantitative and qualitative effects on employment will depend on the existing institutional and organizational framework. The impacts of technical change are thus seen as varied and dependent upon the nature of social and political processes at differing levels and the macroeconomic environment.

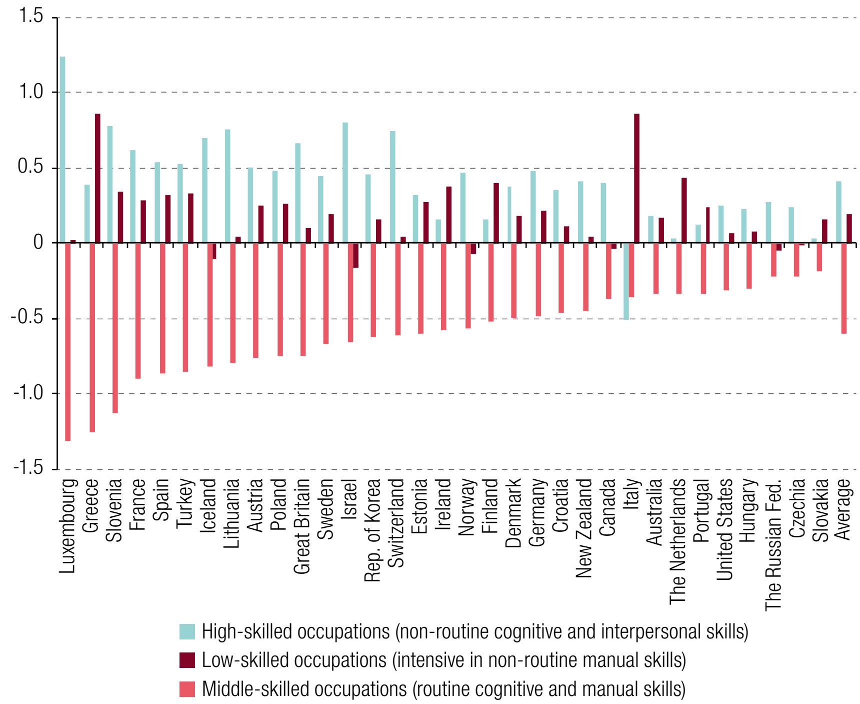
The analysis presented in this article is based on the idea that new technologies are usually not confined to a single type of use and that their implementation does not have a linear impact. The specific ways in which they are used are determined by regulatory mechanisms that are specific to each society. It is not denied, however, that in order for new technologies to be efficiently applied in competitive market economies, the nature of those technologies generally does impose certain lines of action and certain constraints. Thus, it is argued that a proper analysis should start out by taking a relativized contextual approach. (An absolute approach of this nature would lead to the conclusion that the institutional and organizational framework would permit an arbitrary use of the technologies in question.) Technological determinism, which maintains that there is no scope —either legal or on the basis of negotiations between employers and workers— for regulating the use of technologies is ruled out, as is the compensatory approach, since the idea is not for just any type of job to be created but rather productive and decent forms of employment, as envisaged in Sustainable Development Goal 8.

III. Recent trends: job destruction, job creation and changes in forms of employment

The debate about the future impact of new technologies should include an exploration of the changes that they have recently brought about in the labour market. The job destruction seen in developed countries in recent decades that has been brought about by various factors, with one of them being technological change, has primarily involved cognitively or manually routine functions. This has given rise to a polarization of the occupational structure, with the creation of jobs in occupations involving non-routine cognitively intensive activities (i.e. functions that can only be performed by highly educated persons) and jobs in occupations involving non-routine manual jobs that are generally performed by people with lower levels of formal education (see figure 1).[3]

[3] See the discussion on the polarization of the occupational structure in the United States in Acemoglu and Autor, 2012.

Figure 1
Developed countries: average annual variation in the percentage of types of employment involving different levels of qualification, from around 1995 to around 2012
(Percentage points)



Source: Prepared by the author on the basis of data from World Bank, *World Development Report 2016: Digital Dividends*, Washington, D.C., 2016.

For developed countries, on average, between around 1995 and 2012, occupations based on routine cognitive or manual tasks shrank by 0.6 percentage points as a proportion of total employment, while the share of jobs based on non-routine cognitive and interpersonal tasks or non-routine manual tasks expanded by 0.4 and 0.2 percentage points, respectively. This shift in the occupational structure is attributable to a variety of factors, one of which is technological change, as the increased use of ICTs in manufacturing and services is positively correlated with the proportion of jobs involving non-routine functions (OECD, 2017, p. 46).

This type of polarization is also found in low- and middle-income countries, although it is not as widespread as in the case of high-income countries (World Bank, 2016). Figure 2 depicts the results for the countries of Latin America and the Caribbean for which information is available.

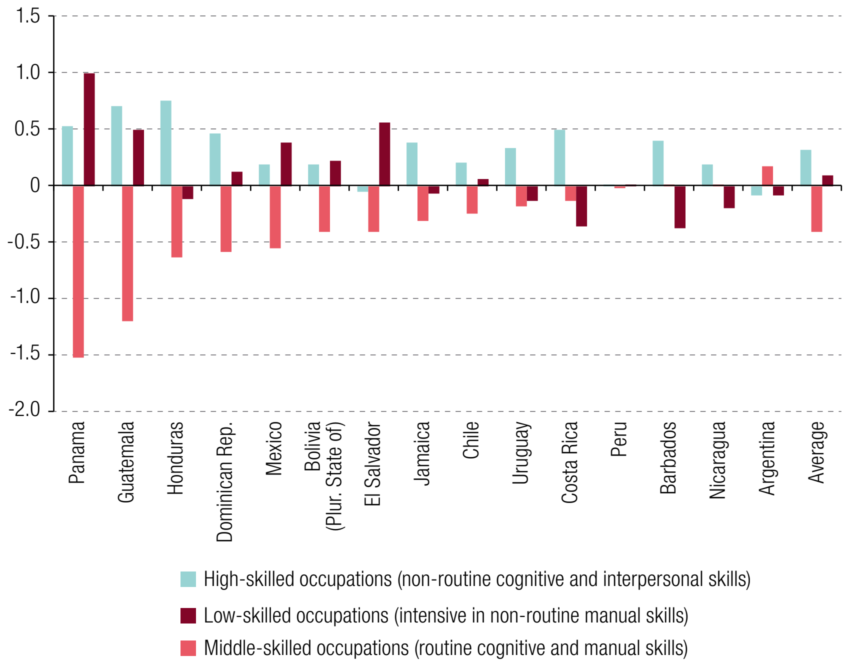
As an average for the countries of the region for which information is available, the intermediate segment's share in the occupational distribution slipped by 0.4 percentage points, while the share of the high-skilled and low-skilled segments expanded by 0.3 and 0.1 percentage points, respectively.

The results of a similar study of 30 countries in Latin America and the Caribbean covering the period 1995–2015 conducted by the International Labour Organization (ILO) (2016c, p. 55) were somewhat different. Although that study also showed that the highest growth rate (over 3.5% per year) was for occupations involving non-routine cognitive tasks, it found that highly routine occupations expanded more than non-routine manual ones (2.3% and 1.6%, respectively).[4] In any case, that study also pointed to a trend towards more highly skilled occupations. A study by Aboal and Zunino (2017)

[4] These figures are based on ILO calculations and estimates (2015) and include some larger countries not covered in the World Bank study, such as the Bolivarian Republic of Venezuela, Brazil and Colombia.

on the impact of innovation in the manufacturing industries of three Latin American countries also confirmed the existence of this trend, as in two countries (Argentina and Uruguay) innovation had a stronger positive impact on skilled job creation than on unskilled job creation, while, in Costa Rica, it had a very similar impact on both occupational categories.

Figure 2
Latin America and the Caribbean: average annual variation in the percentages of job categories, by skill level, around 1995 and around 2012
(Percentage points)



Source: Prepared by the author, on the basis of data from World Bank, *World Development Report 2016: Digital Dividends*, Washington, D.C., 2016.

As in previous technological revolutions, the job losses caused by technological changes are paired with the creation of new jobs, and the strength of this latter phenomenon has often been underestimated. Acemoglu and Restrepo (2016) contend that technological change and automation are precisely what is creating new increasingly complex occupations. According to these authors, between 1980 and 2007 approximately half of all the jobs created in the United States were in occupations that did not even exist in 1980. This would indicate that potential job creation is highly unpredictable. These authors also argue that self-correcting mechanisms are at work, as automation tends to depress wage levels, making the creation of new jobs more profitable, although goods market and labour inefficiencies may block that process and, if technological changes are of a type that speeds the development of new innovations, they may have a more adverse effect on labour. An empirical analysis carried out by those same authors led them to conclude that robots have had a significantly negative impact on local labour markets in the United States in terms of both the number of jobs and wage levels, which means that any possible compensatory effect has not been strong enough to result in the creation of an equal number and quality of jobs as those that have been destroyed (Acemoglu and Restrepo, 2017).

Graetz and Michaels (2017) confirm earlier findings that technological change has been associated with the low labour intensity of recent post-recession recoveries in the United States since 1990, especially in routine-intensive industries that are more exposed to automation. They did not, however, find this to be the case in other developed countries.

Aside from the structural aspects of these trends, the phase of the economic cycle also influences the immediate impact of technological changes in the aggregate. Depending on the prevailing circumstances in an economy (which are in part a result of the momentum generated by technological change), the loss of certain types of jobs may be counterbalanced to a greater or lesser degree by the emergence of new jobs. In the United States, Aaronson and Phelan (2017) found that, among low-wage jobs, those in which routine but cognitive tasks predominated were the most likely ones to be replaced. In a swiftly growing economy, many of the people who lost their jobs in these types of occupations succeeded in finding other employment but at lower pay levels.

Another example is provided by an empirical study by Hathaway and Muro (2016), who analysed the impact of the introduction of business platforms in the transportation and temporary housing rental sectors in the United States. They found that, as employment linked to those platforms expanded, not only did the numbers of jobs in more traditional activities in those industries not decrease but they actually rose, although more slowly.

Under certain circumstances, labour-saving technological changes actually promote job creation. Bessen (2015) cites the case of the introduction of automatic teller machines, which was supposedly going to result in a sharp reduction in financial service jobs and especially in bank teller positions. However, the restructuring and expansion of the business (in part owing to the cost savings brought about by that new technology) led to the creation of new types of tasks, and the number of bank employees actually rose.

Thus, employment trends reflect not only the impact of technological change but also the general situation in an economy. Developed countries are currently in a growth phase, but there is no guarantee that job creation will continue at its present pace. Nevertheless, it is clear that, viewed in dynamic terms, the impact of new technologies on employment is more complex than simply the replacement of people's jobs by machines or other types of work, as is usually argued by advocates of technological determinism.

IV. The outlook for changes in employment and in occupations

Before looking at the results of a number of studies on the impact of technological change on employment, it should be noted that, in addition to the macroeconomic situation, employment trends are also influenced by other long-term factors such as demographic changes, economic growth and the restructuring of production (e.g. changes in value chains and efforts to reduce various industries' carbon footprints).[5]

Some experts are of the view that the most endangered occupations will continue to be those that entail a large proportion of routine work. For example, the McKinsey Global Institute (2017a) has said that middle-skill jobs are the most susceptible to automation and specifically mentions physical activities in highly structured and predictable environments and the collection and processing of data as the areas under the most threat. Thus, technological change would appear to be maintaining the polarization of the occupational structure that has been seen, especially in developed countries, in recent times. KPMG International Cooperative (2016) projects that middle-income routine jobs are the ones that are most likely to be replaced by cognitive platforms in the future, while Manpower Group (2017) believes that low- and middle-skilled jobs are the ones under the greatest threat. What is clear is that,

[5] In the United States, the Bureau of Labor Statistics has projected that the largest numbers of new jobs created in 2016–2026 will be in the health-care industry, business and financial operations, food preparation and service, and personal care (cited in World Economic Forum, 2018). The McKinsey Global Institute (2017b) has estimated the net impact of automation and the number of new jobs that will be created as a result of a number of these trends for six countries with differing levels of per capita income.

as further changes take place in production and the labour market, the big losers will be people with low skill profiles, especially if there are obstacles that prevent them from acquiring the knowledge and skills required by the new job options that will be opening up.

Women may also be strongly affected by this changing landscape. Many women are employed in middle-skilled occupations —such as administrative jobs, sales and financial operations— that are threatened by new technologies, whereas they are underrepresented in university careers and some of the occupations that have a strong potential for expansion.[6]

Other researchers have focused on the cross-cutting impact of present and future technological changes on a wide range of occupations (Krull, 2016, p. 20). Some of them believe that, in addition to the routine activities that have been most affected by automation in the past, these changes will also affect jobs requiring intermediate or advanced qualifications, as well as middle- or low-skilled non-routine activities (e.g. in retail trade, transport and social services). Cases in point include the automation of many administrative tasks; expanding sensor capacity and cloud robotics, which may make machines much more mobile than they are today; artificial intelligence and the “deep learning” algorithms that function without human intervention; and probability-based decision-making processes, which are facilitated by the exponential growth of hardware technologies (Pratt, 2015).

The introduction of these new technologies is taking place in a globalized world where production has become internationalized, with global value chains being composed of production processes located in various countries. The consideration of the possible impact of technological changes should therefore take into account the ways in which value chains may be affected by these changes as well.

Two opposing trends can be observed in this respect. On the one hand, by reducing the cost of capital, new technologies are altering the relative prices that served as a basis for the development of these chains while at the same time increasing the importance of their cognitive components. What is more, the distance between each link in the chain and between its final component and its end market can become a problem. In this specific context, the importance of cheap labour as a factor of production may be lessened. For a few years now, there have been signs of the reversal of some offshoring processes, with certain types of production units being repatriated from low-wage countries to developed ones, especially as global economic growth slows (Kinkel, 2012; Saxer, 2017). As the growth of world trade slackens, these changes may be reflected in the strategies of many companies, as almost all labour-intensive industries that have not been automated have already been moved from developed countries to low-wage countries (Wolf, 2016; ILO, 2016a).

On the other hand, business platforms may facilitate the extension of the practice of outsourcing services such as administrative support, financial operations, sales and others to include skilled work in a wide variety of occupational areas. There are many different forms of outsourcing, ranging from the use of established teams to crowdworking or similar approaches. This may give rise to new types of global interaction in, for example, the area of problem-solving, that may be network-based rather than chain-based.

In recent years a series of quantitative estimates have been developed of technology-driven job destruction and job creation and of the net outcome. For developed countries, Frey and Osborne (2013) have made some of the most pessimistic projections, as they estimate that 47% of existing jobs in the United States may be replaced by technology in the not-too-distant future. Autor (2013 and 2015) questions these results, arguing on the basis of the “task approach” that a variety of tasks are bundled into many occupations and, if new technologies come into use that take the place of human labour for some of those tasks, that does not necessarily imply that the job itself will be eliminated in many

[6] See OECD (2017). The United States Bureau of Labor Statistics estimates that 57% of the jobs that will be done away with between 2016 and 2026 are held by women (cited in World Economic Forum, 2018). This marks a change from previous job losses, especially in manufacturing, which hit men the hardest (Miller, 2017).

cases. Since there is apparently a tendency for individual workers to perform a growing number of tasks, replacing an entire human worker with technologies that will automate specific tasks becomes a more complex undertaking.[7] Consequently, what may occur is that new combinations of ways in which these tasks are performed may arise (Akçomak, Kok and Rojas-Romagosa, 2016). Estimates of job destruction arrived at using this approach naturally are lower. For example, Arntz, Gregory and Zierahn (2016) estimate the proportion of jobs at high risk of substitution in the countries belonging to the Organization for Economic Cooperation and Development (OECD) at 9%.

The McKinsey Global Institute (2017a) also takes occupational and task differentiation into account in analysing the potential substitution of 2,000 activities spread across 800 occupations. That study found that around half of those activities could be automated by existing technologies (between 41% and 56%, depending on the country) but that less than 5% of those occupations could be entirely automated, while 60% of them have at least 30% of constituent activities that could be automated, leading to the conclusion that those occupations are more likely to change a great deal than to be automated away. The scenario that served as a basis for that study is one in which about 50% of those activities could be automated by 2055, but the authors emphasize that this time horizon may be influenced by a series of factors. In a later study by the McKinsey Global Institute (2017b), the same group of authors use a midpoint scenario in which 15% of the hours now worked worldwide would be automated by 2030, but they allow for a wide margin in which that number could vary from only slightly more than 0% up to 30%.

And what about Latin America? Few projections are as yet available. Using the methodology developed by Frey and Osborne (2013), the World Bank (2016) found that, of the 11 Latin American countries that it analysed, between 62% (Dominican Republic) and 75% (El Salvador and Guatemala) of jobs might be automated, with the average for the 11 countries being 67% (compared with 57% for the OECD countries). If the lag in the adaptation of new technologies typically found in less developed countries is taken into account, the range drops somewhat to the still quite high levels of between 40% (Nicaragua) and 65% (Argentina), with an average figure of 49% for the countries of the region.

Interestingly enough, while the unadjusted average for the Latin American countries is higher than the average figure for OECD, when the numbers are adjusted for the lag in switching production processes over to new technologies typical of poorer countries in which knowledge assets are in scarcer supply, then the average for Latin America is lower than the OECD average.

Also using the methodology of Frey and Osborne (2013), Aboal and Zunino (2017) arrive at similar results for Argentina (64.1% probability of automation) and Uruguay (66.4%), with slightly higher rates for men than for women.

OECD, the Andean Development Corporation (CAF) and ECLAC (OECD/CAF/ECLAC, 2016, p. 263) estimate the net loss of jobs for Latin America as a whole, based on data compiled by the World Economic Forum and ILO, at 3.38 million (between 1% and 2% of all jobs) by 2030. Projections place the losses chiefly in the manufacturing sector, with the destruction of around 3.5 million jobs; administrative and support positions, with a loss of around 1.3 million jobs; and the construction industry, which is expected to lose slightly over 1 million jobs. These losses will not be entirely offset by the projected gains in retail trade (slightly over 2 million new jobs), transportation (around 500,000) and other branches of activity.

Using the task approach to analyse a limited group of Latin American countries, McKinsey Global Institute (2017a) finds the highest percentages of automatable activities (over 51%) in Colombia, Costa Rica, Mexico and Peru, followed by Brazil, Argentina, Chile and the Dominican Republic

[7] Becker and Muendler (2014) found a sharp increase in the number of tasks that German workers report performing (a rise from 1.67 in 1979 to 7.24 in 2006, on average). The creation of global supply chains that break the production process down into specialized steps presumably works against this trend (see ILO, 2016a).

(between 45% and 47%). As mentioned earlier, the time horizon for these projections is 2055. For the updated base scenario used by the McKinsey Global Institute (2017b), that study puts the proportion of activities (not jobs) that will be automated between 2016 and 2030 at around 7% for Peru and around 14% for Brazil.

It should be remembered that the replacement of activities does not necessarily translate into job losses. If the estimate of the McKinsey Global Institute (2017a) of the impact of technological changes at the global level (5% of occupations become completely automatable) are applied to Latin America, then the region stands to lose around 14 million jobs in that time period.

However, the technological changes in question are unlikely to have any direct effect on the informal sector, since it generally employs technologies that are far from the leading edge of innovation or technology. If this structural difference between the labour markets of Latin America and developed countries is taken into account and the above percentage is applied only to sectors with intermediate or high levels of productivity, then the figure for job losses drops to approximately 8 million. This would be the minimum number of jobs replaced by technology, since, in addition to these completely automatable positions, other jobs that are not 100% automatable could still be subject to replacement.

Given the way the labour market operates in Latin America, Weller and Kaldewei (2014, pp. 68-72) posit that many of the people who lose their jobs will become employed in the informal sector if they cannot find work in other occupations in the formal sector, rather than remaining entirely unemployed or leaving the workforce altogether. The effect of the loss of a large number of formal sector jobs as a result of technological change is therefore likely to be an increased informalization of the occupational structure.

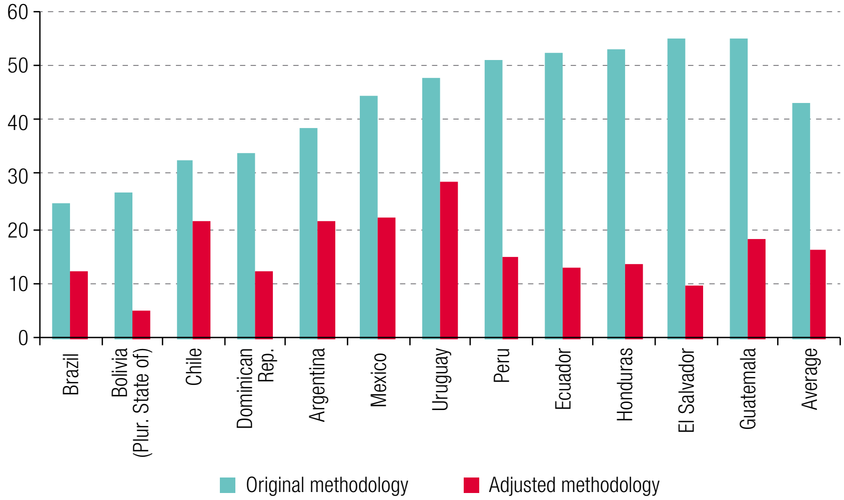
In line with these considerations, Weller, Gontero and Campbell (2019) adjusted the methodology of Frey and Osborne (2013) to take the structural differences between Latin American and developed-country labour markets into account. They found that, for a group of 12 countries in the region, the proportion of jobs at high risk of substitution drops from the range of between 25% for Brazil and 55% for El Salvador and Guatemala that was computed using the original methodology to a range of between 5% for the Plurinational State of Bolivia and 29% for Uruguay when the adjusted methodology is used; they also found that the proportion of jobs at high risk of being replaced by technology is greater in the Latin American countries with a higher per capita GDP and larger mid-and high-productivity sectors (see figure 3). The lower risk level for the region compared to developed countries is, however, a reflection of the continued existence of low-productivity sectors in which, for many workers, employment serves primarily to maintain their households at a subsistence level and which have little capacity for introducing new technologies or reallocating factors of production on a competitive basis, and the jobs that will be left in these sectors are typically of poor quality.

The studies discussed above, most of which are based on the opinions of experts or corporate managers, dovetail with the views of employees in formal sector enterprises. According to a survey conducted by Randstad (2016), in the Latin American countries that it covered (Argentina, Brazil, Chile and Mexico) between 45% of workers (Mexico), and 60% (Brazil) think that they perform repetitive work or routine tasks that could be automated. It is noteworthy that managers' and workers' assessments of the number of jobs that could be affected by automation are so similar and are higher than the worldwide average (44%). On the other hand, the proportion of Latin American workers who believe that, if their repetitive tasks were automated , they could add more personal value to their work, is also higher than the global average (between 70% and 74% versus 62%, respectively). This finding clearly reflects the optimistic view that the automation of routine tasks would boost the productivity and quality of jobs rather than destroying them.

Figure 3

Latin America: estimated proportion of jobs at a high risk of being replaced by technology based on the original and adjusted versions of the Frey and Osborne methodology

(Percentages)



Source: Prepared by the author, on the basis of J. Weller, S. Gontero and S. Campbell, "Cambio tecnológico y empleo: una perspectiva latinoamericana. Riesgos de la sustitución tecnológica del trabajo humano y desafíos de la generación de nuevos puestos de trabajo", *Macroeconomics of Development series*, No. 201 (LC/TS.2019/37), Santiago, Economic Commission for Latin America and the Caribbean (ECLAC), 2019.

Returning to the projections made by corporate experts, it is interesting to note that many Latin American companies have indicated that, in the very near future (a two-year time span), they expect to take on more employees as a consequence of the digitization of their operations. The eight Latin American countries covered by a survey conducted by the Manpower Group (2018) reported that they planned to hire more people, and Latin America was the most optimistic region of all in that respect. In contrast, a majority of the respondent companies in 7 out of a total of 23 European countries said that they expected a reduction in their workforce in response to digitization and, in those that did expect to hire more workers, the projected number of additional employees was smaller than in the case of the Latin American firms. This discrepancy between favourable expectations in the short run and a more negative outlook for the long term may be explained by the fact that, in a relatively brief period of time, many Latin American companies will need to incorporate new technologies into their production processes in order to remain competitive and will therefore need to hire ICT specialists, while the possible labour-saving impact of those technologies will be felt later on. In contrast, this process is already quite advanced in the developed countries. If this is the case, then this situation can be viewed as a reflection of the lag in the introduction and adaptation of new technologies that has long been a characteristic of the Latin American development process.

What specific factors play a part in the differentiation of the impact of new technologies in terms of job substitution in mid- and high-productivity sectors in Latin America? It must be remembered that not all tasks whose replacement is technologically feasible will necessarily be automated (Bensusán, Eichhorst and Rodríguez, 2017). The factors that influence the probability of a given job being replaced by technology can be summed up as follows:

$$PS = f\,(+\delta PL_i,\ +w_i,\ +PT_i,\ -C1_i,\ -C2_i,\ +I_i,\ +x_i)$$

where the probability of substitution (PS) of a given job in sector i rises in step with the productivity differential between the new and old technologies (δPL_i), the cost of labour (w_i) and the proportion of the tasks bundled into that job which lend themselves to substitution (PT_i). This probability declines, on the other hand, as the cost of introducing the new technology ($C1_i$) rises (this includes the cost of acquiring it, making any necessary adjustments, installing it, training employees to use it and any necessary modifications in the workplace, among others) and as the cost of maintaining and updating it ($C2_i$) increases.

The impact of the available capacity for technological innovation and adaptation and the available organizational capacity in an economy and a specific sector (I_i) is uncertain. On the one hand, the presence of a high level of innovation capacity tends to be accompanied by the introduction of more labour-saving technologies; on the other hand, if innovation capacity is low in occupations with a large proportion of automatable activities, it will be difficult to devise efficient ways of combining new technologies with the non-automatable tasks that still need to be performed by human beings. This will then pose the risk of a loss of competitiveness (in tradable goods and services) that would in turn destroy the jobs in question.

Finally, there is another set of factors (x_i) whose impact is uncertain. These factors include such aspects as outside infrastructure requirements, aspects specific to the sector concerned (e.g. expectations for growth and for changes in market structure and future technological development) and aspects specific to the company in question.

In the case of Latin America, where wages are low, much greater productivity gains would be needed in order for substitution to be profitable.[8] Furthermore, the capacity for technological and organizational innovation and adaptation is, on average, lower in the region than it is in developed countries and, in the case of many of the new technologies, the $C1_i$ and $C2_i$ costs are presumably higher owing, for example, to the costs associated with the importation of technologies and to the fact that adaptation costs may be higher as well because there are fewer specialists with the necessary expertise to introduce new technologies and to do the necessary follow-up work (e.g. maintenance and training). Finally, outside infrastructure may be needed that will require public investments that may not always be forthcoming.

Consequently, there are a number of factors that make it less likely that jobs will be replaced by new technologies in Latin America, as the gap between technologically possible and economically viable job substitutions is greater than it is in developed countries. However, while this indicates that fewer jobs are likely to be replaced by technology in the region, which would seem to be good news, the fact remains that this conclusion is based on the existence of economic lags and gaps (in infrastructure, innovation capacity, productivity and wages, for example) that the region should be attempting to close as part of the its sustainable development strategy.

Finally, an analysis of the relationship between technological change and employment must take indirect impacts into account as well. According to Berger, Chen and Frey (2017), job creation in the services sector via the multiplier effect of skilled job creation in the manufacturing sector is greater in developing than developed countries, which may lessen, in the aggregate, the impact of new labour-saving technologies.

V. Policies for guiding and supporting technological change

If the introduction of new technologies is viewed from a conditioned contextual perspective, it becomes clear that public policy has a pivotal role to play in various areas, ranging from technological development as such to the approaches to be used for incorporating technologies into production processes and mitigating their undesirable but unavoidable impacts.

[8] Persons employed in comparable occupations usually earn much lower wages in less developed countries (Freeman and Oostendorp, 2000).

The actual impact that these technological changes will have on employment in quantitative and qualitative terms will depend in large measure on how they are handled. Therefore, in many countries (especially developed ones), these processes are not left entirely in the hands of market forces. Instead, special programmes are put in place to promote their development and introduction into the production sector and society at large (Bensusán, Eichhorst and Rodríguez, 2017). This is an area of policy in which Latin America and the Caribbean lag far behind (Cimoli and others, 2017).[9]

Two areas of policy that are closely related to the impact of technological changes on employment will be discussed in this section: the regulation of labour relations, and the development of the skills and capabilities required to take advantage of their potential.[10]

1. The regulation of labour relations

The nature of labour relations varies widely across Latin America (Bensusán, Eichhorst and Rodríguez, 2017; Novick, 2018). This heterogeneity is the outgrowth of a number of different phases in the region's history. The informal sector has traditionally accounted for a large proportion of the jobs in the region's economies, and the concept of "atypical employment", as opposed to employment in the predominantly formal labour markets of developed countries that arose during the post-war period, is therefore not applicable to the region. The formal sector also includes a sizeable number of informal jobs, in many cases as a result of corporate cost-cutting strategies. Moreover, during the 1990s many Latin American countries introduced new types of formal employment that differ from the traditional type of full-time, permanent employment, such as part-time work and fixed-term contracts.

The technological changes now taking place have also given rise to new types of employment relationships in Latin America, such as those associated with the gig economy and the "sharing economy" (Artecona and Chau, 2017; IE/IDB/MIF, 2016). Thus, the technological changes now under way are giving rise to a trend towards increasingly heterogeneous ways of working that are posing new challenges for labour institutions.

Some of these new employment modalities tend to depress people's earnings, such as in the case of crowdworking, in which a company can seek inputs from an unregulated global source of supply. The "winner takes all" modality, in which an employer pays only for the work that turns out to be most useful for it, is an especially precarious one for workers, as all those involved except the "winner" go unpaid (Krull, 2016, p. 16).

In addition to the fact that, in many cases (although obviously not in all), the income streams from these new modalities are unstable, new technologies have also opened up new ways of monitoring workers (Krull, 2016, pp. 19 and 24). These technologies make it possible to generate huge amounts of data that facilitate an increasingly detailed tracking of workers' activities. Another increasingly important aspect (as in the case of Uber drivers, for example) is the ability to disseminate reviews of people's work, thereby creating a reputation that may provide —or block— access to job opportunities.

The pressure on people to remain connected with information networks at all times tends to be a source of overload and stress. What is more, the lack of full-time work may oblige people to hold a number of different jobs, interferes with the workings of traditional labour institutions and blurs the line between work and private life (OECD/CAF/ECLAC, 2016, p. 264). A number of countries (including many in Latin America) have therefore proposed legal initiatives for helping people to disconnect outside of working hours and to achieve a better work/life balance (*Diario Financiero*, 2017a).

[9] ECLAC (2016) has advocated linking these aspects with an increase in investment in what it has called an "environmental big push" in Latin America.

[10] Other relevant issues include, for example, fiscal policy and the possibility of levying a tax on robots (Shiller, 2017), the protection of people hurt by technological changes by guaranteeing a universal basic income (United Nations, 2017) and the possibility of shortening the workday (Mokyr, Vickers and Ziebarth, 2015).

The growing heterogeneity of types of employment has sparked a debate around the question of whether or not specific regulations need to be framed for the various types of relationships existing between workers, clients and employers or intermediaries (traditional employers, outsourcers, Internet business platforms and so forth) or if regulators should simply use certain key indicators to determine whether a person is a wage earner (albeit with certain specificities) or an independent or own-account worker (Bensusán, Eichhorst and Rodríguez, 2017; ILO, 2016b). Either option involves a number of complex tasks. In the first case, the challenge will be to design regulations for the new forms of work that comply with the mandates of labour institutions while offering an appropriate mix of efficiency and protection. In the second case, regulators would have to ensure that wage earners receive the benefits that they are entitled to under a country's labour laws while moving towards the formalization of independent work by clearly establishing the rights and duties associated with this occupational category.

Wage earners and their labour institutions are also encountering new challenges. For example, the question arises as to whether the automation of large segments of the production process undermines the right to strike (*Diario Financiero*, 2017b).

The analysis of the impact of technological changes on labour relations and the design of the corresponding regulations should be a participatory process that includes labour unions and workers in the activities where these new types of employment relationships are taking shape, along with corporate employers. It is often argued that the regulation of these activities can interfere with efforts to take advantage of the potential for boosting productivity. However, realizing that potential on the back of a reduction in the quality of employment will hinder the creation of virtuous circles of productivity, labour income and non-wage aspects of employment quality that serve as the foundation for the economic and social sustainability of the prevailing economic model.

Since there is no first-best solution for the implementation of new technologies (as advocates of technological determinism would argue), this needs to be the outcome of participatory efforts that provide a framework for a learning process. Bensusán, Eichhorst and Rodríguez (2017) assert that the application of labour regulations to new employment modalities should be based on negotiation and dialogue.[11] In this context, Sundararajan (2017) advocates the reformulation of the social contract to take account of the labour force's growing heterogeneity, while Adigital/GOVUP (2017) highlight the importance of cooperative efforts on the part of public agencies and platforms to facilitate the collection of taxes and social security contributions, the possibility of platforms functioning with a mix of types of employee relationships on the basis of agreements with workers, the need for a clear delimination of what constitutes own-account work, the establishment of wage and social protection floors, the importance of having third-party liability insurance schemes and the need to provide greater access to information on workers' and employers' rights and duties.

Participatory processes tend to result in more centrist, socially acceptable arrangements (neither total deregulation nor overly strict regulation). For example, on the one hand, a lack of regulation of platform-based passenger transportation businesses has led to the persons employed in those businesses to form movements of their own to protest poor working conditions and to demand suitable benefits; yet, on the other hand, the evidence indicates that many of the people taking part in these new modalities value the flexibility that they provide.[12] Another consideration is that people's views about the money they earn from these new types of arrangements differ depending on whether this is income that supplements the wages people earn from their main job and is earned in their free time or if it is a person's main source of income, in which case, aspects such as the variability of working

[11] Along these lines, the Ministry of Labour of Germany has underscored the importance of cooperation between employers and workers and has advocated the pursuit of a joint learning experience within the framework of this paradigm shift, using it as the starting point, and of a trial period to test out new concepts on an experimental basis (BMAS, 2017, p. 13).

[12] In a survey of the members of the German trade union Vereinte Dienstleistungsgewerkschaft (ver.di), own-account workers reported a high degree of satisfaction with their work, they also said that they were concerned about the instability of their incomes and about retirement (Koch, 2017).

hours or earnings are a much more important consideration. A final point is that there appears to be an increasing variability in the values that determine workers' preferences in terms of their forms of employment (BMAS, 2017, pp. 36–37).

2. Skills and capabilities required to take advantage of the potential of new technologies

While a great deal of uncertainty remains about the impact that technological changes will have on employment, there is a broad consensus that education and vocational and professional training are crucially important tools for capitalizing on the potential benefits of these changes and for limiting their negative impact.[13] With regard to the realization of these technologies' potential, it has been argued that the reason why labour productivity is rising so slowly in developed countries, despite the introduction of new technologies, is that few managers and few workers have the necessary knowledge and skills to take full advantage of them (Baily and Montalbano, 2016).[14] If this is the case, then once the bottlenecks are cleared away by the right kinds of training and education, major productivity gains can be made (and the lag in the realization of those gains will have been similar to the lags observed in other technological revolutions).

As a result of the job destruction and the disappearance of some occupations that this will entail, an undetermined number of people will lose a large part of their human capital and will therefore need to be retrained for other occupations. Experience has shown that this is not a smooth process (Miller, 2017). An interesting perspective has been presented by the World Economic Forum (2018), which suggests that people who lose their job may be retrained for an occupation that, according to certain criteria, is quite similar to their previous one.

There is a general consensus that the skills that people need in order to perform successfully in jobs involving the use of new technologies are primarily non-routine cognitive ones. However, recent studies indicate that the most important factor in the successful performance of such jobs is the possession of a combination of these skills with interpersonal and social skills (such as problem-solving and communication skills and teamwork) that cannot be readily replaced by new technologies (OECD, 2017; Edin and others, 2017; Manpower Group, 2018).

Unfortunately, comparative international studies indicate that the countries of Latin America and the Caribbean lag far behind both developed countries and some emerging ones in terms of basic skills (as measured by the OECD Programme for International Student Assessment (PISA) test) and the competencies needed in the workplace (as measured by the OECD Programme for the International Assessment of Adult Competencies (PIAAC)) (Fiszbein, Cosentino and Cumsille, 2016; OECD, 2017).

In both developed countries and in Latin America and the Caribbean, there appears to be a mismatch between the skills people acquire at school and in training courses, on the one hand, and the skills required on the job, on the other, as is attested to by employers' frequent complaints that they are unable to find people who have the qualifications that they need.[15] This mismatch is also evident in the high youth unemployment rates seen in Latin America and the Caribbean, even among highly educated young people. In order to address this problem, the skills that are and will be in demand need to be identified more accurately (Novick, 2017), the necessary adjustments need to be made in educational curricula and in professional and vocational training courses to align them with those skill

[13] See, for example, Fiszbein, Cosentino and Cumsille (2016); OECD (2017); World Economic Forum (2018); and Manpower Group (2018).

[14] Even in the OECD countries, there appear to be wide gaps between the skills that will be in demand in the future and the qualifications of today's workforce, as 56% of the adult population in those countries have no more than basic ICT skills or none at all (OECD, 2016).

[15] See, for example, the results of the Manpower talent survey: [online] https://www.manpowergroup.com/talent-shortage-2016.

requirements, and steps need to be taken to ensure that this information is then made available to all concerned, especially young people who are making decisions regarding their future studies (Gontero and Zambrano, 2018). As observed by Rathelot and Van Rens (2017), however, this mismatch should also be addressed from the demand side by improving the way labour markets function (including employers' wage-setting practices) so that the shortages of given skills are reflected more clearly in higher salaries.

The lag in the acquisition of some of the skills needed to use new technologies efficiently is mirrored in the generation gap, since younger generations are much more adept in this sense than older generations are (OECD, 2016). A workplace-centred, inter-company approach is needed in order to build on the skills of persons who are already in the workforce (OECD/ILO, 2017). On-the-job training is a good way to bring existing employees' skills into line with current demand. This can be coupled with sectoral initiatives coordinated by chambers of commerce or other employers' associations to allay individual companies' fears that, once they have retrained their employees, those people may leave for employment elsewhere. A three-pronged approach that also involves workers' organizations in identifying demand and appropriate training mechanisms —e.g. skills certification systems— has been shown to contribute to the effectiveness of these processes. Online learning options are another low-cost way to enhance training outcomes (Frey, 2017).

The underrepresentation of women in technology-related occupations with strong growth potential, which threatens to widen the existing gap between men and women in the labour market, underscores the need to mainstream a gender perspective into training efforts. There are two positive developments in this regard. First, while, international comparisons show that, among persons between the ages of 55 and 65, men generally have greater problem-solving abilities in a technology-rich environment than women do, the results are mixed when it comes to the 25–34 age group, with women outperforming men in roughly half of the countries. This would suggest that, in the younger generations, with their greater proximity to new technologies, this kind of differential will not be seen between men's and women's learning abilities in this type of environment (OECD, 2017, p. 107). Second, the wage premium for ICT-intensive tasks is greater for women than it is for men, which may encourage more women to acquire ICT skills (OECD, 2017, p. 48).[16]

VI. Concluding remarks

This analysis has taken a conditioned contextual approach to the assessment of the possible impact of technological changes on employment based on the belief that the compensatory, deterministic and unconditional contextual approaches do not capture the complexity of the technological, economic and social processes associated with these changes and thus do not provide useful insights for the formulation of public policies that will capitalize upon their development-enhancing potential and mitigate their negative impacts.

This having been said, in Latin America and around the world, a great deal of uncertainty persists as to the impact that new technological advances on employment and on the nature of work. It is known, however, that there will be some extent of job destruction as new technologies are brought into the workplace and as global value chains are restructured. According to what appear to be realistic estimates, net job destruction may amount to between 1% and 2% (3.38 million jobs) of total employment in Latin America by 2030 and to 5% of formal sector jobs (around 8 million jobs) by 2055. This, however, would be a minimum figure for job destruction relating to jobs that involve a large proportion of automatable tasks. A conditioned contextual line of reasoning would suggest that, setting aside jobs having a large number of automatable components, the net result in terms of job destruction and job creation will depend upon the actions of the parties involved, although they cannot act with absolute

[16] This does not mean that women in these professions earn more than men but rather that the wage gap between these women and women in other occupations is greater than the wage gap between men in ICT occupations and men employed in other types of activities.

freedom because their scope of action is conditioned by the characteristics of the technologies that become available as time goes on. Thus additional job losses will ensue if production processes —and particularly the human labour they involve— are not adapted to the emerging technological context and —as the opposite also holds true— if those technologies are not adapted to human beings.

In Latin America and the Caribbean, one of the obstacles to the introduction of new technologies is the low cost of labour, since the existence of cheap labour means that new technologies must trigger a bigger jump in productivity in order for it to be profitable to introduce them. Other obstacles include the cost of acquiring, maintaining and updating these technologies, the region's limited extent of innovation and adaptation capacity and its shortcomings in terms of infrastructure. These factors curb the pace of transition to new technologies, which, on the one hand, softens the impact of direct job destruction but, on the other, they also make it take longer to take advantage of the potential offered by these technologies and thus slow down new job creation.

It appears that, rather than actual job destruction, the greatest or most widespread impact of these technological changes will be seen in the changing nature of how people work and what kinds of jobs they perform. As new technologies are incorporated into the performance of certain tasks, they will have to be integrated into the varied set of tasks performed in any given job in different ways. This being so, education and training systems will have to adapt to the sweeping changes that these technological changes will bring in terms of the job skills that are in demand.

First, the knowledge and skills gaps that, according to comparative studies, put Latin America and the Caribbean at a disadvantage will have to be closed (ILO, 2016c). Given this situation and the differentiated impact that the introduction of new technologies appears to have on men and women, along with the biases existing in the region's education and training systems, the adoption of a gender perspective is essential.

Second, new technologies are opening the way for a much wider range of different forms of employment, which poses new challenges for the design of labour institutions that will realize the productive potential of these new ways of working without sacrificing workers' labour rights or job quality. In the specific case of Latin America, it appears that the loss of mid- and high-productivity jobs in the formal sector is more likely to give way to an increase in low-productivity employment in the informal sector rather than to an outright decrease in the number of employed persons.

It should also be borne in mind that technological changes are not the only kinds of changes that are taking place. The ageing of the population in many countries of the region is generating new types of needs that require an integrated response. In addition, major changes need to be made in the energy matrix and in production and consumption patterns in order to ensure that growth will be sustainable (ECLAC, 2016).

Thus, even if new technologies were not posing any threat to employment, Latin America would still need to make a series of structural changes in order to transform its production structure, and public policies focused on this objective will need to provide a framework for the incorporation of new technologies into that structure. New technologies could therefore allow the region to make a leap forward in its development process by enabling it to move closer to the production frontier without first having to become competitive in areas of production in which traditional technologies still predominate.

The complexity of this challenge and the need for policy sustainability call for a participatory approach that is in line with the compacts for equality, sustainability and structural change proposed by ECLAC (2014).

In the aggregate, it is difficult to estimate the net impact of technological change in terms of the number of jobs that will be eliminated and the number of new jobs that will be created. What is clear, however, is that there is a need to leverage human-technology interactions and adapt the workforce's skills and competencies to new demands and opportunities while at the same time addressing the threat of an intensification of existing and emerging inequalities and the new challenges that this poses for labour institutions.

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A comparative analysis of medicine prices in Latin America[1]

Roberto Álvarez and Aldo González

Abstract

This paper compares medicine prices in the six largest economies in Latin America. Using a panel-based econometric model with country fixed effects and controlling for variables related to the medicines' characteristics, the comparison covers 19,741 units sold during the 2010–2015 period and has been carried out at the wholesale and retail levels and by type of medication (innovative, branded generic and generic). At the aggregate level and at the retail pharmacy level, the classification from least to most expensive is: Peru, Mexico, Argentina, Chile, Colombia and Brazil. In innovative medicines, Argentina and Peru have the lowest prices. In branded generic medicines, Mexico and Argentina have the lowest prices, while for pure generics, Peru and Chile appear to be the least expensive. The classification does not change substantially if ex-factory prices are compared.

Keywords

Pharmaceutical industry, pharmaceuticals, prices, comparative analysis, econometric models, statistical data, Latin America

JEL classification

L16, L65

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I. Introduction

This paper compares medicine prices in different Latin American countries. Pharmaceuticals are a not inconsiderable proportion of health spending and as such is an issue that has been analysed by international organizations in order to facilitate the population's access to these products.[2]

This comparative price analysis covers the largest economies in the region: Argentina, Brazil, Chile, Colombia, Mexico and Peru. We compare the prices of all medicines and also disaggregate them by category. We use the category classifications commonly employed in the sector: innovative, branded generic and pure generic. In Latin America, unlike the United States and Europe, there is a significant presence of branded generic medicines in the market. Therefore, it is appropriate to include such medicines in the analysis as a special category.

The data were provided by IMS Health (now known as IQVIA). A panel of monthly observations made between October 2010 and November 2015 was used, corresponding to a total of 19,741 units sold in the six countries examined. A panel-based econometric model with country fixed effects was used, controlling for the variables related to products' selling format, to obtain a classification of countries by prices. The statistics provided by IMS Health allow comparisons to be made at the wholesale level —meaning ex-factory sales— and at the retail level.

Price comparison or benchmarking studies are useful as they underpin countries' policies on access to medicines. Economies with pharmaceutical price regulation mechanisms —such as Brazil and Colombia— rely on international comparisons to set price limits. In that regard, this study contributes on multiple fronts. Firstly, the econometric specification used takes advantage of the panel's extensive data on the variety and number of units of medicines sold in each country and their selling format. Secondly, the comparison is performed at different stages of the production chain and also by type of medicine.

The results are described below. In terms of ex-factory sales for all medicines, the classification of countries, from the least to most expensive, is as follows: Argentina, Peru, Mexico, Chile, Colombia and Brazil. In innovative products, Argentina appears as the least expensive country and Brazil the second least. In branded generics, Argentina is found to have the lowest prices, followed by Mexico. Lastly, in pure generics, Peru is the least expensive country, followed by Chile. The relative positions of the countries do not change substantially when retail prices are compared.

The classification of prices should be interpreted as the country effect on the price, which is obtained by comparing products that are as similar as possible. Therefore, in the comparative analysis, controls are applied for various factors, other than country of sale or manufacture, that affect prices.

The price differences detected that are attributable to the country effect can have various causes, including input costs, tariff barriers, taxes, industry regulations, participants' market power or consumer preferences. This paper only compares prices among countries, without assessing the factors that could explain these differences. It is one of the first studies to use a sample of several countries over an extended period of time. In addition, a large group of variables relating to the medicines' characteristics are controlled for in the comparisons.

The paper is structured as follows: section II describes the data used in the analysis. Section III outlines the econometric methodology. The results are presented in section IV, both by type of pharmaceutical and by stage in the value chain. Lastly, section V contains the conclusions.

[2] According to OECD (2011), medical goods account for 19% of total health spending in OECD countries, on average.

II. Data

The data on prices and other product characteristics were provided by IMS Health, a company specialized in gathering key information in the health sector worldwide and the main source of data for medicine price studies, as well as for the commercial management of market participants. The period studied covers the 60 months from October 2010 to November 2015.

The comparison was made by selecting 80% of the best-selling oral solid molecules in Chile. The sample contains 118 different molecules, of which 103 were available in the six countries for at least one month of the study period. The term "molecule" refers to the set of active ingredients in a single tablet, capsule or other dosage format, marketed under a brand name or as a generic.

IMS Health's price data are collected at different points in the production chain in the countries analysed. A proper comparison must be made between prices at the same stage, at the vertical level. To obtain the prices, both retail and ex-factory, the factors recommended by IMS Health for each country were used, which are considered invariable over time.[3] For the retail market, information is obtained at the pharmacy level, and therefore excludes purchases made and allocated to patients through the public health system.

For the Chilean market, differentiated factors were used for prescription medicines, over-the-counter (OTC) and generic medicines. Differentiated factors were also used for direct sales, through one of the three pharmacy chains, and indirect sales, through independent pharmacies. Table 1 shows the factors used in each country to obtain the retail and ex-factory prices.

Table 1
Latin America (6 countries): price conversion factors

Country	Factor Retail price		Factor Ex-factory price
Argentina	1.5125		0.87
Brazil	1.3574		0.85
Colombia	1.3300		0.92
Mexico	1.2150		0.84
Peru	1.2000		0.89
	Direct sales	Indirect sales	
Chile			1.00
Prescription	1.428	1.671	
OTC	1.618	1.733	
Generic	1.761	1.779	

Source: Prepared by the authors, on the basis of data from IMS Health.

To apply each factor, we have details of direct and indirect sales for each medicine as of October 2015. Based on this, percentages sold through each channel were calculated for each product and this percentage was applied for all the periods. It has been assumed for each product that the percentage sold through each channel does not vary over time.

The quantity data corresponds to normal units, representing the number of packs sold in the month, and standard units, representing the quantity of pills. For the purposes of this study, unit retail prices are calculated by dividing the dollar price into standard units.

[3] The factors recommended by IMS Health, estimated on the basis of its knowledge of local wholesale and retail markets and the margins applied by the various segments, are an imperfect but useful substitute for measurement at the same stage of the production chain.

The database contains information on a number of variables relating to the products' characteristics that may affect their selling price. Using these variables allows us to isolate the country effect from other factors that may influence the pharmaceuticals' price. The following characteristics are taken into account.

Firstly, the format, as the active ingredient of the medicine can be presented in coated tablets, capsules, special formats, tablets, powders and ointments. The total sample includes only the solid formats. Table 2 shows distribution by country. For all the countries except Brazil, tablets accounted for the majority of the products analysed.

Table 2
Latin America (6 countries): format by country, total sample

	Argentina	Brazil	Chile	Colombia	Mexico	Peru	Total
Capsules	547	783	382	625	931	330	3 598
Special	0	2	1	1	0	1	5
Coated tablets	1 739	2 056	873	738	459	722	6 587
Tablets	2 077	1 633	895	1 585	2 485	876	9 551
Total	4 363	4 474	2 151	2 949	3 875	1 929	19 741

Source: Prepared by the authors, on the basis of data from IMS Health.

Regarding classification by type of medication, the information provided by IMS Health allows for division into innovative, branded generic, and generic medicines. The term "innovative" refers to originator medicines, first marketed under patent, regardless of whether the patent remains valid. Branded generic products have the same active ingredient as the innovative medicines, but are sold under a different trademark. Lastly, generic medication is sold under the name of the compound or active ingredient it contains.

The original database contains the categories "generic", "branded generics" and "branded". According to IMS Health, the "branded" category contains both branded generics and innovative medicines. To differentiate between the two types of pharmaceuticals, we divided the "branded" category by classifying branded products from national laboratories as branded generics and products from multinational laboratories as innovative products. This was done because the data used does not allow us to identify the national laboratories that have patents, so an approximation has been used. According to the information provided by IMS Health, 98% of the innovative products come from multinational laboratories.[4] Table 3 shows the distribution by type of medication. As can be seen, products classified as branded generics predominate in the total sample, and in each country.

Table 3
Latin America (6 countries): types of medication by country, total sample

	Argentina	Brazil	Chile	Colombia	Mexico	Peru	Total
Innovative	654	449	426	828	823	388	3 568
Branded generic	3 200	2 299	1 592	1 153	1 768	1 096	11 108
Generic	509	1 726	133	968	1 284	445	5 065
Total	4 363	4 474	2 151	2 949	3 875	1 929	19 741

Source: Prepared by the authors, on the basis of data from IMS Health.

The medicines come in different formats; this may be a factor behind price differences for the same pharmaceutical. The sample includes 1,114 types of packaging; one example is the 10 mg x 30 pack. Table 4 shows the number of observations, different molecules and different forms of packaging by country. As the table illustrates, there is a great variety in all the countries.

[4] The list of multinational and national laboratories was also provided by IMS Health.

Table 4
Latin America (6 countries): packaging formats

	Observations	Molecules	Packaging
Argentina	4 363	114	492
Brazil	4 474	109	581
Chile	2 151	117	401
Colombia	2 949	112	467
Mexico	3 875	112	489
Peru	1 929	110	371
Total	19 741	674	2 801

Source: Prepared by the authors, on the basis of data from IMS Health.

Table 5 shows the number of instances when packaging types were the same in different countries. The numbers indicate how many forms of packaging are the same in the different country and the diagonal shows the total number of different packaging formats in each country. As shown, there is a significant degree of overlap, which is useful for the comparison of prices among countries. For example, of the 492 types of packaging that exist in Argentina, more than half are available in the other countries analysed.

Table 5
Latin America (6 countries): packaging matches between countries, total sample

	Argentina	Brazil	Chile	Colombia	Mexico	Peru
Argentina	492	291	249	266	278	239
Brazil		581	244	286	275	233
Chile			401	226	236	203
Colombia				467	269	238
Mexico					489	236
Peru						371

Source: Prepared by the authors, on the basis of data from IMS Health.

III. Methodology

One of the main shortcomings of straightforward price comparisons is that medicines have very heterogeneous characteristics. This situation becomes even more complicated when comparing prices between countries and over time. The specialized literature indicates that product prices may differ among countries for various reasons: for example, owing to differences in the unit of measurement or type of packaging (Cameron and others, 2009; Danzon and Furukawa, 2011).

It is therefore necessary to control for the largest possible number of characteristics, to achieve a better comparison. In our study, this is possible because there is a wealth of information available on the characteristics of the medicines described in the preceding section. The following equation was used to determine whether there are price differences among countries for similar products:

$$LogP_{mct} = \delta_c + \delta_t + \sum_{k=1}^{K} \beta_k X_{km} + \varepsilon_{mct}$$

where P is the price of the molecule,[5] c is the country and t is time. δ_c is a specific country fixed effect that captures the price differences among countries, defined as a categorical variable with a value of 1 if the molecule is sold in country c and 0 if it is not. These price differences are obtained after controlling for time effect variables (δ_t) and the variables relating to the characteristics of the molecules (summarized in vector X).

5 Prices are expressed in United States dollars, as a common unit.

Vector X is composed of a set of categorical variables defined by molecule (more than 100 different molecules per country), format (coated pills, capsules, special and tablets), the medicine's effect (immediate or delayed), packaging (more than 1,000 varieties) and type (innovative, branded generic and generic). In all cases, a base category is excluded from the estimate. Given the large number of parameters associated with these categorical variables, the parameters do not appear in the results tables.

The price differences captured by the country fixed effects summarize everything that affects prices and varies between countries. Examples include differences in margins, taxes and preferences, which are assumed not to change over time. For the purposes of this study, given the short time period analysed, this assumption is considered reasonable.[6]

The specific country fixed effect is interpreted as the percentage price difference —since the price is expressed in logarithm— of country c compared to that used as a reference, which in our estimates is Argentina.[7]

Tables 6A and 6B show the descriptive statistics of the prices (logarithm of dollar prices) used in the estimates, as well as the number of observations available. For both the retail price and the ex-factory price, the highest averages are in Chile, surpassed only by Colombia. Figures 1 and 2 plot movements in average retail and ex-factory prices over time, showing a downward trend and convergence towards smaller differences at the end of the period analysed.

Table 6
Latin America (6 countries): descriptive statistics of the logarithm of the unit price
(Logarithm of United States dollar prices)

A. Retail

Country	Observations	Mean	Standard deviation	Minimum	Maximum
Argentina	192 676	1.42	3.97	0	301.7
Brazil	181 698	1.76	3.73	0.0034	149.3
Chile	87 802	1.88	4.21	0.006	111.4
Colombia	123 974	2.75	6.85	0.006	144.4
Mexico	131 903	1.66	4.23	$7.59x10^{-6}$	162.7
Peru	75 879	1.58	4.95	0.0000286	173.1

Source: Prepared by the authors, on the basis of data from IMS Health.

B. Ex-factory

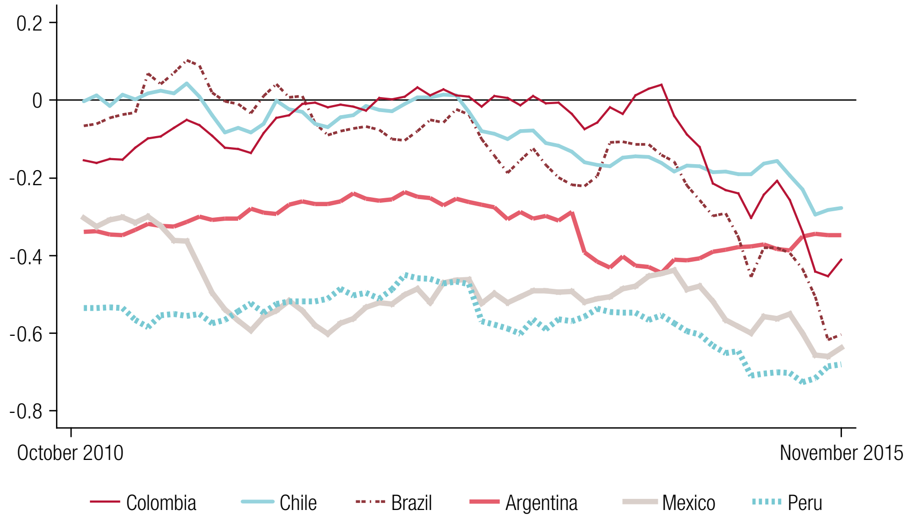
Country	Observations	Mean	Standard deviation	Minimum	Maximum
Argentina	192 676	-0.88	1.07	-9.58	5.16
Brazil	181 698	-0.61	1.13	-6.16	4.54
Chile	92 551	-0.49	1.195	-5.69	4.35
Colombia	123 974	-0.46	1.61	-5.48	4.60
Mexico	131 903	-0.87	1.57	-12.16	4.72
Peru	75 879	-0.87	1.52	-10.76	4.85

Source: Prepared by the authors, on the basis of data from IMS Health.

6 We reviewed these countries for substantive regulatory changes and found no evidence of such changes.

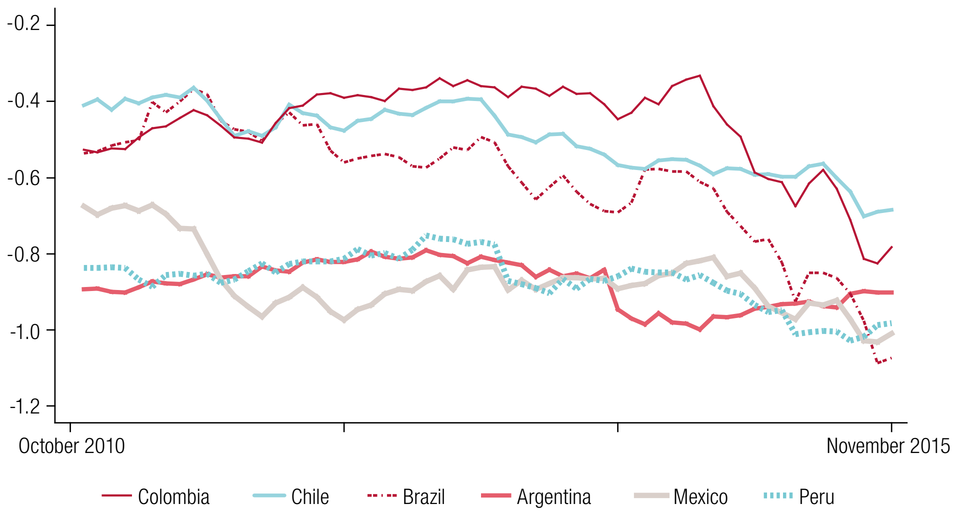
7 Argentina was chosen as it is first in the alphabetical order. The choice of base country does not change the results of the estimate, it only changes the interpretation of the parameter.

Figure 1
Latin America (6 countries): retail prices of medicines, October 2010–November 2015
(Logarithm of the unit price in United States dollars)



Source: Prepared by the authors, on the basis of data from IMS Health.

Figure 2
Latin America (6 countries): ex-factory prices of medicines, October 2010–November 2015
(Logarithm of unit price in United States dollars)



Source: Prepared by the authors, on the basis of data from IMS Health.

IV. Results

The price equation was estimated for the whole sample at two points in the chain —ex-factory and retail— and for the three types of medication mentioned. The econometric results for the total sample are shown in table 7 for ex-factory prices and in table 8 for retail prices. The control variables relating to the characteristics of the products have been entered into columns (1) to (5). Column (5) includes all the control variables.

Table 7
Latin America (6 countries): ex-factory prices at the aggregate level

Variables	(1)	(2)	(3)	(4)	(5)
Brazil	0.267***	0.359***	0.368***	0.323***	0.539***
	(0.000870)	(0.00187)	(0.00478)	(0.0131)	(0.0940)
Chile	0.387***	0.255***	0.255***	0.237***	0.201***
	(0.000482)	(0.0205)	(0.0217)	(0.0259)	(0.0219)
Colombia	0.419***	0.371***	0.392***	0.394***	0.451***
	(0.000370)	(0.0171)	(0.0211)	(0.0232)	(0.0807)
Mexico	0.0107***	0.112**	0.157**	0.123*	0.148*
	(0.00152)	(0.0417)	(0.0503)	(0.0559)	(0.0695)
Peru	0.0140***	-0.0692**	-0.0585**	0.104	0.111
	(0.000457)	(0.0172)	(0.0170)	(0.0535)	(0.0567)
Constant	-0.836***	-1.115**	-0.946**	-0.700**	-1.379**
	(0.0353)	(0.291)	(0.321)	(0.261)	(0.375)
Observations	798 681	798 681	798 681	798 681	798 681
R-squared	0.021	0.554	0.568	0.680	0.751
Time	Yes	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes	Yes
Format	No	No	Yes	Yes	Yes
Effect	No	No	Yes	Yes	Yes
Packaging	No	No	No	Yes	Yes
Type	No	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 8
Latin America (6 countries): retail prices at the aggregate level

Variables	(1)	(2)	(3)	(4)	(5)
Brazil	0.182***	0.272***	0.281***	0.238***	0.451***
	(0.000877)	(0.00137)	(0.00524)	(0.0133)	(0.0930)
Chile	0.236***	0.0966***	0.0959***	0.0724**	0.0369
	(0.00127)	(0.0220)	(0.0234)	(0.0259)	(0.0216)
Colombia	0.235***	0.186***	0.206***	0.209***	0.265**
	(0.000372)	(0.0163)	(0.0205)	(0.0233)	(0.0802)
Mexico	-0.173***	-0.0725	-0.0277	-0.0620	-0.0384
	(0.00154)	(0.0419)	(0.0504)	(0.0562)	(0.0693)
Peru	-0.240***	-0.323***	-0.312***	-0.150**	-0.145*
	(0.000457)	(0.0175)	(0.0173)	(0.0540)	(0.0567)
Constant	-0.281***	-0.571	-0.402	-0.167	-0.837*
	(0.0360)	(0.283)	(0.314)	(0.255)	(0.372)
Observations	793.932	793.932	793.932	793.932	793.932
R-squared	0.021	0.555	0.569	0.680	0.751
Time	Yes	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes	Yes
Format	No	No	Yes	Yes	Yes
Effect	No	No	Yes	Yes	Yes
Packaging	No	No	No	Yes	Yes
Type	No	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

In the case of ex-factory medicine prices (table 7), in Chile the prices are higher overall than in Argentina, with a difference of nearly 20% that has been stable over time. Prices in Chile are also higher than those in Mexico and Peru, but lower than in Colombia and Brazil. In retail prices (table 8), the results are quite similar: Chile does not have retail medicine prices that are statistically different to those in Argentina, which is the base country, but its retail prices are higher than those in Mexico and Peru. Again, prices in Chile appear to be lower than those in Colombia and Brazil.

Fisher's exact test was applied to determine whether the differences in the rankings are statistically significant. The results indicate that in the total sample for ex-factory prices, Chile is not statistically less or more expensive than Mexico or Peru (see annex 1). With respect to retail prices in the total sample, Chile's position does not appear to differ from that of Colombia or Mexico.

Tables 9–14 show the results by type of medication, broken down into innovative, branded generics and generics. For innovative medicines, the estimates indicate that Argentina has the lowest prices, well below those countries that are ranked second and third: Brazil and Chile in ex-factory, and Peru and Chile in retail prices. For branded generics, Argentina and Mexico have the lowest average prices in both the wholesale and retail markets, although retail prices in Mexico are 12% below those in Argentina. Lastly, for generic medicines, Peru has the lowest retail prices, followed by Chile, and the two countries share the lowest ex-factory prices in the comparison.

Table 9

Latin America (6 countries): ex-factory prices for innovative medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0.695***	0.595***	0.580***	0.534***
	(0.000681)	(0.0240)	(0.0232)	(0.0254)
Chile	0.787***	0.685***	0.675***	0.625***
	(0.000932)	(0.0331)	(0.0314)	(0.0346)
Colombia	1.091***	1.087***	1.101***	1.034***
	(0.000915)	(0.0306)	(0.0299)	(0.0283)
Mexico	0.781***	0.750***	0.768***	0.717***
	(0.00129)	(0.0314)	(0.0327)	(0.0279)
Peru	0.738***	0.679***	0.678***	0.644***
	(0.00172)	(0.0265)	(0.0248)	(0.0239)
Constant	-0.633***	-1.314**	-1.330**	-0.843**
	(0.0269)	(0.365)	(0.360)	(0.223)
Observations	161 925	161 925	161 925	161 925
R-squared	0.088	0.772	0.783	0.875
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 10
Latin America (6 countries): retail prices for innovative medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0.610***	0.510***	0.495***	0.448***
	(0.000682)	(0.0240)	(0.0232)	(0.0258)
Chile	0.619***	0.503***	0.492***	0.440***
	(0.000370)	(0.0336)	(0.0318)	(0.0351)
Colombia	0.906***	0.903***	0.917***	0.850***
	(0.000915)	(0.0305)	(0.0299)	(0.0283)
Mexico	0.597***	0.566***	0.584***	0.533***
	(0.00129)	(0.0313)	(0.0327)	(0.0282)
Peru	0.484***	0.425***	0.423***	0.389***
	(0.00172)	(0.0265)	(0.0248)	(0.0238)
Constant	-0.0767**	-0.765*	-0.780*	-0.294
	(0.0274)	(0.362)	(0.358)	(0.225)
Observations	161 218	161 218	161 218	161 218
R-squared	0.063	0.765	0.776	0.871
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 11
Latin America (6 countries): ex-factory prices for branded generic medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0.0768***	0.278***	0.290***	0.240***
	(0.000242)	(0.0164)	(0.0154)	(0.00952)
Chile	0.366***	0.266***	0.265***	0.259***
	(0.000664)	(0.0185)	(0.0191)	(0.0363)
Colombia	0.847***	0.725***	0.717***	0.681***
	(0.00144)	(0.0313)	(0.0375)	(0.0303)
Mexico	0.00591**	0.0917*	0.0997**	0.0678*
	(0.00201)	(0.0378)	(0.0385)	(0.0272)
Peru	0.363***	0.242***	0.244***	0.326***
	(0.00110)	(0.0161)	(0.0181)	(0.0228)
Constant	-0.839***	-0.969***	-0.859***	-0.464**
	(0.0198)	(0.189)	(0.204)	(0.173)
Observations	447 017	447 017	447 017	447 017
R-squared	0.056	0.628	0.635	0.748
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 12
Latin America (6 countries): retail prices for branded generic medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0.00817***	0.190***	0.202***	0.155***
	(0.000246)	(0.0156)	(0.0146)	(0.0102)
Chile	0.205***	0.0999***	0.0991***	0.0867*
	(0.00160)	(0.0179)	(0.0188)	(0.0374)
Colombia	0.662***	0.539***	0.532***	0.497***
	(0.00146)	(0.0305)	(0.0373)	(0.0307)
Mexico	-0.178***	-0.0926*	-0.0841*	-0.117***
	(0.00203)	(0.0378)	(0.0386)	(0.0272)
Peru	0.109***	-0.0113	-0.00915	0.0703**
	(0.00110)	(0.0167)	(0.0188)	(0.0231)
Constant	-0.285***	-0.421*	-0.313	0.0700
	(0.0210)	(0.186)	(0.203)	(0.184)
Observations	443 149	443 149	443 149	443 149
R-squared	0.042	0.623	0.630	0.744
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 13
Latin America (6 countries): ex-factory prices for generic medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0,808***	0,450***	0,440***	0,456***
	(0,00392)	(0,0655)	(0,0697)	(0,0272)
Chile	-1,181***	-1,164***	-1,168***	-1,236***
	(0,00332)	(0,0181)	(0,0212)	(0,0357)
Colombia	-0,382***	-0,650***	-0,663***	-0,671***
	(0,00107)	(0,0412)	(0,0424)	(0,0316)
Mexico	-0,432***	-0,569***	-0,571***	-0,587***
	(0,00518)	(0,0173)	(0,0215)	(0,0342)
Peru	-1,173***	-1,449***	-1,454***	-1,278***
	(0,00173)	(0,0286)	(0,0313)	(0,0621)
Constant	-1,366***	-1,644***	-1,504***	-0,945*
	(0,0300)	(0,218)	(0,142)	(0,426)
Observations	189 739	189 739	189 739	189 739
R-squared	0,242	0,700	0,702	0,796
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table 14
Latin America (6 countries): retail prices for generic medicines

Variables	(1)	(2)	(3)	(4)
Brazil	0.723***	0.364***	0.354***	0.370***
	(0.00391)	(0.0651)	(0.0692)	(0.0266)
Chile	-1.160***	-1.161***	-1.165***	-1.239***
	(0.00409)	(0.0176)	(0.0204)	(0.0349)
Colombia	-0.566***	-0.835***	-0.848***	-0.857***
	(0.00107)	(0.0410)	(0.0421)	(0.0314)
Mexico	-0.616***	-0.753***	-0.756***	-0.774***
	(0.00517)	(0.0171)	(0.0208)	(0.0337)
Peru	-1.427***	-1.703***	-1.709***	-1.534***
	(0.00173)	(0.0286)	(0.0313)	(0.0619)
Constant	-0.812***	-1.091***	-0.952***	-0.386
	(0.0298)	(0.218)	(0.141)	(0.421)
Observations	189 565	189 565	189 565	189 565
R-squared	0.267	0.709	0.712	0.802
Time	Yes	Yes	Yes	Yes
Molecules	No	Yes	Yes	Yes
Format	No	No	Yes	Yes
Effect	No	No	Yes	Yes
Packaging	No	No	No	Yes

Source: Prepared by the authors, on the basis of data from IMS Health.
Note: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

The scope of this study does not extend to explaining the causes of price differences among the countries. Nonetheless, we will compare our results to the price control policies of the sample countries. The countries with both the highest ex-factory and retail prices —Brazil and Colombia— are also the only ones with formal medicine price regulation mechanisms. If we focus on innovative products, which are more susceptible to regulation because they face less competition, Colombia appears the most expensive in both stages of the vertical chain. However, Brazil's position improves substantially, making it the second least expensive after Argentina in terms of ex-factory prices and third in retail.

Since 2003, Brazil has had a system under which the price of regulated pharmaceuticals cannot exceed the lowest price in a group of benchmark countries.[8] In Colombia, which medicines are regulated is determined based on considerations concerning competition, which is measured in terms of concentration in the respective market. International reference price (IRP) is then calculated for each medicine based on a sample of 16 countries, including economies of the Organization for Economic Cooperation and Development (OECD) and from Latin America. The maximum regulated price is equivalent to the twenty-fifth percentile of the lowest sample prices.[9]

The observed relationship between high prices and price regulation policies may seem counter-intuitive. It appears to show that price controls are not achieving the desired effects on the medicines market, or that pharmaceutical companies are reacting in an unexpected way to regulatory regimes. An alternative hypothesis, which is consistent with the results obtained, is that regulation is more necessary in economies where prices tend to be higher.

[8] See Law No. 10.742, which "defines regulatory standards for the pharmaceutical sector, creating the Medication Market Regulation Chamber - CMED", (Presidency of the Republic, 2003). The benchmark countries are Australia, Canada, France, Greece, Italy, New Zealand, Portugal, Spain, the United Kingdom, the United States and the country of origin of the medicine.

[9] See National Committee on Prices of Medicines and Medical Devices (2003).

Furthermore, reference pricing systems affect prices in the countries used as benchmarks. Indeed, if a laboratory wishes to lower the price of a medicine in a certain country that is used as a benchmark by another country, then the laboratory will also be forced to cut the price of its pharmaceutical in the country with regulated prices. Naturally, this reduces the incentives for laboratories to lower prices, since they will have to pass on at least part of the reduction to countries with regulated pricing. A similar pattern occurs with price rises. Price increases in benchmark countries allow laboratories to increase the price of the same medicine in the country that has regulated pricing. This is another possible reason to expect prices in countries with regulated pricing to be lower than those with no medication price controls.

As the data show, the effects of price regulation can be varied and raise interesting research questions. Using the available data, it is difficult to reach a conclusion regarding the impact of regulation on prices, but we believe that this work provides a useful background for future research on this topic.

V. Conclusions

This study compares medicine prices among Argentina, Brazil, Chile, Colombia, Mexico and Peru, both overall and disaggregated by the categories commonly used in the sector: innovative products, branded generics and generics.

A panel of monthly observations made between October 2010 and November 2015 was used, corresponding to a total of 19,741 units sold in the six countries examined, according to data provided by IMS Health. A panel-based econometric model with country fixed effects was used, controlling for the variables related to products' characteristics and selling format, to obtain a classification of the countries by prices. The comparisons are made at the ex-factory and retail levels.

Our results indicate that when ranked by ex-factory prices, at the aggregate level, the order of the countries, from the least to most expensive, is as follows: Argentina, Peru, Mexico, Chile, Colombia and Brazil. In this regard, Chile's position does not differ in statistical terms from that of Mexico. For retail prices, only the order of the least expensive countries changes, with the cheapest being Peru, followed by Mexico and then Argentina, while the rest of the countries maintain their positions. In terms of the magnitude of the price differential, the difference between the most and least expensive countries is 54% in ex-factory sales and 60% in pharmacy sales.

For ex-factory innovative products, Argentina, Brazil and Chile, in that order, have the lowest prices in the sample. For branded generics, Argentina, Mexico and Brazil are the least expensive, while for pure generics, Chile and Peru share the lowest prices, as there is no statistically significant difference in their position. The countries are ranked in the same order when comparing retail prices for the three categories of medicine analysed.

Notably, the two countries with the highest prices at the aggregate level —Brazil and Colombia— are also the countries that have formal medicine price control systems. However, the analysis performed does not allow a causal relationship to be established between the two factors since, as previously mentioned, price differences between countries depend on a number of variables in addition to the regulatory system, such as trade tariffs and the degree of competition among producers and among retailers. However, regulations may be established in response to high prices, thus explaining the correlation between the two.

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Annex A1

Fisher's exact test

The results of the Fisher's exact test for Chile with respect to the rest of the countries, corresponding to each sample, are presented below. To interpret the values, it should be noted that probability values greater than 0.05 do not reject the null hypothesis that the means are statistically equal, with a 95% confidence interval.

For example, for the retail price (table A1.1):

- For the total sample, Chile's coefficient, with a 95% confidence interval, is statistically different from the coefficients of Brazil and Peru, but not from the coefficients of Mexico and Colombia.

Table A1.1
Fisher's exact test of retail prices

Prob > F	Retail price			
Chile	Total sample	Generics	Innovative	Branded generics
Brazil	0.0111	0.0000	0.7455	0.1660
Colombia	0.0546	0.0001	0.0000	0.0002
Mexico	0.4125	0.0000	0.0108	0.0156
Peru	0.0373	0.0162	0.0500	0.5196

Source: Prepared by the authors, on the basis of data from IMS Health.

For the ex-factory price (table A1.2):

- For the total sample, Chile's coefficient, with a 95% confidence interval, is statistically different from the coefficients of Brazil and Colombia, but not from the coefficients of Mexico and Peru.

Table A1.2
Fisher's exact test of ex-factory prices

Prob > F	Ex-factory			
Chile	Total sample	Generics	Innovative	Branded generics
Brazil	0.0244	0.0000	0.0091	0.6673
Colombia	0.0404	0.0000	0.0000	0.0001
Mexico	0.5528	0.0000	0.0104	0.0186
Peru	0.2158	0.6341	0.3485	0.0303

Source: Prepared by the authors, on the basis of data from IMS Health.

The fact that the difference between two coefficients is not statistically significant means that nothing conclusive can be said about this difference. In a classification they could be in the same position since their distributions are not that different.

Innovation systems and changes in the core-periphery divide: notes on a methodology to determine countries' trajectories using science and technology statistics[1]

Catari Vilela Chaves, Leonardo Costa Ribeiro, Ulisses Pereira dos Santos and Eduardo da Motta e Albuquerque

Abstract

This paper presents a methodology to evaluate the international position of national innovation systems. Data on patents, scientific articles, population and gross domestic product (GDP) for all countries for 1974, 1982, 1990, 1998, 2006, 2012 and 2014 form the basis for the application of this country clustering methodology. In addition to establishing a threshold between clusters (the core-periphery divide interpreted on the basis of science and technology data), it is possible to capture movement in thresholds, driven by technological revolutions in core countries. The result is a dynamic framework, which makes it increasingly difficult to implement convergence processes.

Keywords

Science and technology, innovations, peripheral capitalism, science and technology policy, economic development, developed countries, developing countries, least developed countries, case studies, science and technology statistics, Brazil

JEL classification

O30, O33, O57

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I. Introduction

This paper presents a methodology based on science and technology statistics to evaluate the international position of national innovation systems. In addition to determining the position of specific national innovation systems, this methodology enables intertemporal tracking of the trajectories of selected countries. This procedure allows countries to be placed in clusters according to the quantitative characteristics of their innovation systems, helping to determine whether there is a core-periphery divide and assess its movement, based on science and technology data.

The concept of a national innovation system appeared in literature in the late 1980s (see Freeman, 1987; and the section on national systems of innovation in the book edited by Dosi and others, 1988). Over the last 30 years, innovation systems have been the subject of enormous body of theoretical study. Teixeira (2014) presents the results of this work in a bibliometric analysis that systematizes the diffusion and refinement of the concept. The consolidation of this concept in literature on economics, particularly economics of technology, is further evidenced by its inclusion in economics handbooks (see Fagerberg, Mowery and Nelson, 2005, chapter 7; Hall and Rosenberg, 2010, chapter 27).

The body of studies on innovation systems posed new challenges, including the applicability of the concept to countries on the capitalist periphery. A group of researchers in the so-called "Global South" dealt with this issue (Coutinho and Suzigan, 1991; Villaschi, 1992; Cassiolato, Lastres and Maciel, 2003; Viotti, 2002; Silva, 2003). The emergence of initiatives such as Globelics in 2003 (led by Lundvall) and the Catch-Up Project in 2005 (led by Nelson) enabled significant progress to be made in defining new questions for researchers working on the topic. The works of Lundvall and others (2009) and Nelson (2004) are two important outcomes.

The starting point of this article is the possibility of evaluating innovation systems using selected statistics, as pioneered by Patel and Pavitt (1994). Since then, a tradition has formed of empirical studies —directly or indirectly related to innovation systems— based on statistics for patents and scientific articles (for a comprehensive account see Moed, Glänzel and Schmoch, 2004). The main hypothesis of this article is that statistics on patents and scientific articles synthesize and summarize assessment of the key components of innovation systems: technology produced by enterprises; scientific knowledge produced by universities and research institutions; and the interactions between the two.

The article is divided into six sections including this introduction. Section II reviews the literature on the construction stages of innovation systems and the regimes of interaction between science and technology. The databases on scientific and technological output and the economic development indicator are described in section III, together with the methodology. Section IV explains the intertemporal trajectories of the science and technology output thresholds of the countries that make up each regime of interaction. The case of Brazil is presented in section V, linking the position and trajectory of the country with a preliminary assessment of its industrial structure. Lastly, section VI details the main conclusions of the study.

II. National innovation systems: differentiation, measurement and typology

Before the concept of the innovation system had been defined, neo-Schumpeterian literature had already systematized an interpretation of the role of technological revolutions in the long-term dynamics of the capitalist system (see the special issue of the magazine *Futures*, edited by Freeman in 1981, later published as a book (Freeman, 1983)). The theoretical development regarding the role of technological revolutions is summarized in Freeman and Louçã (2001) and Pérez (2010).

Technological revolutions are at the root of the metamorphoses of capitalism (Furtado, 2002) that periodically reconfigure the entire system. The emergence of the concept of the innovation system is related to the dynamics of technological revolutions in two ways. Firstly, technological revolutions are the result of the innovation systems' component institutions: by systematizing the body of institutions that drive technological progress, analysis of innovation systems helps to understand the roots of technological revolutions. Secondly, systematization of the relationship between technological revolutions and metamorphoses of capitalism suggests that innovation systems must transform periodically, in keeping with such changes.

The dynamic framework resulting from linking these two elements of neo-Schumpeterian theory has important implications for efforts to quantify innovation systems. These systems cannot be evaluated statically; changes must be captured over time.

The theoretical framework offered by the combination of technological revolutions and innovation systems poses two challenges. On one hand, differentiation between innovation systems —which has been evident since the first comparative studies (Nelson, 1993)— resulted in construction of innovation system typologies. On the other hand, such typologies should allow for the possibility of changes over time, both within innovation systems and in the resulting international context.

Freeman (1995) was a pioneer in proposing a typology, suggesting a differentiation between four types: advanced country systems (exemplified by Japan); East Asian countries; Latin American countries; and the former Union of Soviet Socialist Republics. Freeman opened a discussion on the particularity and differentiation between peripheral countries, illustrated by the contrast between Latin America (which remains on the periphery) and the Republic of Korea and Taiwan Province of China, which have proved able to undergo convergence processes and move out of the periphery. The structure of the book by Nelson (1993) suggests another means of organizing the differentiation among innovation systems.

An important theoretical issue is the link between the analysis of innovation systems and the literature on varieties of capitalism. The important and significant structural differences among the different types of innovation systems can be linked to the nature of the institutions built by the various varieties of capitalism. The literature on varieties of capitalism has concentrated on the analysis of core countries (for example Coates, 2000). The study of the different varieties of capitalism in the periphery in general, and in Latin America in particular, is a challenge. Ribeiro and others (2015, pp. 11-12) suggest five different types of capitalism involving countries on the periphery and countries where convergence processes have been found to have taken place: (i) India; (ii) Republic of Korea and Taiwan Province of China; (iii) China; (iv) countries that are rich in natural resources, such as South Africa, and countries in the Middle East and North Africa; and (v) Latin America. There is possibly another variety of peripheral capitalism, represented by the Russian Federation post-1991 (Ribeiro and others, 2015, p. 16). This linkage is key to a more widespread understanding that the literature on innovation systems describes much more comprehensive institutional arrangements than science and technology institutions.

Since 1995 there has been a profusion of studies on innovation systems and specific cases —the systematization of which is not addressed in this article— that can be re-examined in works such as Teixeira's (2014). The frame of reference for innovation systems resulted in papers that systematized, in some cases in detail, the characteristics of innovation systems in Africa (Kruss, Adeoti and Nabudere, 2012), Latin America (Dutrénit and Arza, 2010) and Asia (see the special issue of the *Seoul Journal of Economics*, edited by Keun Lee, in 2009).

A challenge arises from this wide and detailed body of literature regarding the formulation of a typology based on statistical data, helping to systematize somehow the differentiations identified in the literature, while also capturing any intertemporal movement in innovation systems.

III. Quantitative elements for a typology of innovation systems

Although the statistical analysis proposed herein is mainly based on a measure of wealth, as a proxy variable for economic development, this study adopts a broader perspective of this phenomenon. Development is interpreted here as a process of structural change based on greater income distribution and improvement in living conditions (Furtado, 2002; Fajnzylber, 2016). In other words, development is a comprehensive process, based on economic growth and the distribution of benefits from the creation or internalization and adaptation of new technologies. Authors who have investigated underdevelopment or comparative development have noted significant relationships between changes in the production structure, the process of income distribution and the expansion of national scientific and technological capabilities.

According to Furtado (1987), technological deficiencies resulting from importation of technologies that are not suited to local specificities is one of the main imbalances in the later industrialization process. Fajnzylber (2016) also states that this may be one of the main causes of greater income concentration in less developed economies. He considers that the lack of an "endogenous nucleus of technological dynamization" —a concept similar to the national innovation system— may limit internal capacity to open the "black box" of technical progress, leading countries of the periphery to prioritize imitation rather than creating their own technologies adapted to local shortcomings and potentialities. In this regard, Fajnzylber (2016) details how the contradictions of industrialization in the periphery, the main one being social inequality, appear to be related to limited scientific and technological activity in those countries.

When comparing late industrialization and the convergence process in the countries of East Asia and Latin America, Freeman (1995) notes that some factors related to improvements in living conditions —such as the universalization of education— may explain differences in the development trajectories of the countries of these regions from the 1980s onward. In this connection, Amsden (2009) affirms that, in addition to strengthening the national business class, income distribution and internal technological capacity-building appear to be associated with the convergence process in the East Asian economies, but this has not occurred in Latin America.

According to these studies, development of internal scientific and technological capabilities is fundamental to the process of economic development in its broadest sense. In other words, strengthening actors in a national innovation system appears to contribute to income growth, wealth distribution and improvements in living conditions. In this regard, industrialization of the periphery can only take into account national specificities by structuring a comprehensive national innovation system, in order to exploit potentialities and correct current imbalances. Thus, the convergence process is conceived not only as a process of growth in income and in local scientific and technological output, but also as a broader process of social transformation of which these variables are a part. This makes clear the limitations of the proposed statistical exercise. Nonetheless, improvement in the science and technology variables, in particular, may indicate the creation of internal conditions that favour improvements in living conditions, as indicated in the literature.

The hypothesis underlying the methodology proposed herein is the capacity of science and technology statistics to synthesize the relative position of countries in the global context. Statistics for science (scientific articles) and technology (patents) are the "tip of the iceberg" of countries' scientific and technological capabilities.

The scientific capacity of a country is linked to the existence of scientific institutions and universities and financial support for scientific activities, reflecting the presence of significant non-commercial elements. In turn, scientific institutions depend on the presence of an educational system that, from the most basic levels upward, seeks to prepare students for a university education. A good quality educational system, in turn, presupposes essential food and income conditions that enable families to send their children to school in a position to learn and develop creativity. These elements are linked to the more general condition of social welfare systems.

A country's technological output is linked to the presence of stable companies that are able to acquire knowledge, invest in research and development and recruit qualified professionals from the educational system, and that have the financial resources to make innovative investments. These factors are linked to the educational and scientific dimension and to the financial and macroeconomic dimension and are also related to the historical context in which companies and other institutions developed.

Thus, the statistical approach of this paper presupposes this vision of scientific and technological dynamics that is implicit in the development of innovation systems (Freeman, 1995), which undoubtedly interacts with the evolution of social capabilities described by Abramovitz (1986).

Based on this interpretation of the meaning of the data (the "tip of the iceberg" of scientific and technological capabilities), this article aims to evaluate the specific contribution that the data can make, as a synthesis of the information, to studies of changes in the core-periphery divide in the longer term.

A reading of Patel and Pavitt (1994), Freeman (1995) and Nelson (1993), focusing on interpretation of the data presented therein, suggests that there is correlation between measures of nations' wealth (per capita GDP) and indicators of scientific and technological output.

These studies describe the consolidation of scientific and technological infrastructure, the functioning of feedback loops between these two dimensions and the existence of interactions between science and technology and the economic sphere in developed countries (Germany, Japan, the United States of America). In the case of developing countries, such as Brazil, while there is evidence of systematic science and technology activities, and the related publication of articles and patents, there is also evidence that the interactions between science and technology are not yet fully consolidated. In even less developed countries, such as the poorest countries of Africa and Latin America, these data indicate an absence of systematic science and technology activities, meaning that articles are published and patents are registered infrequently. For these countries, this also indicates a lack of interconnection between the scientific and technological spheres.

Examination of this basic statistical information raises doubts as to the existence of divides between these groups of countries and questions as to how the core-periphery divide addressed by structuralist literature (Furtado, 2002) could be determined by using these statistics.

The literature on innovation systems therefore calls for the identification of statistics to measure and a methodology to analyse them.

1. Database: scientific and technological output and economic development

The database prepared for this analysis includes statistics on scientific articles (as a proxy for scientific output), patents (as a proxy for technological output) and per capita GDP (as a proxy for economic development) for the years 1974, 1982, 1990, 1998, 2006, 2012 and 2014. The aim is to collect data for all the countries in the world. In order to create the database on scientific and technological output and economic development, it was necessary to address the geopolitical changes that have taken place since 1974. Some adjustments were therefore made to make the series compatible over time.[2]

(a) Scientific output

Data on scientific articles were obtained from the Institute for Scientific Information (ISI) database[3] and are used as proxies for scientific output.

To analyse scientific infrastructure in each country, the articles used are from all science and engineering disciplines that have a direct relationship with the process of economic development and are in the Science Citation Index Expanded prepared by ISI.

The use of articles as indicators of scientific infrastructure has both advantages and disadvantages. The discussion on the meaning of the statistics published by ISI can be summarized as follows.

Firstly, not all scientific output is indexed by ISI. The requirements for a journal to be indexed are very strict. In the field of economics, for example, it is much easier for an academic journal to be included in the prestigious EconLit database than in the Science Citation Index Expanded.

Secondly, simply counting the number of articles certainly does not capture the different scientific contributions they make. Thus, an article that represents a major scientific breakthrough is counted in the same way as one that only makes an incremental contribution. To overcome this bias, citation statistics are commonly used. However, such statistics also pose problems, in particular they reduce to a certain extent the global share of the least developed countries. This article therefore uses the number of articles as a basis for the statistics.

Thirdly, the marked linguistic bias of ISI statistics favours the scientific output of English-speaking countries to the detriment of others (Sandelin and Sarafoglou, 2004).

Fourthly, scientific output is not expressed solely through the production of articles. Events such as conferences, congresses and debates are also important and are key sources of information on technological flows in interaction with the production sector (Cohen, Nelson and Walsh, 2002).

However, the ISI database is a valuable contribution, owing to its long statistical series, international comparability, disaggregation by disciplines, identification of authors and institutions (enabling geographical location of the activity), and easy access.

(b) Technological output

A patent is a document, issued by an authorized governmental agency, granting the right to exclude anyone else from the production or use of a specific new invention for a stated number of years. The patent is issued to the inventor of the device or process after an examination that focuses on both the novelty of the item and its potential utility. The right embedded in the patent can be assigned by the inventor to somebody else, usually to his or her employer (which may be a corporation), and/or sold to or licensed for use by somebody else (Griliches, 1990).

[2] Given that Germany reunified in 1990, a decision was made to aggregate the scientific publication and patent data of the Federal Republic of Germany and the German Democratic Republic from that year onward. In 1993, Czechoslovakia separated into the Czech Republic and Slovakia. Therefore, the resulting countries were inserted in 1998, 2006, 2012 and 2014. The former Union of Soviet Socialist Republics was included in 1974, 1982 and 1990. Armenia, Azerbaijan, Belarus, Estonia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, the Russian Federation, Ukraine and Uzbekistan were included in 1998, 2006, 2012 and 2014. Yugoslavia was also divided, but data on articles and patents were included for 1974, 1982, 1990 and 1998. Bosnia and Herzegovina, Croatia, Slovenia and North Macedonia (previously known as “the former Yugoslav Republic of Macedonia”) were added in 1998, 2006, 2012 and 2014.

[3] See [online] www.webofknowledge.com.

The patent documents (requested and granted) available from the website of the United States Patent and Trademark Office (USPTO)[4] contain the information used to develop the databases. The research that gave rise to this article focused on granted patents, by the country of the inventor.

In short, with respect to science and technology indicators, the use of published articles and patents in this study (instead of indicators that are derived from articles and patents) is justified, because the parallel observation of these variables is important for analysing relationships between science and technology and for formulating models on innovative processes (Schmoch, 1997).

(c) Per capita GDP and economic development

In this paper, it is assumed that income is one of the variables that determine scientific and technological output in both developed and developing countries. The indicator that will be used to express the wealth of nations is per capita GDP, measured at purchasing power parity (PPP) in constant 2011 international dollars, taken from the World Development Indicators Databank of the World Bank.[5] This particular income level indicator is used because the analysis covers a number of countries at different stages of development.[6]

2. Methodology: superparamagnetic data clustering

Based on the science and technology statistics on scientific articles and patent data, a methodology is needed to form clusters of innovation systems. Ribeiro and others (2006) list the key references with regard to the development of the technique of superparamagnetic data clustering, based on tools used in the field of physics and in theoretical research into the economics of technology.

This article applies a methodology based on a series of generalizations of Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998), which was originally used to simulate magnetic systems in the field of physics. Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998) consists of N points arranged in a lattice. Each point is characterized by its state, which can be either +1 or -1. Points interact with their nearest neighbours (the four points closest to them, in the case of a lattice) so that if two neighbouring points are in the same state an amount of energy is subtracted from the system, while if two neighbouring points are in different states the same amount of energy is added. Thus, in order to minimize system energy, neighbouring points tend to remain in the same state.

One of the generalizations made is to allow points to be continually distributed spatially, rather than fixed in a regular lattice. Therefore, the means of determining the neighbours of each point must be defined, which is a simple operation in a regular lattice. The concept used here is that of mutual neighbourhood. Point i is a neighbour of j if j is among K points closest to i and i is among K points closest to j. Accordingly, the maximum number of neighbours of a point is K.

The second generalization is that interaction J between neighbouring points is no longer a constant but a function of the distance between the points. The behaviour required for this function is that, for distances less than the mean distance a between all points, there is strong interaction and, for greater distances, the interaction is weak. This defines a local scale of interaction: neighbouring points (at a distance less than a) interact strongly and distant points (at a distance greater than a) interact weakly.

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[4] See [online] www.uspto.gov.

[5] See [online] https://databank.worldbank.org/source/world-development-indicators.

[6] The concept of purchasing power parity relies on the law of one price, according to which goods or baskets of goods have the same price in an integrated market, measured in a common currency (Dornbusch, 1987). In algebraic terms:

$$e = P/P^*$$

where: e = exchange rate; P = price level at home; P^* = price level abroad. However, the assumptions underlying PPP are very strong.

In a non-homogeneous distribution, with high- and low-density regions of points, this means that there is strong interaction within high-density regions and weak interaction within low-density regions. With a given distribution of points, it is possible to study this model using the same techniques as those described for Domany's model (Blatt, Wiseman and Domany, 1996, 1997 and 1998). In the case of low temperatures, the system shows unitary magnetization, since all the points are in the same state. In the case of high temperatures, magnetization is null, and the states are distributed equally among the points. However, a new phase arises between those of low and high temperatures, called the superparamagnetic phase, in which the spins of points belonging to the same cluster are strongly correlated, while the spins of points in different clusters are weakly correlated. This causes a plateau in the susceptibility graph owing to the fluctuations caused by the change in the state of the clusters.

In this analysis, these clusters translate into sets of countries with similar quantitative characteristics in terms of their innovation systems, as measured by statistics on patents and scientific articles. The differences between the groups of innovation systems may suggest a quantification of the core-periphery divide.

IV. Analysis of the results

Having constructed the database and described the clustering methodology, the science and technology statistics were then analysed to understand how they can contribute to improving differentiation between innovation systems at various stages of development.

To this end, this section is structured in such a manner to examine the existence of correlations between science, technology and the wealth of nations, to test the clustering of countries at different quantitative and qualitative levels of interaction between science and technology, and to evaluate how this analysis and methodology can be used to systematize the dynamic elements of the core-periphery divide.

1. Correlation between science, technology and the wealth of nations

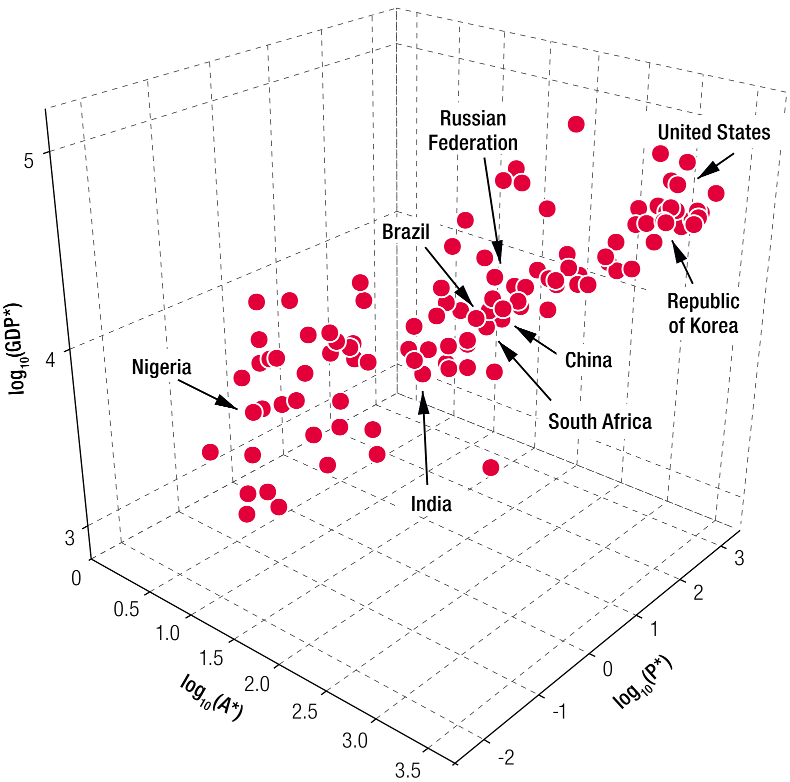
Figure 1 shows, in three-dimensional plot, the data on articles, patents and GDP (measured at PPP) in a logarithmic scale, per million inhabitants, for 111 countries in 2014. All these countries and territories have at least one patent granted by USPTO and one published scientific article included in the Science Citation Index Expanded, organized by ISI.

It can be seen that the more developed a country is, the more articles it publishes and patents it registers and vice versa, indicating a positive correlation between these three variables.

In general, countries that have greater technological capabilities and have endogenized their own technologies generate more wealth and are the richest in the world. Admittedly, there are exceptions to the correlation between wealth and scientific and technological development. While some countries with large oil reserves have high per capita GDP, their capacity to generate science and technology is far from proportionate to the wealth provided by the extraction and sale of this commodity.

As shown in figure 1, the United States and the newly included Republic of Korea are examples of countries located at the core of the capitalist system. The periphery can be divided into at least two groups: countries such as Nigeria, which are in a less developed position, and countries such as Brazil, India, China, South Africa and the Russian Federation, which are in more advanced positions, with an intermediate level of economic, scientific and technological development.

Figure 1
Selected countries and territories:[a] articles, patents and per capita GDP, 2014
(Per million inhabitants and in 2011 constant international dollars at purchasing power parity)



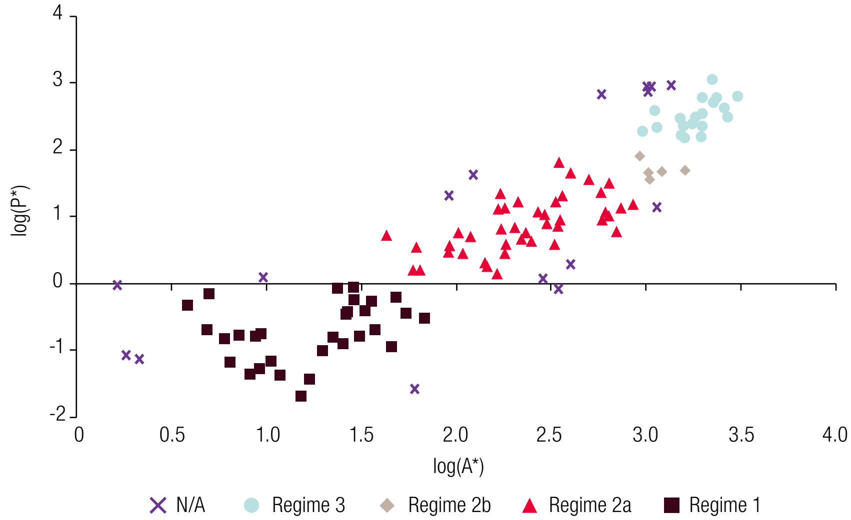
Source: Prepared by the authors, on the basis of data from World Bank, Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).

[a] The countries and territories analysed are: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belgium, Bermuda, the Bolivarian Republic of Venezuela, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chad, Chile, China, Colombia, Costa Rica, Croatia, Czechia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Eswatini, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Hungary, Iceland, India, Indonesia, Iraq, Ireland, the Islamic Republic of Iran, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Liberia, Lithuania, Luxembourg, North Macedonia, Madagascar, Malaysia, Malta, Mexico, Monaco, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, the Plurinational State of Bolivia, Poland, Portugal, Qatar, the Republic of Korea, the Republic of Moldova, Romania, the Russian Federation, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan Province of China, Thailand, Tunisia, Turkey, Turkmenistan, Ukraine, the United Arab Emirates, the United Kingdom of Great Britain and Northern Ireland, the United Republic of Tanzania, the United States of America, Uruguay, Uzbekistan, Viet Nam and the West Bank and Gaza.

2. The clustering technique and three regimes of interaction in 2014

The data presented in dimension xy of figure 1 (scientific output x technological output) constitute the input for application of the clustering methodology presented in section III.2. The result is shown in figure 2.

Figure 2
Selected countries and territories:[a] articles and patents per capita, 2014
(Per million inhabitants)



Source: Prepared by the authors, on the basis of data from Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).

[a] The countries and territories analysed are: Albania, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Barbados, Belgium, Bermuda, the Bolivarian Republic of Venezuela, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chad, Chile, China, Colombia, Costa Rica, Croatia, Czechia, Cyprus, Denmark, the Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Eswatini, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Hungary, Iceland, India, Indonesia, Iraq, Ireland, the Islamic Republic of Iran, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Liberia, Lithuania, Luxembourg, North Macedonia, Madagascar, Malaysia, Malta, Mexico, Monaco, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, the Plurinational State of Bolivia, Poland, Portugal, Qatar, the Republic of Korea, the Republic of Moldova, Romania, the Russian Federation, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan Province of China, Thailand, Tunisia, Turkey, Turkmenistan, Ukraine, the United Arab Emirates, the United Kingdom of Great Britain and Northern Ireland, the United Republic of Tanzania, the United States of America, Uruguay, Uzbekistan, Viet Nam, and the West Bank and Gaza.

Using the clustering technique, the body of countries with recorded scientific and technological output —in the form of articles and patents— were divided into three large groups. The analysis suggests that each of these groups can be considered representative of a different "regime of interaction". The reasoning behind this suggestion assumes that, in line with the literature, not only is there a quantitative difference between advanced and less developed countries—greater scientific and technological output— but also an important qualitative difference: the interaction between the scientific and technological dimensions is assumed to be more consolidated in advanced countries, allowing for a positive feedback loop between them. This group is "regime 3" in figure 2. Countries in an intermediate position are in "regime 2", characterized by less output, which is less sophisticated. In this regime, there is a feedback loop between the two dimensions but it is weaker. Lastly, the poorest and least scientifically and technologically advanced countries are in "regime 1".

Regime 3 includes 19 countries that are among the most advanced in the world, i.e. the richest in economic, scientific and technological terms: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Singapore, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland. It is important to contrast this situation with the case of the five countries that are close to regime 3 but are considered outliers of the model: Israel, Japan, the Republic of Korea, Taiwan Province of China and the United States. They are indicative of a differentiation between the most advanced countries, reflecting a subset of countries that transform their scientific output into technological output with greater efficiency.[7]

[7] The position of the European countries, compared to the United States in particular, illustrates the so-called European paradox (Dosi, 2006). For the purposes of this article, the discussion presented by Dosi (2006) is part of an initiative to subdivide the group of developed countries.

Regime 2 comprises 50 countries, including Brazil. During application of the technique outlined in section III.2, a subgroup was seen to decouple, without being characterized as a new separate group. Consequently, it is considered that, in 2014, regime 2 has a special feature, as it divided into two subgroups.

The first subgroup (referred to as "regime 2B" in figure 2) consists of five countries that were in regime 1 in 2012, but lost their places in 2014, shifting away from their peers. They are Czechia, Estonia, Italy, Slovenia and Spain. The second subgroup ("regime 2A") comprises 45 countries (there are six outliers close to this regime) at an intermediate stage of development: Argentina, Armenia, Bahrain, Barbados, Bermuda, Brazil, Brunei Darussalam, Bulgaria, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Egypt, Georgia, Greece, Hungary, India, Jamaica, Jordan, Kuwait, Latvia, Lebanon, Lithuania, Malaysia, Malta, Mexico, Namibia, North Macedonia, Oman, Panama, Poland, Qatar, Romania, the Russian Federation, Saudi Arabia, Seychelles, Slovakia, South Africa, Thailand, Turkey, Ukraine, the United Arab Emirates and Uruguay.

Lastly, "regime 1" countries are the least developed, with low per capita GDP, few patents granted and few scientific articles published, as shown in figure 1. The 30 countries in this regime are: Albania, Azerbaijan, Bangladesh, the Bolivarian Republic of Venezuela, Cameroon, the Dominican Republic, Ecuador, El Salvador, Eswatini, Ghana, Guatemala, Indonesia, Iraq, Kazakhstan, Kenya, Liberia, Madagascar, Nepal, Nicaragua, Nigeria, Pakistan, Paraguay, Peru, the Plurinational State of Bolivia, the Republic of Moldova, Sri Lanka, Turkmenistan, the United Republic of Tanzania, Uzbekistan and Viet Nam. There are seven countries, considered outliers, that are close to this regime.

Figure 2 shows a great deal of dispersion and heterogeneity among the countries of the periphery, covering regimes 1 and 2 (2a and 2b). This growing dispersion and heterogeneity of the periphery is one of the results of the dynamics of the metamorphoses of capitalism caused by the successive technological revolutions that are spread unevenly across the system.

These three regimes of interaction can be characterized by analysing the correlation between scientific and technological output within each regime. There are key differences in this correlation between groups of countries, depending on the regime of interaction to which they belong. Analysis of the dynamics between scientific and technological output in the 1999–2003 period for a group of 116 countries by Ribeiro and others (2006) produced an interesting result: the richer the nation, the greater the correlation between articles and patents. The correlation coefficient for regime 1 countries was 0.74 and for all of regime 2 it was 0.52. However, group 3 countries showed relatively low correlation, of 0.24. This result may be an indicator of the efficiency of developed countries in transforming their scientific output into technological output. It may also represent a consensus between structuralist and neo-Schumpeterian approaches.

3. Intertemporal trajectories of thresholds and countries

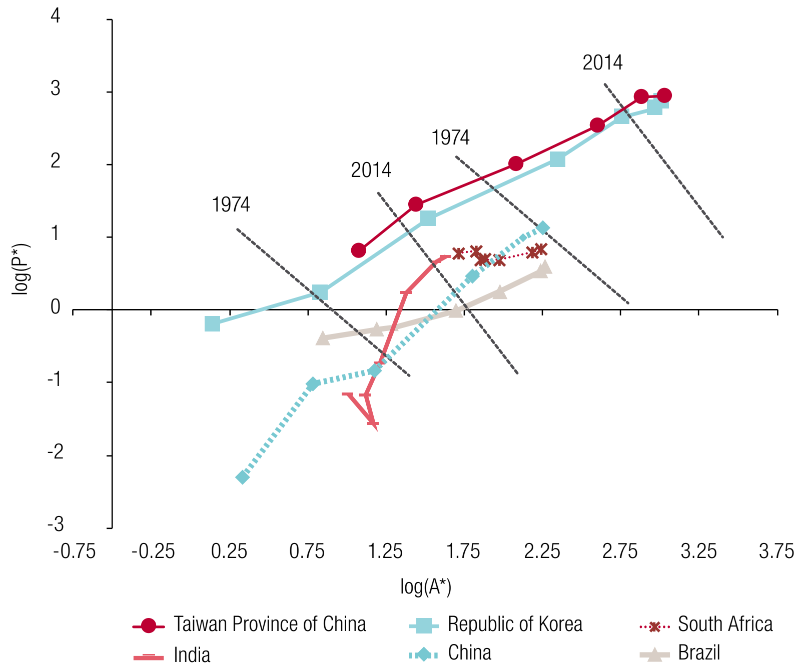
Based on the data collected for 1974, 1982, 1990, 1998, 2006, 2012 and 2014 and application of the clustering technique to these data sets, two interrelated questions are raised. Firstly, is it possible to delimit the interaction regimes with thresholds that characterize them? And secondly, are the thresholds static?

It is possible to define thresholds. First, a linear regression is performed, considering all the points (countries) in figure 2. To establish the threshold between regimes 1 and 2, the rightmost point of regime 1 is located. The line that passes through this point and is perpendicular to the line of the linear regression of all the points is then calculated. The definition is similar for the threshold between regimes 2 and 3, but uses the leftmost point of regime 3.

The threshold between regimes 3 and 2 can be expressed as the quantitative definition of the core-periphery divide, based on science and technology data.

A comparison of the position of the thresholds in 1974 and 2014 suggests that they are not static. This is consistent with the neo-Schumpeterian vision of an economic system that is in constant transformation as a result of successive technological revolutions. The movement of the thresholds over time is shown in figure 3.

Figure 3
Selected countries and territories:[a] intertemporal trajectories of the scientific and technological output thresholds
(Per million inhabitants)



Source: Prepared by the authors, on the basis of data from Institute for Scientific Information (ISI) and United States Patent and Trademark Office (USPTO).
[a] Brazil, China, India, the Republic of Korea, South Africa and Taiwan Province of China.

The 2014 line in the upper right of figure 3 represents the threshold between regimes 3 and 2 in 2014, while the 1974 line immediately to the left represents the position of the same threshold in 1974. The 1974 line at the bottom left of figure 3 represents the threshold between regimes 1 and 2 in 1974, while the 2014 line immediately to its right represents the same threshold in 2014.

Movement in the thresholds has important repercussions. In particular, movement in the threshold between regime 3 and 2 shows that the core-periphery divide is not static. The core-periphery divide exists, transforms and moves. In other words, the challenge of implementing a convergence process is made more complex by the successive technological revolutions in the core countries.

Figure 3 also shows the position of selected countries and territories for all years between 1974 and 2014. This makes it possible to trace the trajectories followed by these countries and to assess the dynamic behaviour of the movement of countries and thresholds.

Brazil's trajectory, for example, shows its move from regime 1 to regime 2 between 1974 and 1982. However, the country remained in regime 2 throughout 1990, 1998, 2006, 2012 and 2014. In 2014, it approached the 1974 threshold that marks a shift from regime 2 to regime 3. However, it took the country 40 years to meet the conditions to become part of regime 3. The scientific and technological requirements for entering regime 3 in 2014 were much more stringent than in 1974. This is the case not only for Brazil, but also India and South Africa (the "Red Queen effect"): these countries are increasing their scientific and technological output, but not fast enough to move from regime 2 to regime 3 (Ribeiro and others, 2006).

As a speculative exercise, with all the care that is required owing to the weight of uncertainty over the dynamics of scientific and technological change, it is possible to calculate the speed of movement in the thresholds. Between 1974 and 2014, the threshold for transition from regime 2 to regime 3 rose exponentially at a rate of 6.6% per year (in terms of scientific output), while the threshold between regime 1 and regime 2 rose at an average rate of 4.2% per year.

This methodology makes it possible to determine the convergence processes, which translate into the ability to cross the threshold between regimes 2 and 3. Both the Republic of Korea and Taiwan Province of China managed to make this transition and have been in regime 3 since 1998. Perhaps because they preserved a high capacity for absorbing technology during the convergence process, these countries appear as model outliers in figure 2, positioned close to Japan and the United States.

Assuming that the countries continue to expand their scientific and technological output at the same rate as they did between 1974 and 2014, and that the thresholds continue to move at the same speed (both are extremely restrictive assumptions), Brazil would be in a position to enter regime 3 in 2144, if its average growth rate of 8.6% per year (from 1974 to 2014) is maintained. South Africa, with a growth rate of 2.8% per year, could fall back into regime 1 in 2044. India, with a growth rate of 3.4% per annum, is on course to remain in regime 2. As can be seen in figure 3, China began in regime 1 in 1982, moved to regime 2 in 2006 and is on course to join regime 3 in 2050, as its growth rate is 15% per year. Although these are purely speculative exercises, they at least serve to express concern about maintaining policies that are ineffective in implementing convergence processes.

V. A note on technological intensity and the Red Queen effect: the case of Brazil

This section, which focuses on Brazil, seeks to establish a link between data on the country's position in the international context (see figure 3) with more disaggregated statistics on the position of the country's industry.

This data comparison is based on the hypothesis that the relative stagnation of Brazil shown in figure 3 is related to the absence of structural changes in national industry. This supposition is based on studies of successful convergence processes, in particular that seen in the Republic of Korea. The case of the Republic of Korea suggests that, for convergence processes to succeed, an innovation system must push the country's industrial structure towards economic sectors that are closer to the new sectors created by the most recent technological revolutions, i.e. high-tech sectors (Lee, 2013).

This is key to understanding why the Brazilian economy remained in regime 2 for most of the period analysed in figure 3, which may be linked to the middle-income trap. This refers to a situation where efforts made by middle-income countries to maintain trade advantages related to mass production and low production costs hinder their transition to the group of high-income countries (Paus, 2014). In contrast, countries that have succeeded in making this transition, such as the Republic of Korea and Taiwan Province of China, appear to have undertaken initiatives related to changes in the technological profile of local industry. In these countries, after an initial phase of industrialization, the realignment of industrial policy to favour sectors based on new, "short-cycle" technologies together with incentives for research and development seem to have been the key elements in overcoming the middle-income trap (Lee, 2013). According to this line of thought, specialization in such sectors opens up more opportunities for innovation, as technical change is faster, resulting in long periods of rapid income growth. It is thus possible to formulate a hypothesis concerning the link between the speed of movement shown in figure 3 and production specialization in high-tech sectors.

This section therefore compares Brazil's trajectory (set out in figure 3) with more disaggregated data on the country's industrial structure, provided by the Annual Report of Social Information (RAIS), which makes it possible to determine the distribution of industrial activities according to their technological intensity.

For this analysis, RAIS data on formal employment in the segments that make up the processing industry have been used, covering the period from 1995 to 2014. This information provides an overview of the industrial structure in the country and enables analysis of trends in high-tech sectors compared to other sectors. Therefore, the analysed sectors were grouped according to technological intensity, based on the classification proposed by Cavalcante (2014), which links the divisions of the National Classification of Economic Activities (CNAE) with the technological classification proposed by the Organization for Economic Cooperation and Development (OECD).[8] Thus, the processing industry sectors, classified in divisions 15 to 36 of CNAE 1.0, were grouped into four categories related to their degree of technological intensity.[9] The categories are: low, medium-low, medium-high and high technological intensity.

These data were used to determine the trend in employment in Brazilian industry at these four levels of technological intensity, in the period from 1995 to 2014. Taking into consideration the concept of the middle-income trap (Lee, 2013), this analysis will indicate whether during this period there were any changes in the country's industrial structure that could indicate a shift in the Brazilian economy towards the most dynamic of the aforementioned regimes.

Table 1 presents data on the total and industrial employment trends and the sector's share of total formal employment created in the country in the selected period. As shown, the absolute number of jobs created in the country more than doubled over the analysed period, while industrial employment grew at a slower rate (67% between 1995 and 2014). Owing to lower growth in the processing industry's capacity for absorbing workers, its share of jobs in the country declined: the sector's share of formal employment fell from 20.4% in 1995 to 15.87% in 2014. The industrial sector's share of formal establishments operating in the Brazilian economy also fell from 11.5% to 9% over the period in question.[10]

Table 1
Brazil: total formal and industrial employment, 1995–2014

Year	Industry *(number of people)*	Total *(number of people)*	Industry's share *(percentage)*
1995	4 853 311	23 755 736	20.43
1998	4 530 693	24 491 635	18.07
2002	5 241 560	28 683 913	17.85
2006	6 602 248	35 155 249	18.26
2010	7 840 220	44 068 355	17.31
2014	8 124 011	49 571 510	15.87

Source: Prepared by the authors, on the basis of Ministry of Economy (2016), Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

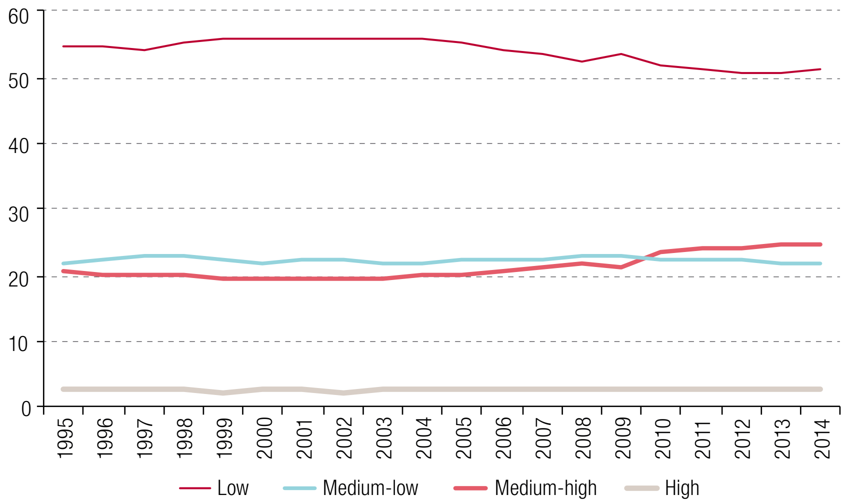
Figure 4 analyses the data on employment in the processing industry according to the levels of technological intensity of the component sectors.

8 Cavalcante's work (2014) is a technical note prepared under the aegis of the Institute of Applied Economic Research (IPEA), with a view to creating a classification of industrial segments that can be used when formulating public policies in Brazil.

9 Given that the segmentation of RAIS data by CNAE 2.0 is only available for the years after 2002, a decision was made to use CNAE 1.0, which is available for all the years considered in this study.

10 Information available on the databases of the Ministry of Economy, Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

Figure 4
Brazil: sectors' share of processing industry employment, by level of technological intensity, 1995–2014
(Percentages)



Source: Prepared by the authors, on the basis of Ministry of Economy (2016), Annual Report of Social Information (RAIS), Brasilia, 2016 [online] https://portalfat.mte.gov.br/relacao-anual-de-informacoes-sociais-rais-2016/.

As shown, in the period from 1995 to 2014, the pace of employment growth in the four technology-intensive categories generated little change in the distribution of workers within them. As can be seen in figure 4, the main change is the inversion of the positions of the medium-low and medium-high technology intensity segments from 2010 onward. Between 1995 and 2014, while the medium-low intensity segment's share of national industrial employment fell from 22% to 21.7%, the medium-high segment's share increased from 20.7% to 24.4%. The share of medium-high technology intensity sectors improved because of faster employment growth in those sectors compared to other sectors. During the period under review, the number of jobs grew by 91% in the medium-high tech industrial sectors and 52% in the medium-low tech sectors.

The high-tech group's share of national industrial employment is stable, despite the increase in the number of jobs in the component sectors. Thus, technology-intensive sectors maintained a share of about 3% of formal employment in the processing industry over the analysed period. In this regard, the 65% growth in the number of formal jobs for the high-tech segments did not change their share of the national industrial total.

Overall, the data indicate that the changes in the distribution of formal employment in the Brazilian processing industry among the different levels of technological intensity were only superficial. The medium-low and medium-high technology intensity segments swapping positions cannot be considered a major change in this structure, as the two groups always accounted for similar shares of the country's industrial employment. In addition, the inertia in high-technology sectors' share of industrial employment in Brazil indicates that the production structure lag in relation to core economies increased over the period covered by the series. While technology-intensive sectors' share of total employment in industry remained around 3% in Brazil, it increased from 45% to around 60% in the Republic of Korea between 1995 and 2013 (OECD, 2015). This comparison with the Republic of Korea —which underwent a successful convergence process during that period— helps to understand why the Brazilian economy was unable to move in the same direction. In this respect, the absence of changes in the industrial structure that promote sectors that are more technology-intensive and more predisposed to innovation appear to explain Brazil's inability to narrow the gap that separates it from the most developed economies (Lee, 2013).

The constraints on Brazil's convergence process also seem to be exacerbated by the high proportion of low-tech sectors in the country's industrial structure. In a context of increased international competition, based mainly on dynamic comparative advantages rather than static comparative advantages, high dependence on low-tech sectors limits the country's participation in external markets. This is because these sectors, which are generally based on mature technologies, offer little room for innovation and limited product differentiation. Once more, it is instructive to perform a comparison with the Republic of Korea, where high-tech sectors accounted for 29% of the export structure in 2010, while in Brazil their share was 7% (Romero and others, 2015).

Hence, the period between 1995 and 2014 was not sufficient to bring about significant changes in Brazil's industrial structure. In that time, the low-tech segments continued to account for a large proportion of job absorption, as opposed to the small share of the high-tech sectors. In view of the changes in the world economy since the end of the twentieth century, this is indicative of a deepening structural lag in Brazilian industry, in terms of both production practices and internalization of sectors with greater technological dynamism.

Figure 4 therefore shows growth without any structural changes. Brazil's limited progress in science and technology can thus be attributed to high-tech industry's unchanged relative position, i.e. a movement in figure 3 that is insufficient to overcome the Red Queen effect. This is even more evident when comparing Brazil's record with that of the Republic of Korea over the analysed period.

This finding suggests that it is possible to reconcile the trajectories of national innovation systems —traced using science and technology statistics— with more detailed analyses of national industrial structures. The two approaches are compatible even in dynamic terms.

However, it should be borne in mind that the above analysis assumes that a specific techno-economic paradigm, based on the technological revolution triggered by the microelectronics boom, will continue to prevail. Therefore, the definitions of high, medium and low technology are influenced by the effects of this paradigm on the economic sectors (Dosi, 2006). Technological revolutions are characterized by their ability to modify existing production patterns, disseminating not only new products but also new processes (Pérez, 2010). In this process, new industries emerge while those hitherto considered high-tech may become obsolete or reach maturity. Other segments may simply cease to exist or undergo profound transformations (Freeman and Louçã, 2001). Consequently, technology classifications must be understood as evolving over time, as they can be greatly influenced by changes in techno-economic paradigms. Therefore, if a new technological revolution is confirmed, supported by recent phenomena such as the growth of Industry 4.0 and the search for new renewable energy sources, the industrial structure as it is today could be modified considerably. This type of change and the potential resulting instabilities create windows of opportunity that are aligned with the emergence of new technologies. The act of harnessing these emerging technologies opens up room for structural change in economic systems and thus for convergence, as happened in the Republic of Korea from the 1970s onward (Kim, 1993). In this regard, such technological shifts may offer a path to change in the structural framework of the Brazilian economy, making its convergence process viable.

VI. Conclusions

Science and technology statistics can be used to monitor the intertemporal trajectories of national innovation systems and are an important tool for assessing countries' stages of development and levels of technological capacity-building.

The methodology for clustering countries proposed by Ribeiro and others (2006) helped to form a link between analysis of science and technology statistics and more structural assessments of the global capitalist dynamic —of the metamorphoses of capitalism— as defined by Furtado (2002). In particular, defining thresholds between the three “regimes of interaction” using a clustering technique contributes to assessment of a special dimension of these metamorphoses of capitalism: the persistence of the core-periphery divide and the changes in it.

Owing to the contribution of technological revolutions (Freeman and Louçã, 2001) to metamorphoses of capitalism (Furtado, 2002), science and technology have played an ever-increasing role in sustaining the wealth of nations. These changes are reflected by movement in the thresholds between developed countries and the rest of the world (see figure 3). Movement in the thresholds can translate into shifts in the core-periphery divide. Moreover, these changes in the position of the core-periphery divide highlight the growing challenge relating to the policies that are required in peripheral countries to overcome underdevelopment.

The methodology presented herein is also able to capture the growing heterogeneity of the periphery, shaped by the existence of two well-defined groups and an incipient subdivision of the peripheral group that is closer to the core.

Lastly, the methodology also detected the potential to overcome underdevelopment, i.e. the peripheral situation is not insurmountable. The trajectories of the Republic of Korea and Taiwan Province of China are examples of this. In other words, the methodology was able to capture successful convergence processes.

The set of data collected and analysed can serve as a starting point for discussion of the Brazilian case, based on a diagnosis of the relative stagnation of the national innovation system, which is still cursed by the Red Queen effect. This can be interpreted as an observation —in terms of science and technology statistics— of the middle-income trap, which can only be overcome by effectively building an innovation system.

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Corruption, production structure and economic development in developing countries

Helis Cristina Zanuto Andrade Santos
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Abstract

Corruption has reached alarming levels in recent years and now costs the equivalent of about 5% of global output annually. Given this backdrop, this study sets out to investigate how corruption and the production structure affects the socioeconomic development of developing countries, applying a dynamic panel data procedure to the period 2002-2014. The main findings include the fact that the relation between corruption and development is non-linear. The study of the different dimensions of development also needs to encompass both economic and social perspectives. In general, there are signs that a more sophisticated production structure distorts the effects of corruption control by strengthening the influence of corruption itself on socioeconomic development.

Keywords

Corruption, corporate corruption, economic aspects, production, productivity, economic development, social development, economic analysis, developing countries

JEL classification

O11, O50, E00

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I. Introduction

Globalization and the speed with which information is disseminated have made it possible to detect greater signs of corruption, which have fuelled concern among the authorities and given rise to research on this subject. Each year, the cost of corruption represents more than 5% of global gross domestic product (GDP), equivalent to US$ 2.6 trillion. According to the World Economic Forum (2012), more than US$ 1 trillion is paid in bribes. In this context, many researchers, both academic and non-academic, have been analysing both the determinants of corruption and its effects on the growth and development of economies.

One of the earliest studies on the subject is that of Leff (1964), who considers that corruption can have a positive influence, by "lubricating the wheels" of economic growth. The most recent studies have also focused on spending on sophisticated technologies in countries that probably do not need them, and on the sophistication of the production structure, which have been suggested as some of the potential drivers of corruption. In this connection, Shleifer and Vishny (1993) and Rose-Ackerman (1997) have made important theoretical contributions to the area of study that relates corruption to the sophistication of the production structure and economic development.

Shleifer and Vishny's (1993) theoretical model considers the supply of and demand for government goods by private agents, both at a normal price to be charged and at a price that includes a bribe. The authors argue that poor countries prefer to spend their resources on infrastructure and defence projects, which offer greater opportunities for corruption, than on improvements in education and health. As for new technologies, these could be concentrated in monopolies or oligopolies to ensure the continuity of bribery and embezzlement. In this case, new firms face entry barriers and there are obstacles to innovation, which undermine investments and growth in the economy. Rose-Ackerman (1997) argues that corruption can have a positive influence and that, in some cases, bribes and kickbacks may not impose costs on society. However, once a person succumbs to these, he/she is likely to become increasingly corrupt, and eventually negative impacts will make themselves felt.

Although the literature contains various studies that attempt to explain development, there is a gap in terms of the joint effects of the production structure and corruption in terms of improving national living standards. This makes it important to analyse the simultaneous effects of the country's production structure and corruption on development.

With this as a backdrop, this study sets out to analyse the relation between corruption, the production structure and development. It also examines the potential effects of the interaction between corruption and the country's production structure on the socioeconomic development of developing countries.

In this study, social development is proxied by the percentage of the population that suffers from undernutrition; and economic development is measured by the logarithm of per capita GDP. Corruption is represented by the control-of-corruption indicator. The production structure is represented by the sectoral outputs of manufacturing industry, agriculture and services, together with the economic complexity index. The empirical estimation controls for other effects, such as the level of human capital, foreign investment and drinking water. The estimations are conducted using the dynamic panel data procedure.

The article is divided into five sections, including this introduction. While section II presents the empirical literature, the next section describes the data and the empirical strategy used, and section IV details and discusses the econometric estimates. The fifth and last section offers final thoughts.

II. Empirical literature

This section discusses a number of empirical studies that address the relation between corruption, the production structure and development. Authors examining the effects of corruption on development include Akçay (2006), Sodré (2014) and Dalberto (2016), who obtained econometric results suggesting a negative relationship between corruption and development or growth. Some results also suggest that corruption is likely to intensify income concentration and inequality and increase poverty.

Other research suggests that the effects of corruption can be represented graphically as U-shaped or non-linear. Li, Xu and Zou (2000) find that income inequality is lower at either high or low levels of corruption, whereas a medium level of corruption is associated with high income inequality. Houston (2007) performs an exhaustive analysis of the effects of corruption on economic growth, to verify whether these are expansionary or restrictive, and concludes that they can be either, depending on the degree to which the country's property protection laws are enforced. Aidt, Dutta and Sena (2008) study the non-linear effects of this relationship and differences in institutional quality. In countries with high-quality political institutions, corruption has an adverse effect on growth, while in countries where institutional quality is low, corruption has no effect on output. This evokes the idea of corruption as a "lubricant for the wheels of economic growth".

Analysis by Swaleheen (2011) suggests that corruption has both a direct and an indirect effect on growth, depending on the level of corruption in the country in question. Along the same lines, Sobral (2014) explains that the relationship between the variables may not be linear in the case of countries with greater civil liberty.

The various studies use different criteria to measure the effects of the production structure on development. For example, Hartmann and others (2015) use the economic complexity index as a proxy for production sophistication and the Gini coefficient of output. The authors find that, in addition to contributing to economic growth, increased economic complexity is accompanied by a reduction in income inequality.

Mauro (1997b and 1998) reports that corrupt governments find it easier to collect bribes on some types of expenditure than on others. Large projects that are difficult to value, such as infrastructure or high-tech defence systems, are likely to be more susceptible to corruption than teachers' wages for example, which alters the composition of government expenditure, specifically by reducing spending on education. Ruhashyankiko and Yehoue (2006) suggest that technology-driven expansion of the private sector leads to a reduction in aggregate corruption, and that a reduction in public corruption could outweigh a possible increase in its private counterpart.

Mahdavi (2014) documents the existence of a relationship between corruption and countries with an oil-oriented production structure only when countries establish national oil regulatory agencies. These agencies can facilitate corruption, as they are set up with political guidelines, and their officials have greater opportunities to solicit bribes. In addition to fluid political connections, there is also a greater propensity for corruption, as these managers handle the oil licenses and access to contracts, and can make them more lucrative.

Leite and Weidmann (1999) use a growth model to analyse the relations that exist between natural resources, corruption and economic growth. The authors find that the adverse effects of corruption on economic growth are non-linear: the effects are intensified in less developed countries, and natural resource abundance creates opportunities for rent-seeking activities, which in turn fosters corruption.

Lastly, a study by the Organization for Economic Cooperation and Development (OECD, 2013) reviews specific cases of countries with high economic growth in unfavourable environments.[1] As countries such as the Republic of Korea and areas such as Taipei, China, move into the high-income

[1] Rock and Bonnett (2004) explain that corruption reduces growth in most developing countries, especially in small ones, but boosts growth in the larger newly industrialized East Asian countries.

group, they are seeing improvements in their corruption levels. This situation may indicate that, while the levels of corruption remained high as these economies attained higher levels of technology, the production structure may have mitigated the perverse effects of corruption in that period, since they succeeded in achieving high growth in that environment.

III. Data and empirical strategy

1. Database and description of variables

To achieve the proposed objectives, the study used panel data on 98 developing countries (listed in annex A1) spanning 2002–2014.

Two proxy variables were chosen, one for the production structure and another for corruption. The sophistication of the production structure is represented by the economic complexity index (ECI) and by the GDP shares of manufacturing industry, agriculture and services.[2] Corruption is represented by the control-of-corruption (CC) indicator, which is based on the strength of the country's governance.[3] The interaction between the CC indicator and each of the production structure proxies is discussed below to test the significance of each result.

According to the empirical literature, the variables are defined and interpreted as follows:[4]

(i) *loggdp*: "Logarithm of GDP per capita (constant 2010 US$)" —the higher the *loggdp* value, the greater the expected level of development;

(ii) *sub*: "Percentage of population who are undernourished", which is below the minimum level of dietary energy consumption (United Nations, n/da and n/db)[5] —the higher the value of *sub*, the lower the expected level of development;

(iii) *eci*: "Economic complexity index", which represents the complexity of the country's products (OEC, n/da and n/dc) —the higher the *eci* value, the higher the levels of sophistication of production and *loggdp* and the lower the level of *sub*;

(iv) *gdpagro*: "Agriculture, value-added (% of GDP)" —the higher the *gdpagro* value, the lower the sophistication of production relative to the industry share of GDP and the lower the value of *sub*;

(v) *gdpind*: "Industry, value-added (% of GDP)" —the higher the value of *gdpind*, the greater the production sophistication with respect to the agriculture and services sectors of GDP, the greater the expected values of both *loggdp* and *sub*;

(vi) *gdpser*: "Services and others, value-added (% of GDP)" —the higher the *gdpser* value, the lower the productive sophistication with respect to the industry's share of GDP, the higher the value of *loggdp* and the lower the value of *sub*;

[2] Although the ECI variable is used to represent a given country's knowledge, it is constructed according to the ubiquity and diversity of the products that it exports. The variable will represent a more complex economy or one with a knowledge-sophisticated production structure. For further information see the Atlas by Hausmann and others (2011). When considering sectoral GDPs, the sophistication of the production structure will be understood in terms of technology or machinery.

[3] This indicator measures perceptions of the extent to which corruption has been controlled in the country. The lower its value, the less control the country has over corruption, in other words the greater the perception of corruption. It is built on the perception of public authority exercised for private gain, including small and large forms of corruption and elite interests (Kaufmann, Kraay and Mastruzzi, 2010; World Bank, n/dc).

[4] Some estimates used the World Bank indicators *Domestic credit provided by the financial sector (as a percentage of GDP) and High-tech exports (as a percentage of manufacturing exports)* (World Bank, n/da), which are also the source of the variables for items (i), (iv), (v), (vi), (viii), (ix) and (xii).

[5] This is calculated using the minimum dietary energy requirement, which varies according to gender, age and different levels of physical activity (FAO, 2016). According to data available from FAO (2016) for various countries, the minimum food energy requirement ranged from 1,654 kilocalories per person per day for Timor-Leste to 1,987 kilocalories per person per day for the United Arab Emirates over the period 2014–2016. The values for the least developed countries and the world as a whole were, respectively, 1,747 and 1,844 kilocalories per person per day.

(vii) *controlcorrup*: "Control of corruption" (World Bank, n/db and n/dc) —the higher the *controlcorrup* value, the lower the level of corruption, the higher the value of *loggdp* and the lower the value of *sub*;

(viii) *abecom*: "Trade (% of GDP)" —the higher the value of *abecom*, the greater the trade openness, the higher the value of *loggdp* and the lower the value of *sub*;

(ix) *fdii*: "Foreign direct investment (FDI), net inflows (% of GDP)" —the higher the value of *fdii*, the higher the net inflow of FDI, the higher the value of *loggdp* and the lower the value of *sub*;

(x) *water*: "Proportion of population using improved drinking water sources, total" (United Nations, n/da) —the higher the value of *water*, the higher the proportion of the population using improved drinking water sources, the higher the value of *loggdp* and the lower the value of *sub*;

(xi) *hc*: "Human capital index, based on years of study and return to education" (Feenstra, Inklaar and Timmer, 2015) —the higher the value of *hc*, the higher the human capital index, the higher the value of *loggdp* and the lower the value of *sub*;

(xii) *gini*: "Gini index" —the higher the *gini* value, the greater the income inequality and the greater the value of *sub*;

(xiii) *ores_metal*: "Minerals and metals (% share of exports)" (WITS, 2018) —the higher the *ores_metal* value, the greater the abundance of non-agricultural commodities, the higher the values of both *loggdp* and *sub*;

The descriptive statistics of the variables are presented in table 1.

Table 1
Descriptive statistics, 2002–2014

Variable *(global)*	Media	Standard deviation	Minimum	Maximum	Comments
sub	14.99677	11.20825	5	53.5	N = 1 144
loggdp	8.032544	1.330887	5.268729	11.22033	N = 1 272
controllcorrup	0.3610675	0.1279468	0	0.75	N = 1 274
eci	-0.3656327	0.76884	-3.17674	1.86034	N = 1 074
gdpind	32.57637	13.80958	6.896044	77.41366	N = 1 173
gdpagro	15.25261	12.21122	0.0344685	58.20515	N = 1 175
gdpser	52.15547	12.53512	18.90939	92.98227	N = 1 171
corceci	-0.1025409	0.3013437	-0.9692	1.395255	N = 1 074
corind	11.73966	6.391206	0	45.2799	N = 1 173
coragro	5.066135	4.306053	0	27.06063	N = 1 175
corser	19.50751	10.37118	0	69.7367	N = 1 171
abecom	87.028	57.6045	19.11879	455.2767	N = 1 240
fdii	4.817579	7.002263	-8.400837	89.47596	N = 1 256
cre	47.5557	42.93937	-114.6937	236.1799	N = 1 231
tech	8.173824	12.39399	0	74.17846	N = 1 098
water	82.90496	16.30681	33	100	N = 1 231
hc	2.234161	0.5793039	1.088122	3.593633	N = 1 105
gini	43.10034	9.424866	24	59.5	N = 291
ores_metal	9.430601	15.58277	0	86.42	N = 1 131
corcon	0.1467273	0.1076587	0	0.5625	N = 1 274

Source: Prepared by the authors.
Note: Not all countries report data on all variables. Twenty-four countries report data for the gini variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub* : Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Democratic Republic of the Congo, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Guinea-Bissau, Liberia, Libya and; variable *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of the Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia.

The mean values of the *sub* and *loggdp* variables for the selected sample of countries are 14.997 and 8.033, respectively, while *controlcorrup* has a mean of 0.361. For the production structure, *eci*, *gdpind*, *gdpagro* and *gdpser* display mean values of -0.366, 32.576, 15.253 and 52.156, respectively. When these variables interact with *controlcorrup*, the mean values of their respective interactions become -0.103, 11.740, 5.066 and 19.508.

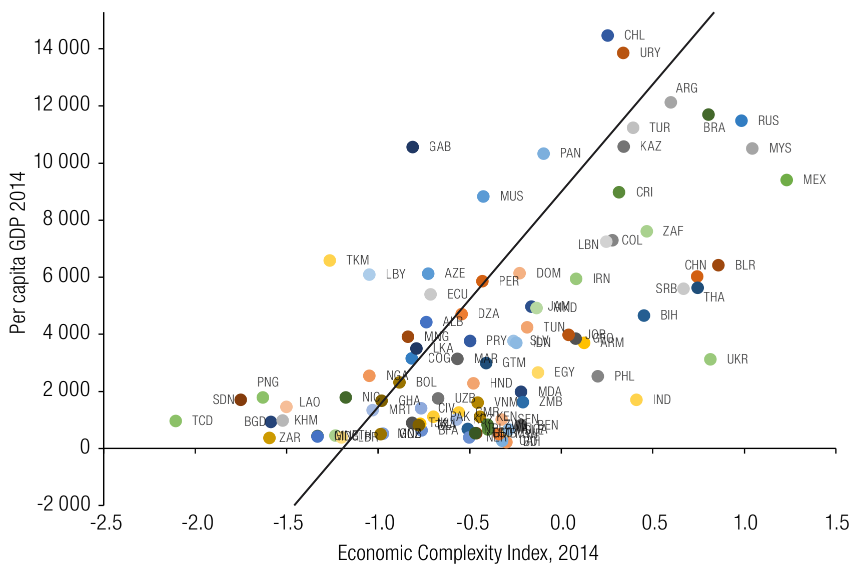
In many African and Central American countries, a large proportion of the population was undernourished in 2014 (United Nations, n/da). Of these developing countries, Haiti had the highest percentage of undernourished population, with 52.3% of its population below the minimum level of dietary energy consumption.

Data on per capita GDP growth by region (World Bank, n/da) show that, in Africa and Central America, undernutrition data coincide with low levels of per capita GDP in 2014. Overall, South Asia seems to differ significantly when comparing these indicators, as this region has the highest trend in per capita GDP growth (5.4% in 2014) but also high rates of undernutrition. The differences that emerge when comparing socioeconomic development indicators are due to various factors, such as the methodology used to calculate the indicator or the different characteristics of the countries in question. The characteristics of a South Asian country are likely to differ significantly from those of another country in the same group and will tend to be captured by one indicator rather than another.

In view of this, an analysis of corruption and the production structure can contribute to a better understanding of the characteristics of these countries and the values of their development indicators. In 2014, Latin America and the Caribbean, Africa and some areas of Asia seemed to have the lowest levels of corruption control. Sudan was the country with the least control of corruption, while Sweden was among the least corrupt (World Bank, n/db).

Figure 1 depicts the relationship between ECI and per capita GDP in 2014. Although countries with high levels of output relative to their number of inhabitants have high levels of per capita GDP, income may be highly concentrated. So, when analysed individually, per capita GDP can give a misleading picture of the country's real standard of living, hence the importance of observing the rate of undernutrition as well.

Figure 1
Selected developing countries: comparison of the economic complexity index and per capita GDP, 2014
(US dollars at constant 2010 prices)



Source: Prepared by the authors, on the basis of information from The Observatory of Economic Complexity (OEC), "Economic complexity rankings", Cambridge, Massachusetts Institute of Technology (MIT), n/da [online] https://oec.world/en/rankings/country/eci/.
Note: Data refer to the 98 developing countries listed in annex A1.

In 2014, the most economically complex country was Japan, while South Sudan was the least economically complex (OEC, n/da).

This brief presentation and comparison of a number of indicators reveals the need for different proxy variables to interpret the behaviour of the economies. Accordingly, the following sections perform econometric estimations and tests, focusing on social and economic development.

2. Empirical strategy

Aidt, Dutta and Sena (2008) analyse the role of political accountability as a determinant of corruption and economic growth. By treating corruption as an endogenous and non-linear variable associated with differences in institutional quality, the authors find that the relation between corruption and growth is specific to the governance regime. The study's empirical contributions are as follows: the way regimes are chosen for different sets of countries; the proposal of a model that allows for threshold effects and obtains results for the consequences of corruption on growth; the estimation of the impact of growth on corruption; the introduction of non-linearities in the corruption-growth relation; differentiation between short- and long-term growth rates and the use of instrumental variables. It is argued that the links between corruption, growth and institutions may not be straightforward, so non-linear and reverse-causality effects should be considered.

Accordingly, an empirical dynamic panel model is proposed for this study, inspired by Aidt, Dutta and Sena (2008). The model treats corruption as an interaction variable with respect to the production structure (there may be reverse causality); and attention will be paid to any differences in structure that may exist. The generalized method of moments (GMM) methodology is chosen as it allows for the use of instrumental variables. Subsequently, potential non-linearity effects will also be considered. The empirical model to be estimated is represented in equation 1:

$$DE_{it} = \alpha_0 + \lambda DE_{it-1} + \beta_1 \sum_{i=1}^{3} PS_{it} + \beta_2 C_{it} + \beta_3 C \sum_{i=1}^{3} PS_{it} + \beta_4 CV_{it} + \mu \qquad (1)$$

Development *(DE)* is the variable to be explained, as a function of its lagged effects, the control variables *(CV)*, the selected variables of interest and the error term (μ). Economic development will be measured by *(loggdp)*, and social development will be denoted by *(sub)*. The country's development is slow to transition over time, and past development influences the current stage of development. Because its evolution depends on institutional and social characteristics that do not change frequently, the use of the dynamic panel is appropriate. Depending on the type i of production structure *(PS)* that predominates in the country (agriculture, manufacturing industry or services), the relationship with development can be differentiated by assuming a greater or lesser sophistication in that structure. A predominantly industrial production structure can be represented by the measure *(eci)*.

Corruption *(C)* is measured by the control-of-corruption indicator *(controlcorrup)*, which is expected to be positively related to socioeconomic development. As is generally suggested in the literature, the greater the control of corruption, the lower the perception of corruption in the country, which thus improves socioeconomic development. Accordingly, the relationship between *(controlcorrup)* and *(loggdp)* is expected to be positive, improving economic development; and the relationship between *(controlcorrup)* and *(sub)* is expected to be negative, since greater control of corruption and the resulting improvement in social development could help to reduce undernourishment.

With regard to the interaction variable relating corruption and the production structure $\left(C\sum_{i=1}^{3} PS_i\right)$, an inverse causality relation is suggested. On the one hand, people might be willing to choose more advanced technologies than necessary, owing to greater facility for embezzlement. In addition, some investment projects in more sophisticated sectors could conceal future illicit gains. Thus, an attempt to benefit through the misappropriation of funds would result in investment projects and technologies that would not necessarily be aligned with the country's production model.

On the other hand, once these technologies are implemented and a certain level of sophistication is attained in the country's production structure, actions such as project renewal and machinery and equipment replacement could increasingly stimulate corrupt behaviour and embezzlement. Thus, the following interpretation is possible: when a country has a complex production structure involving technology-intensive goods, it is harder to measure those goods compared to standard ones. For example, measuring aircraft production may be more complex than the production of motor vehicles, because there are more firms that produce and sell cars than those that manufacture aircraft. Thus, corruption could occur more easily in countries that produce more technology-intensive goods because these sectors tend to be composed of just a few firms (oligopolies), and the prices of equipment needed for production may be overestimated (see Shleifer and Vishny, 1993; Hines, 1995; Mauro, 1997b and 1998; and Rose-Ackerman, 1997).

It can therefore be seen that the development effects of corruption can be enhanced or mitigated through the sophistication of the production structure. These effects will be analysed in the econometric model by interpreting the sign of the interaction variable. The relation between this variable and socioeconomic development is expected to be ambiguous: the more complex the country's production structure, the greater the opportunities for embezzlement and bribery, which generate more corruption and less development. However, if there is no joint influence between corruption, the sophistication of the production structure and the country's development, or if that relationship is weak, the effects of corruption will not prevail, resulting in an improvement in development the more sophisticated are the goods produced, even when corruption exists.

That said, the interaction variable between the indicator *(controlcorrup)* and measures of the production structure *(PS)* can be either negatively related to development —if the greater sophistication of the production structure boosts corruption, so that the influence of greater corruption control is diminished and ultimately reduces socioeconomic development— or else positively related, if there is no joint influence or if the greater sophistication of the production structure mitigates the effects of corruption itself on development, such that greater corruption control enhances development.

The specification of the empirical model and description of the database show that this is a panel data estimation. The advantages of this procedure, as discussed in Baltagi (2005), include the ability to control for heterogeneous effects in each country or individual. They also provide more information about the data and allow greater variability, efficiency and freedom and less collinearity.

For the estimation of the dynamic panel data, Arellano and Bond (1991) and Arellano and Bover (1995) contribute to the use of GMM, which was subsequently developed further with the GMM system of Blundell and Bond (1998).

The moment, or orthogonality condition is observed in equation 2.

$$\begin{aligned} E\left[DE_{i,t-2}\left(\mu_{it}-\mu_{i,t-1}\right)\right] &= 0 \qquad \forall \quad t=3,\dots,T \\ E\left[X'_{i,t-2}\left(\mu_{it}-\mu_{i,t-1}\right)\right] &= 0 \qquad \forall \quad t=3,\dots,T \end{aligned} \qquad (2)$$

Thus, as explained by Baltagi (2005), in the equation of first differences, DE_{t-2} is a valid instrument because it is strongly correlated with $(DE_{i,t-1} - DE_{i,t-2})$ but not correlated with $(\mu_{it} - \mu_{i,t-1})$. Following the estimation, tests will be performed to check for possible autocorrelation and validity problems in the instruments.

IV. Estimations and tests

1. Corruption, production structure and social development

In relating corruption and the production structure to verify its effects on social development, the specifications shown in tables 2 and 3 were estimated, using the percentage of the population who are undernourished as dependent variable.

Table 2

Selected developing countries (88): basic dynamic panel model with undernutrition as dependent variable, 2002–2014

Variables	(1)	(2)	(3)	(4)	(5)
sub$_{(t-1)}$	0.902***	0.925***	0.909***	0.948***	0.882***
	(0.00986)	(0.0141)	(0.0153)	(0.00970)	(0.0608)
controlcorrup	-0.315**	-0.777***	1.324**		-1.789*
	(0.133)	(0.163)	(0.645)		(0.996)
controlcorrup$_{(t-1)}$			-1.534**		
			(0.693)		
eci		-0.239**	-0.138		
		(0.0951)	(0.118)		
eci$_{(t-1)}$			-0.251**		
			(0.128)		
corceci				0.719***	
				(0.272)	
gini					0.123***
					(0.0431)
ores_metal					0.00696
					(0.00784)
Constant	1.190***	0.919***	0.891***	0.481***	-3.907***
	(0.181)	(0.193)	(0.201)	(0.141)	(1.441)
No. of instruments	38	72	72	80	24
Sargan Test (Prob>chi^2)	0.4578	0.1216	0.1849	0.1527	0.4849
Arellano-Bond test (AR 2 autocorrelation)	0.9728	0.7464	0.3945	0.5831	0.1525
No. of observations	1 056	916	893	916	266
No. of countries	88	85	78	85	24

Source: Prepared by the authors.

Note: Some estimations correspond to a smaller number of countries owing to lack of data on the explanatory variables. Twenty-four countries report data for the *gini* variable: Argentina, Armen)ia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub*: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo. Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Democratic Republic of the Congo, Guinea-Bissau, Liberia and Libya; variable *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of the Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia.
Standard error in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 3
Selected developing countries (88): dynamic panel with undernutrition as dependent variable, 2002–2014

Variables	(1)	(2)	(3)	(4)	(5)	(6)
$sub_{(t-1)}$	0.864***	0.811***	0.880***	0.827***	0.788***	0.745***
	(0.0305)	(0.0294)	(0.0273)	(0.0165)	(0.0244)	(0.0824)
controllcorrup	1.127***	-8.069***	-3.370*	1.891***	10.39**	-3.387***
	(0.367)	(2.577)	(2.027)	(0.707)	(4.846)	(1.128)
corceci	-0.0703					-1.756
	(0.865)					(3.537)
$corceci_{(t-1)}$	2.440***					1.457**
	(0.797)					(0.696)
corind		0.314***	0.170**			
		(0.0859)	(0.0708)			
$corind_{(t-1)}$		-0.0652**	-0.0644**			
		(0.0270)	(0.0268)			
coragro				-0.0514		
				(0.0476)		
$coragro_{(t-1)}$				-0.0686**		
				(0.0288)		
corser					-0.158*	
					(0.0919)	
$corser_{(t-1)}$					-0.0344**	
					(0.0141)	
eci	0.0698					0.750
	(0.325)					(1.091)
$eci_{(t-1)}$	-0.633**					
	(0.314)					
gdpind		-0.149***	-0.0916***	-0.0165	-0.0159	
		(0.0432)	(0.0299)	(0.0140)	(0.0202)	
$gdpind_{(t-1)}$		0.0616***	0.0539***	0.0319**	0.0312**	
		(0.0176)	(0.0187)	(0.0129)	(0.0125)	
gdpagro			0.0335*	0.0390**		
			(0.0202)	(0.0190)		
gdpser		0.00729			0.0605*	
		(0.0267)			(0.0316)	
fdii	-0.0166	0.0400**	-0.00182	0.00127	0.0297**	-0.0875*
	(0.0132)	(0.0165)	(0.0133)	(0.0117)	(0.0140)	(0.0509)
hc	-0.0977*	-1.246**	-1.508***	-1.710***	-2.069***	-1.651***
	(0.0565)	(0.519)	(0.313)	(0.153)	(0.349)	(0.571)
water	-0.0738***	-0.0303	0.0503**			-0.115*
	(0.0196)	(0.0309)	(0.0254)			(0.0634)
gini						0.0207
						(0.0233)
ores_metal						0.0982**
						(0.0448)
Constant	7.897***	10.16***	1.343	4.977***	3.695**	17.24**
	(2.087)	(2.861)	(2.397)	(0.792)	(1.696)	(6.846)
No. of instruments	74	80	80	80	80	30
Sargan Test (Prob>chi^2)	0.9406	0.6768	0.8676	0.6925	0.1275	0.9563
Arellano-Bond test (AR2 autocorrelation)	0.8147	0.2314	0.7585	0.6243	0.2828	0.4327
No. of observations	811	863	865	878	876	212
No. of countries	71	74	74	75	75	21

Source: Prepared by the authors.

Note: Some specifications are similar, as an attempt was made to check the robustness of the results of the interaction variables. Not all countries report data on all variables. Twenty-four countries report data for the *gini* variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub* : Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Guinea-Bissau, Democratic Republic of the Congo, Liberia and Libya; *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of the Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia.
Standard error in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 2 shows the effects of corruption control *(controlcorrup)* and the production structure *(eci)* on the rate of undernutrition. This parsimonious analysis will help verify the behaviour of these relations without considering the control variables.

Estimation (1) only uses corruption control measured in terms of level. Estimations (2) and (3) use corruption control and *(eci)* at level, and estimation (3) also considers its lagged effects. Estimation (4) only uses the interaction variable *(corceci)* between *(controlcorrup)* and *(eci)*, while estimation (5) controls for the effects of income inequality and non-agricultural commodities.

Estimation (1) shows that increased corruption control reduces the size of the undernourished population. This result is consistent with findings reported in the literature (Blackburn, 2012; Sodré, 2014; Dalberto, 2016), as greater corruption control suggests a lower prevalence of corrupt activities in the country, which in turn improves social development. This result is maintained in estimation (2) and in the lagged estimation (3). At level, estimation (3) finds that greater corruption control is associated with a higher rate of undernutrition. This suggests that lower levels of corruption could be increasing undernutrition, and could be explained by theoretical and empirical literature that exploits arguments and evidence on the benefits of corruption for developing countries (Leff, 1964; Nye, 1967; Huntington, 2002; Li, Xu and Zou, 2000). The results of estimation (3) suggest a non-linear relationship between corruption and development, given the changing direction of the direct effects of corruption control.

In estimations (2) at level and (3) lagged, the isolated effects of the sophistication of the production structure on undernutrition were negative. This suggests that a production structure that is more sophisticated in terms of knowledge, represented by *(eci)*, will generate improvements in the country's social development (Rodrik, 2004; Schteingart, 2015). When considering the interaction variable *(corceci)*, estimation (4) shows that a more sophisticated production structure mitigates the effects of corruption control on undernutrition.

It is arguable that this sophistication of the production structure could be contributing to the effects of corruption as a "lubricant for the wheels", in the sense that less control over corrupt actions would reduce the proportion of the population that is undernourished. This relation can also be interpreted as follows: irrespective of whether the effect of corruption itself on undernutrition is perverse, the more sophisticated production structure enhances that effect, thus reversing the expected relation between corruption control *(controlcorrup)* and undernutrition.

In control estimation (5), the variables generally maintain the same sign as in the other estimations. The non-agricultural commodities sector was not significant, and income inequality contributed to an increase in undernutrition.

Table 3 reports estimations that include control variables. Estimation (1) uses the control of corruption *(controlcorrup)*, production sophistication *(eci)* and the interaction variable *(corceci)*, while controlling for FDI, human capital and the proportion of the population with access to improved drinking water sources. The difference between estimations (2) and (3) is that (2) also considers the GDP of the services sector, while (3) considers agricultural GDP. Estimation (4) uses the control of corruption, agricultural GDP, the interaction variable with agricultural GDP, manufacturing industry GDP, FDI and human capital. Estimation (5) considers corruption control, services GDP, the interaction variable with services GDP, industrial GDP, FDI and human capital. Estimation (6) controls for the effects of income inequality and non-agricultural commodities.

In the case of estimations that control for other effects, the lagged dependent variable should also be analysed. The coefficients of these variables had a value of about 0.80, which may represent the dynamic effect of undernutrition over time. Thus, current undernutrition was persistently influenced by the level of undernutrition in the country in earlier periods. This indicates the difficulty and possible delay in the transition of least developed countries. Given the persistence of the past, this result suggests that the policies implemented will have little immediate impact on undernutrition.

The effects of corruption control were sensitive to the control variables used: in estimations (2) and (3), which used the interaction of corruption control with manufacturing industry GDP, corruption control had a direct negative impact on undernutrition. In the other estimations, the estimated coefficient was positive. This sensitivity to the effects of corruption control on social development reinforces evidence of a non-linear relationship.

With respect to the interaction variables, when considering the lagged interaction of corruption control with manufacturing industry GDP *(corind)* in estimations (2) and (3), agriculture *(coragro)* in estimation (4) and services *(corser)* in estimation (5), the impact on undernutrition was negative. The results show, therefore, that this case —in which the lagged interaction between more or less sophisticated production structures and corruption control affects social development in the same way— evokes the idea that the country's economic structure will not necessarily mitigate or enhance the past effects of corruption. On the other hand, the result of the lagged variable *(corceci)* again shows that corruption control increases the rate of undernutrition.

A consideration of interactions in terms of level shows that, in the case of the relatively less sophisticated production structure represented by services GDP in estimation (5), the expected negative effects of corruption control on undernutrition (negative interaction) were strengthened. In other words, greater control of corruption in a less sophisticated structure is associated with less undernutrition. In the more sophisticated structure represented by manufacturing in estimations (2) and (3), the expected negative effects of corruption control on undernutrition were mitigated, generating a positive interaction.

Here again, this idea can be interpreted as follows: since greater control of corruption can be expected to reduce undernutrition and the interaction variable will be positive, it is suggested that the more sophisticated production structure mitigates or reverses the effects of greater corruption control on undernutrition; or even that such a structure strengthens the effects of corruption itself on undernutrition. In this case corruption might help reduce undernutrition. It is then suggested that a more sophisticated production structure distorts the expected effects of corruption control on development, so that the effects of corruption itself and not its control prevail (Shleifer and Vishny, 1993; Rose-Ackerman, 1997; Mauro, 1997b and 1998), while, under a less sophisticated structure, the effects of controlling corruption dominate.

For the other variables of interest, there were indications that an increase in agricultural GDP *(gdpagro)* does not necessarily reduce undernutrition (see Rao and Caballero, 1990; Reis, 2012), while manufacturing industry GDP *(gdpind)* at level had negative effects, but its lagged value suggested a positive effect. This latter relationship is consistent with the literature, since the industrial part of the economy will not necessarily have direct relationships with the social variables. The services share of GDP *(gdpser)* resulted in an increase in undernutrition. Lastly, economic complexity *(eci)*, when lagged, decreased undernutrition as expected (Hartmann and others, 2015).

With respect to the control variables, for the selected developing countries as a whole, although FDI and water quality may have contributed to reducing undernutrition, this result is specification sensitive. On the other hand, human capital contributed to reducing undernutrition in all estimations.

In the control estimation (6), the variables generally maintain the same sign as in the other estimations. Income inequality was not significant, and the non-agricultural commodities sector contributed to an increase in undernutrition, as non-agricultural resources may not be directly related to social variables, unlike what would happen if only agricultural resources were considered.

In tables 2 and 3, instrument validity tests (Sargan) and autocorrelation tests (Arellano-Bond) showed that the instruments were valid in all estimations and that there was no evidence of autocorrelation.[6]

[6] Other control estimations are reported in annex A2. Additional tests were conducted by region and are available from the authors on request.

2. Corruption, production structure and economic development

The relation between corruption and the production structure and economic development is illustrated in tables 4 and 5, which use the logarithm of per capita GDP as dependent variable.

Table 4

Selected developing countries (98): basic dynamic panel model with log GDP per capita as dependent variable, 2002–2014

Variables	(1)	(2)	(3)	(4)	(5)
loggdp$_{(t-1)}$	0.894***	1.051***	0.822***	0.981***	0.895***
	(0.0196)	(0.0246)	(0.0664)	(0.0101)	(0.0332)
controlcorrup	0.350***	-0.106**	-0.287		0.268***
	(0.0702)	(0.0470)	(0.184)		(0.0996)
controlcorrup$_{(t-1)}$			0.445**		
			(0.174)		
eci		-0.0304	0.0486		
		(0.0188)	(0.0406)		
eci$_{(t-1)}$			0.171**		
			(0.0683)		
corceci				0.0643***	
				(0.0246)	
gini					0.000841
					(0.000635)
ores_metal					-0.000538*
					(0.000309)
Constant	0.749***	-0.359*	1.505***	0.192**	0.801***
	(0.133)	(0.192)	(0.531)	(0.0850)	(0.236)
No. of instruments	92	56	34	85	26
Sargan Test (Prob>chi^2)	0.1039	0.2427	0.5369	0.1597	0.9875
Arellano-Bond test (AR2 autocorrelation)	0.4665	0.4303	0.6330	0.4292	0.0110
No. of observations	1174	934	966	905	266
No. of countries	98	83	85	82	24

Source: Prepared by the authors.

Note: Some estimations correspond to a smaller number of countries owing to lack of data on the explanatory variables. Twenty-four countries report data for the *gini* variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub*: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Democratic Republic of the Congo, Guinea-Bissau, Liberia and Libya and; *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of the Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia. Standard error in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 4 shows the effects of corruption control and the production structure on per capita GDP. Estimation (1) only uses corruption control at level. Estimations (2) and (3) use corruption control and *(eci)* at level; and estimation (3) also considers its lagged effects. estimation (4) only uses the interaction variable *(corceci)*. Estimation (5) controls for the effects of income inequality and non-agricultural commodities.

Estimations (1) and (3) show that greater control of corruption increases per capita output, which is in line with findings reported in the literature (Mauro, 1995 and 1997a; Akçay, 2006). In estimation (2), however, the negative coefficient is consistent with theoretical and empirical literature on the benefits of corruption for developing countries (Klitgaard, 1994; Acemoglu and Verdier, 1998). Again, the shift in the direction of the direct effects of corruption control on development suggests a non-linear relationship. The lagged coefficient of *(eci)* was positive.

When considering the interaction variable *(corceci)*, estimation (4) shows that a more sophisticated production structure enhances the effects of corruption control. This may indicate that corruption can have a harmful effect on per capita output, hence the importance of greater corruption control within a more sophisticated production structure. While the expected positive effects of corruption control on output are enhanced, the effects of corruption itself (which is expected to be negative for production) can be mitigated. The mitigation of corruption within a more sophisticated production structure may indicate that production-structure sophistication and corrupt behaviour are actually not related.

In the control estimation (5), the variables generally maintain the same sign as in the other estimations. The Gini coefficient was non-significant, and non-agricultural commodities had a negative impact on per capita GDP, contrary to expectations but in line with the results reported by Sachs and Warner (2001).

Some additional control variables are considered in table 5. Estimation (1) uses control of corruption *(controlcorrup)*, production sophistication *(eci)*, the interaction variable *(corceci)*, FDI, human capital and the proportion of the population using improved drinking water sources. The difference between estimates (2) and (3) is that agricultural GDP is also considered in the former. Estimation (4) uses control of corruption, agricultural GDP, manufacturing GDP, the interaction variable with agricultural GDP, FDI, human capital and trade openness. The difference between estimations (5) and (6) is that the former also considers manufacturing GDP. Estimation (7) controls for the effects of income inequality and non-agricultural commodities.

The coefficients of the lagged dependent variable were positive around 0.85 and represent the dynamic effect of per capita GDP. The persistence of past effects on current per capita GDP suggests that it is hard for GDP levels to change significantly and for economies to rapidly attain a higher level of development. Consequently, efficient economic policies are needed to improve this situation over time.

The effects of corruption control, both at level and when lagged, were again very sensitive to the control variables used, which may indicate a non-linear relationship between corruption and development.

With respect to the interaction variables, the at-level coefficients of the interaction between corruption and agricultural and services GDP in estimations (4), (5) and (6), which represent a relatively less sophisticated production structure, change sign relative to their lagged values in estimations (4) and (6). In level terms, the expected positive effects of corruption control on per capita GDP are enhanced in a less sophisticated production structure. In other words, when production is less sophisticated, corruption is easier to control, so that the effects of corruption (possibly negative on output) are mitigated and this leads to an increase in per capita GDP. In this case, corruption might have negative effects on economic development, since its control generates an improvement in per capita GDP. Moreover, in a less sophisticated production structure, the effects of corruption control could outweigh the effects of corruption itself.

Table 5
Selected developing countries (98): dynamic panel with the logarithm of per capita GDP as dependent variable, 2002–2014

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
loggdp$_{(t-1)}$	0.748***	0.892***	0.861***	0.921***	0.826***	0.859***	0.920***
	(0.0544)	(0.0364)	(0.0575)	(0.0325)	(0.0605)	(0.0636)	(0.0710)
controlcorrup	0.235***	0.206	0.301	-0.205	-0.692**	-1.177*	2.099
	(0.0644)	(0.205)	(0.259)	(0.127)	(0.340)	(0.603)	(1.374)
controlcorrup$_{(t-1)}$		-0.422**	-0.702**	0.274**		0.960*	1.922*
		(0.211)	(0.282)	(0.134)		(0.554)	(1.158)
corceci	-0.0921						
	(0.0883)						
corind		-0.00847	-0.00678				-0.0705*
		(0.00720)	(0.00887)				(0.0428)
corind$_{(t-1)}$		0.0199***	0.0291***				-0.0518
		(0.00764)	(0.0102)				(0.0340)
coragro				0.0103*			
				(0.00564)			
coragro$_{(t-1)}$				-0.00896*			
				(0.00488)			
corser					0.0174***	0.0219**	
					(0.00626)	(0.0109)	
corser$_{(t-1)}$						-0.0179*	
						(0.0105)	
eci	0.0376						
	(0.0342)						
gdpind		0.0151***	0.0154***	0.0120***	-0.00353		0.049***
		(0.00294)	(0.00348)	(0.00124)	(0.00323)		(0.0163)
gdpind$_{(t-1)}$		-0.0179***	-0.0195***	-0.0105***			-0.00684
		(0.00318)	(0.00428)	(0.00137)			(0.0127)
gdpagro		-0.000506		-0.00395*			0.019***
		(0.00241)		(0.00222)			(0.0075)
gdpagro$_{(t-1)}$		-0.00519**					-0.03***
		(0.00211)					(0.0069)
gdpser					-0.0184***	-0.0194***	
					(0.00418)	(0.00430)	
gdpser$_{(t-1)}$					0.00644***	0.0172***	
					(0.00135)	(0.00446)	
fdii	0.00628***			0.000544	0.00194	-0.000268	
	(0.00159)			(0.000334)	(0.00138)	(0.00216)	
hc	0.149***	0.0822***	0.187**	0.0642***	0.331***	0.241**	0.265*
	(0.0339)	(0.0232)	(0.0765)	(0.0201)	(0.0811)	(0.104)	(0.136)
water	0.0101***						
	(0.00222)						
abecom				0.000135			
				(9.13e-05)			
gini							0.00451
							(0.0049)
ores_metal							-0.00540
							(0.0044)
Constant	0.764***	0.824***	0.730***	0.484**	1.303***	0.724*	-1.512**
	(0.159)	(0.284)	(0.255)	(0.199)	(0.265)	(0.374)	(0.714)
No. of instruments	77	81	52	84	65	45	27
Sargan Test (Prob>chi^2)	0.1976	0.7973	0.3435	0.5232	0.2300	0.8234	0.2546
Arellano-Bond test (AR2 autocorrelation)	0.1752	0.1038	0.0917	0.936	0.1181	0.2665	0.9824
No. of observations	873	950	950	937	947	947	237
No. of countries	83	81	81	81	81	81	22

Source: Prepared by the authors.

Note: Some specifications are similar, as an attempt was made to verify the robustness of the results of the interaction variables. Twenty-four countries report data for the *gini* variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub*: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Democratic Republic of the Congo Guinea-Bissau, Liberia and Libya; *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; hc, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of the Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia. Standard error in parentheses *** p<0.01, ** p<0.05, * p<0.1.

When the lagged values were used, the effects of the interaction variables changed. This suggests that, even when lagged, corruption can have different effects on economic development depending on the sophistication of the country's production structure. When considering the interaction in lagged-value terms with agricultural GDP and services GDP, which have lower levels of sophistication in their production structure than the industrial sector, the effects of corruption control (which is expected to improve per capita GDP values) are actually mitigated or reversed owing to the low production sophistication. Conversely, when considering the interaction with manufacturing industry GDP in estimations (2) and (3), the effects of corruption control are enhanced because production is more sophisticated. In other words, despite the fact that different lagged production structures affect per capita GDP differently, these effects do not support the interpretation that a more sophisticated production structure strengthens the effects of corruption by distorting the effects of corruption control on corrupt behaviour, as the results in tables 2 and 3 and the values in table 5 suggest. Thus, the "lubrication of the wheels" argument for the effect of corruption on economic development, in this case using the lagged variables, would be associated with a less sophisticated production structure.

Among the other variables of interest, agricultural GDP affected per capita GDP adversely both at level and when lagged, as also suggested by some studies in the literature (Sachs and Warner, 2001). This could be seen as the effect of agriculture being greater in social than in economic terms, which would be more strongly influenced by manufacturing. While manufacturing GDP at level increased per capita GDP, its lagged value had a negative impact. On the other hand, while services GDP decreased per capita GDP, possibly for the same reason as the agriculture sector, its lagged values improved current per capita GDP.

Turning to the control variables, FDI and improved drinking water sources both increased per capita GDP in estimation (1); and human capital had the same effect in all of the estimations.

In control estimation (7), the variables generally have the same sign as in the other estimations. The interaction variable *(corind)* at level had a negative impact on per capita GDP, thus corroborating the hypothesis that the expected effects of corruption control cold be distorted in a relatively more sophisticated production structure. The Gini coefficient and non-agricultural commodities were non-significant.

In Tables 4 and 5, the Sargan instrument validity tests indicated that the instruments were valid in all estimations;[7] and the Arellano-Bond tests for autocorrelation proved negative, except for estimations (5) in table 4 and (3) in table 5.

3. Non-linear analysis

While common sense suggests that corruption should affect a country's economy adversely, as documented in Mauro (1997a), its effects are controversial both in theory and also in empirical studies. Authors who discuss the benefits of corruption include Leff (1964), Nye (1967), Huntington (2002), Klitgaard (1994), Bardhan (1997) and Acemoglu and Verdier (1998).

The effects of corruption and the production structure on countries' development suggest a two-way causality, and exploring this aspect could help deepen the analysis. The effects of corruption control would be reversed, as the existence of corruption could boost per capita GDP, for example, and reduce undernutrition by stimulating investments in infrastructure and physical capital. Thus, if corruption exists, people would be willing to choose more advanced technologies or investment projects in more sophisticated sectors, in order to embezzle funds. In other words, corruption would stimulate certain types of investment, which would promote development. Thus, by interacting with the sophistication of the production structure, the development effects of increased corruption control would be reversed.

Considering the results obtained for the lagged variables in table 5, a more sophisticated production structure seems to mitigate the effects of corruption by enhancing the benefits of controlling it. This

[7] Other control estimations are reported in annex A3. Additional tests may be obtained from the authors on request.

result is consistent with the findings reported by Ruhashyankiko and Yehoue (2006). The literature also suggests that embezzlement produces inefficient development outcomes, as argued by Rose-Ackerman (1997) and Mauro (1997b and 1998).

The broad scope of this topic can be understood from the observation made by Hausmann and others (2011) on relations with the sophisticated production structure. Despite suggesting a positive relation between the economic complexity index and per capita GDP, as shown in figure 1, those authors explain that two countries with similar per capita incomes may have different levels of economic complexity. An example is provided by China and Peru; while China's per capita GDP was US$ 6,032.62 in 2014 and Peru's was very similar at US$ 5,861.41 (World Bank, n/da), in constant 2010 values), their economic complexity indices were 0.74 and -0.43, respectively. While the authors use this index, the argument is also valid when using sectoral GDP to represent the production structure.

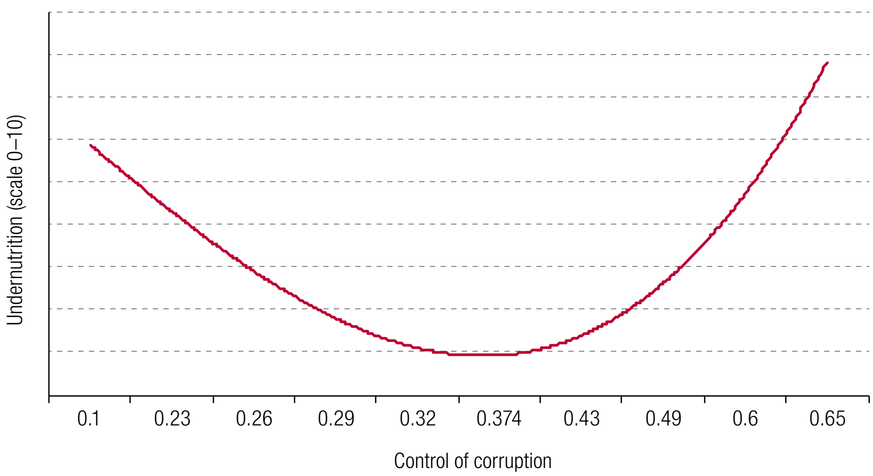
The aim is therefore to understand why the direct effects of corruption control on development are so sensitive to different specifications. One possible reason is that the effect of corruption may depend on other factors that are specific to each country. Thus, corruption is expected to be non-linear and its effects U-shaped.

The quadratic function of corruption control was estimated according to the specification represented by equation (3).[8]

$$\underset{}{sub_t} = \underset{(0.8436)^{***}}{5.0271} + \underset{(0.0165)^{***}}{0.8788 sub_{t-1}} - \underset{(1.1867)^{***}}{6.9247 corcon_t} + \underset{(1.4777)^{***}}{9.2571 corcon_t^2} - \underset{(0.0103)^{*}}{0.0191 fdii_t} - \underset{(0.1701)^{***}}{1.0149 hc_t} \qquad (3)$$

Differentiating with respect to the control of observed corruption reveals that corruption control has a point of inflexion at a value of 0.374. Figure 2 illustrates the quadratic relationship between corruption control and development (simulations of values on a scale of 0 to 10 for undernutrition).

Figure 2
Impact of corruption control on development



Source: Prepared by the authors.

Figure 2 shows that, as corruption control intensifies, undernutrition decreases; but, as from the point of inflexion, further control of corruption increases undernutrition. This is consistent with the findings reported in Houston (2007), Sobral (2014) and Swaleheen (2011), the latter of which justifies this result with the argument of "lubricating the wheels of economic growth".

[8] Standard error in parentheses. The estimated coefficients are statistically significant at ***p<0.01 and *p<0.1. Number of instruments: 80. Sargan test (Prob>chi2): 0.5827. Arellano-Bond test (AR2 autocorrelation): 0.8578. Number of observations: 934. Number of countries:78.

A review of the corruption control data used, relating to 2014, shows that 61% of the 98 countries in the sample have a level of corruption control of up to 0.33, while the remaining 39% have a level of 0.42 or more. This means that, in this context, most of the countries in the sample could benefit from greater corruption control.

The joint analysis of development, production structure and corruption in an applied model has made it possible to verify the non-linear behaviour of the relationship, and to observe how the development effects of corruption are produced through the sophistication of the production structure, thereby contributing to the existing literature on the subject in general.

V. Concluding remarks

The development literature is very wide-ranging. Corruption and the sophistication of the country's production structure are two aspects analysed as determinants of development. Despite the growing literature on the subject, gaps remain, particularly with regard to the joint effects of aspects of corruption and the sophistication of the production structure. This makes it important to analyse the interaction between variables known to affect development in order to observe the intensity of their effects.

The aim of this study was to examine how the production structure, corruption and the possible effects of interaction between these two variables influence the socioeconomic development of developing countries.

While it was found that corruption can have either positive or negative impacts on a country's development, there are signs of consensus on its negative influence. It was also noted that corruption can be enhanced in environments involving a higher level of technology, because more advanced technologies used in the process and structure of production can facilitate the misappropriation of funds.

The study has sought to explore the effects of corruption on development in two areas: in the first place, development is represented by the percentage of the population who are undernourished, while in the second, the development variable is represented by per capita GDP. Although the two estimations differ in terms of the direct development effects of sophistication of the production structure, they suggest that a more sophisticated production structure tends to strengthen the development effects of corruption itself, when this variable interacts with corruption control. This finding is important when economic policies are formulated to promote national development.

As for the direct effects of corruption control, the parameters were not stable with respect to changes in specification. The sensitivity of the results in relation to socioeconomic development was interpreted as a sign of non-linear behaviour and should therefore be treated with care when anti-corruption policies are in place. In the case of the control variables, human capital was shown to be positive for socioeconomic development in different estimations. The foreign investment and drinking water variables were sensitive to specification.

The contribution made by this study has been to analyse the simultaneous effects of these indicators, broadening the discussion on the subject. In addition, the variables selected made it possible to highlight the effects of corruption and the production structure, both from the point of view of economic development and from the social development standpoint.

The development effects of corruption control under different production structures and the non-linearity of the effects of corruption itself highlight the need to consider both aspects when implementing public policies, whether targeted on the sophistication of the production structure or on anti-corruption policies.

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Annex A1

Table A1.1
List of countries

Albania	Ghana	Panama
Algeria	Guatemala	Papua New Guinea
Angola	Guinea	Paraguay
Argentina	Guinea-Bissau	Peru
Armenia	Guyana	Philippines
Azerbaijan	Honduras	Qatar
Bahamas	Hong Kong (Special Administrative Region of China)	Republic of Korea
Bahrain	India	Republic of Moldova
Bangladesh	Indonesia	Russian Federation
Belarus	Iran	Saudi Arabia
Bolivia (Plurinational State of)	Jamaica	Senegal
Botswana	Jordan	Serbia
Brazil	Kazakhstan	Sierra Leone
Brunei Darussalam	Kenya	Singapore
Burkina Faso	Kuwait	South Africa
Burundi	Lebanon	Sri Lanka
Cameroon	Liberia	Sudan
Chile	Libya	Suriname
China	Madagascar	Thailand
Colombia	Malawi	Togo
Congo (Republic of)	Malaysia	Trinidad and Tobago
Costa Rica	Mali	Tunisia
Côte d'Ivoire	Mexico	Turkey
Cuba	Mongolia	Ukraine
Democratic Republic of the Congo	Morocco	Uganda
Dominican Republic	Mozambique	United Arab Emirates
Ecuador	Namibia	United Republic of Tanzania
Egypt	Nicaragua	Uruguay
El Salvador	Niger	Venezuela (Bolivarian Republic of)
Ethiopia	Nigeria	Viet Nam
Gabon	Oman	Yemen
Gambia	Pakistan	Zambia
Georgia		Zimbabwe

Source: Prepared by the authors.
Note: Estimations made with the variable *sub* do not include the following countries: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR), Libya, Papua New Guinea, Qatar, Singapore and Sudan.

Annex A2

Table A2.1
Control estimations, undernutrition as dependent variable, 2002–2014

Variables	Partial		Complete	
	(B1)	(B2)	(B1)	(B2)
$sub_{(t-1)}$	0.819***	0.848***	0.712***	0.756***
	(0.0595)	(0.0605)	(0.0849)	(0.0758)
controlcorrup	-3.238***	-2.478*	-5.715***	2.853
	(1.155)	(1.485)	(2.094)	(28.61)
$controlcorrup_{(t-1)}$		1.541		
		(1.680)		
coragro			0.328*	
			(0.184)	
$coragro_{(t-1)}$			-0.0154	
			(0.163)	
corser				-0.0638
				(0.500)
$corser_{(t-1)}$				-0.0784*
				(0.0440)
eci		-0.623**		
		(0.245)		
$eci_{(t-1)}$		0.0392		
		(0.307)		
gdpind			0.0434	0.138*
			(0.0617)	(0.0829)
$gdpind_{(t-1)}$			-0.0297	-0.0568
			(0.0662)	(0.0756)
gdpser				0.117
				(0.147)
fdii			-0.0842*	-0.103
			(0.0510)	(0.0655)
hc			-4.740***	-4.592***
			(1.475)	(1.538)
gini	0.200***	0.0169	-0.0191	-0.0461
	(0.0566)	(0.0184)	(0.0349)	(0.0416)
ores_metal	0.0206**	-0.0121***	0.0499***	0.0490**
	(0.00865)	(0.00416)	(0.0176)	(0.0192)
Constant	-6.173***	0.904**	16.56***	9.029
	(2.047)	(0.437)	(5.608)	(7.388)
No. of instruments	33	17	31	21
Sargan Test (Prob>chi^2)	0.6692	0.5307	0.9903	0.8736
Arellano-Bond test (AR2 autocorrelation)	0.1925	0.1928	0.5678	0.3358
No. of observations	266	236	223	223
No. of countries	24	23	22	22

Source: Prepared by the authors.

Note: Some estimations correspond to a smaller number of countries owing to a lack of data on the explanatory variables. Twenty-four countries report data for the *gini* variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub*: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Democratic Republic of the Congo, Guinea-Bissau, Liberia and Libya; *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia. Standard error in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Annex A3

Table A3.1
Control estimations, GDP per capita as dependent variable, 2002–2014

Variables	Partial		Complete	
	(C1)	(C1)	(C2)	(C3)
loggdp$_{(t-1)}$	0.867***	0.856***	0.963***	0.931***
	(0.0497)	(0.145)	(0.0483)	(0.0342)
controlcorrup	0.225*	0.401	-2.153	0.241**
	(0.125)	(0.576)	(1.387)	(0.117)
controlcorrup$_{(t-1)}$	0.120	0.591*		
	(0.177)	(0.315)		
corceci				-1.169*
				(0.627)
coragro		-0.0335		
		(0.0481)		
coragro$_{(t-1)}$		-0.0512***		
		(0.0192)		
corser			0.0382*	
			(0.0231)	
eci	0.0203			0.411*
	(0.0289)			(0.224)
eci$_{(t-1)}$	0.0633***			
	(0.0242)			
gdpind		-0.00331	0.00124	
		(0.0120)	(0.00759)	
gdpind$_{(t-1)}$		0.00221		
		(0.0122)		
gdpagro		0.0188		
		(0.0154)		
gdpser			-0.0225**	
			(0.0103)	
gdpser$_{(t-1)}$			0.0118***	
			(0.00439)	
fdii		0.00562**	0.00228**	0.00575*
		(0.00280)	(0.00102)	(0.00305)
hc		0.144	0.0761**	0.0822
		(0.189)	(0.0368)	(0.0782)
water				0.00170
				(0.00493)
abecom		-0.00113		
		(0.00124)		
gini	0.00349**	0.00306	0.00231**	0.00533**
	(0.00146)	(0.00484)	(0.00118)	(0.00235)
ores_metal	0.000980**	-0.00268	-0.000259	-0.000838
	(0.000438)	(0.00213)	(0.000519)	(0.000751)
Constant	0.889***	0.613	0.594	-0.0907
	(0.316)	(1.263)	(0.499)	(0.612)
No. of instruments	27	29	30	20
Sargan Test (Prob>chi^2)	0.9472	0.9950	0.8644	0.4568
Arellano-Bond test (AR2 autocorrelation)	0.0199	0.1284	0.0961	0.5115
No. of observations	247	237	234	213
No. of countries	23	22	22	22

Source: Prepared by the authors.

Note: Some estimations correspond to a smaller number of countries owing to a lack of data on the explanatory variables. Twenty-four countries report data for the *gini* variable: Argentina, Armenia, Belarus, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Georgia, Honduras, Kazakhstan, Mexico, Panama, Paraguay, Peru, the Plurinational State of Bolivia, Republic of Moldova, Russian Federation, Serbia, Thailand, Turkey, Ukraine and Uruguay. The following countries are missing for the following variables: *sub*: Bahamas, Bahrain, Burundi, Democratic Republic of the Congo, Hong Kong (SAR of China), Libya, Papua New Guinea, Qatar, Singapore and Sudan; *eci* and *corceci*, Bahamas, Brunei Darussalam, Burundi, Democratic Republic of the Congo, the Gambia, Guinea-Bissau, Guyana, Sierra Leone and Suriname; *gdpind*, *gdpagro*, *gdpser*, *corind*, *coragro* and *corser*, Angola, Bahrain, Kuwait, Liberia and Libya; *fdii*, Cuba; *cre*, Cuba and Iran; *tech*, Angola, Democratic Republic of the Congo, Guinea-Bissau, Liberia and Libya; *water*, Brunei Darussalam, Hong Kong (SAR) and Libya; *hc*, Azerbaijan, Bahamas, Belarus, Cuba, Democratic Republic of Congo, Georgia, Guinea, Guinea-Bissau, Guyana, Lebanon, Libya, Oman, Papua New Guinea and Suriname; *ores_metal*, Liberia. Standard error in brackets *** p<0.01, ** p<0.05, * p<0.1.

The effects of maritime container transport on economic growth in the countries on the west coast of Latin America

María Jesús Freire-Seoane, Beatriz López-Bermúdez and Ignacio de la Peña Zarzuelo

Abstract

This paper analyses the effects of changes in maritime container transport, unemployment levels, competitiveness and trade agreements on the per capita gross domestic product (GDP) of the countries on the west coast of Latin America. A sample of 23 ports along the west coast is used, with 8 observations over the period from 2008 to 2015. Panel data estimations are performed for basic fixed effects, (robust) fixed effects and panel-corrected standard error (PCSE) models, with the characteristics of the sample. In this research, the estimation method that is found to produce the best results is the PCSE model. The results support the use of containerized cargo volume as a significant variable of economic growth; they also highlight the need to invest in port infrastructure and to continue to implement outward-looking trade policy instruments.

Keywords

Maritime transport, container transport, competitiveness, unemployment, economic agreements, econometric models, transport policy, economic growth, Latin America

JEL classification

C33, F63, N76

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I. Introduction

Globalization has brought countries together and increased trade to such an extent that any remaining barriers are the result of different economic policy approaches, which in some cases have been very restrictive. Globalization has also meant that economies that adopt efficient logistics models can grow faster, be more competitive and increase investment. This hypothesis leads to the conjecture that logistics performance is a key factor in international trade.

It is clear that maritime transport logistics is in every respect a cross-cutting issue, encompassing not only production, trade, business development, the transport industry, information and communications technologies, control of goods, and transport and trade facilities, but also the various entities involved in the whole process. Governments thus have no shortage of reasons to get involved to developing more efficient logistics systems: to increase the competitiveness of exports and national infrastructure, to foster international trade, to open up new markets, and to boost employment in the service sector and ancillary enterprises. Governments also wish to mitigate the environmental and social externalities that are generated by congestion, accidents, insecurity and pollution from port activity (Cipoletta Tomassian, Pérez and Sánchez, 2010).

Historically, Latin American countries' trade relations have been highly dependent on developed economies, especially the United States, the European Union and, more recently, on the Asia-Pacific region. In recent years, Asian countries have become major trading partners for Latin America. To maintain these trade links, the economies on the west coast of Latin America have had to develop commercial instruments that facilitate terms of trade, and which are also fundamental to the region's development (Bernal-Meza, 2015; Girón, 2015).

Trade has been one of the drivers of the growth in Latin America and the Caribbean in recent years. In the countries on the west coast of Latin America in particular, increasing international demand for commodities, especially from the Asia-Pacific region, led to sharp rises in prices between 2009 and 2011. This resulted in widespread growth in gross domestic product (GDP) and labour productivity, as well as giving rise to an incipient and sustained policy of regional integration (ECLAC, 2014).

The main aim of this paper is to determine the effects of changes in maritime container transport, unemployment levels, competitiveness and trade agreements on the per capita GDP of the countries on the west coast of Latin America in the period from 2008 to 2015.

The article has five sections, including this introduction. Section II reviews the background provided by studies on economic growth and maritime transport. Section III outlines the research methodology, indicating the variables used in the analysis and describing the econometric model applied in the empirical analysis. The results of the estimation are presented in section IV and, lastly, the conclusions set out in section V.

II. Background

The general theory on the relationship between economic growth and trade forms the basis of growth theory (Rivera-Batiz and Romer, 1991; Romer, 1990), although globalization has led to some theoretical reformulations (Bolaky and Freund, 2004; Grossman and Helpman, 1993). These approaches were first developed in the work of Radelet and Sachs (1998) and Redding (2002), and became a key element of the annual *Review of Maritime Transport* published by the United Nations Conference on Trade and Development (UNCTAD, n/da) from 2007 onward. However, the first research papers based on empirical specifications are relatively recent, especially regarding the relationship between port activity and economic growth (Grossmann and others, 2007).

Research by Corbett and Winebrake (2008) shows that containerized port traffic is correlated with growth. Today, the study of the dynamics between GDP and port activity indicators is crucial to the commercial strategies of the economic actors involved in the maritime business (The Maritime Executive, 2014; Rodrigue and others, 2010) and also to research into maritime economics, which focuses on calculating additional factors to develop and strengthen the link between GDP and port activity. Other more recent studies that measure the impact of maritime traffic on countries' growth and development include Bernhofen, El-Sahli and Kneller (2016) and Rodrigue, Comtois and Slack (2013). Some authors focus on the relationship between transport costs and distances (Radelet and Sachs, 1998), while others concentrate on transport costs and cross-border cooperation agreements (Micco and Pérez, 2001). The degree of industrial specialization has also been examined (Redding, 2002).

In 2004, the Economic Commission for Latin America and the Caribbean (ECLAC) made a first attempt to highlight the economic importance of Latin American and Caribbean port infrastructure in the complex and changing global system of maritime routes. The purpose of the study was to analyse supply and demand for maritime services, freight prices, fleet ownership and port governance systems (Sánchez, 2004). In their research, UNCTAD (n/db) and Fay and Morrison (2007) also highlight the key role that Latin America could play in international maritime traffic patterns. These studies explicitly urge authorities to take advantage of the economic momentum created by high commodity prices, as many authors consider that it has not been capitalized on to reduce inequality and improve the quality and efficiency of infrastructure (Bitar, 2016).

Sánchez and others (2015) analyse the challenges and opportunities that maritime transport and port development present for Latin America and the Caribbean, introducing the issue of sustainability as a cross-cutting theme in infrastructure improvements. They affirm that, in addition to infrastructure improvements, it is essential to recognize the importance of other factors, such as the characteristics of the port terminal or the governance system, which many authors have researched in relation to the concept of efficiency (Serebrisky and others, 2016; Chang and Tovar, 2014; Núñez-Sánchez and Coto-Millán, 2012; Ramos-Real and Tovar, 2010; Coto-Millán, Baños-Pino and Rodríguez-Álvarez, 2000; and Roll and Hayuth, 1993).

The paper by López-Bermúdez, Freire and Pais (2018) shows that container terminal expansion projects have an effect on per capita GDP, in constant 2011 dollars at purchasing power parity, of 16.22% in Pacific Alliance countries and of 11.42% in Southern Common Market (MERCOSUR) countries.

III. Methodology

1. Variables

The variables considered in the analysis are: per capita GDP, volume of goods moved expressed in twenty-foot equivalent units (TEU), unemployment rate, competitiveness index and trade agreements. Table 1 lists the variables used in the analysis.

Table 1
Variables used in the model

Type of variable		Variable	Unit of measurement
Dependent	Y	Per capita GDP	2011 dollars, at purchasing power parity
Independent	X_1	Volume of containers	Twenty-foot equivalent units (TEU)
	X_2	Unemployment rate	Percentage
	X_3	Competitiveness index	Index
	X_4	Trade agreements	Dummy variable

Source: Prepared by the authors.

(a) Per capita GDP

GDP reflects a country's production of goods and services over a given period of time, usually one year. It is the economic variable par excellence that is used as a gauge of a country's domestic prosperity or recession and is usually used as an indicator of national levels of wealth, especially in international analysis, when expressed in base year dollars and at purchasing power parity.

Per capita GDP has been calculated as the ratio of GDP to the total population of the country in each of the years analysed. In order to be able to compare different economies, a standardized value is needed, eliminating, among other factors, the effects of foreign currencies and inflation. Per capita GDP at purchasing power parity (PPP) in constant 2011 dollars is therefore used (World Bank, n/d).

Table 2 shows the per capita GDP values at PPP in constant 2011 dollars for the 2008–2015 period, for the 10 countries where the 23 ports under analysis are located. Values range from a high of US$ 22,537 in Chile in 2015 to a low of $3,907 in Nicaragua in 2009. Average per capita GDP growth for all the countries for the entire analysed period was 18.27%, meaning that the annual average was 2.28%.

Table 2
Latin America (10 countries): per capita GDP, 2008–2015
(Constant 2011 dollars, at purchasing power parity)

	2008	2009	2010	2011	2012	2013	2014	2015
Chile	19 032	18 547	19 442	20 438	21 330	21 998	22 226	22 537
Colombia	10 547	10 600	10 901	11 496	11 840	12 296	12 716	12 985
Costa Rica	12 835	12 544	13 000	13 397	13 878	14 035	14 392	14 914
Ecuador	9 286	9 184	9 352	9 927	10 322	10 665	10 923	10 777
El Salvador	7 501	7 234	7 300	7 428	7 533	7 636	7 707	7 845
Guatemala	6 782	6 670	6 714	6 844	6 899	7 005	7 147	7 293
Mexico	16 008	15 012	15 535	15 923	16 324	16 316	16 459	16 668
Nicaragua	4 092	3 907	4 029	4 231	4 453	4 619	4 785	4 961
Panama	14 867	14 839	15 419	16 940	18 184	19 057	19 872	20 674
Peru	9 323	9 309	9 957	10 449	10 944	11 430	11 545	11 768

Source: Prepared by the authors, on the basis of data from World Bank, "Indicators", n/d [online] https://data.worldbank.org/indicator?tab=all.

(b) Volume of containers

The effect of maritime transport on a country's economy can be measured using different indicators. This study uses containerized goods because they have the highest added value in the goods and services market, and thus theoretically generate significant benefits that improve the standard of living.

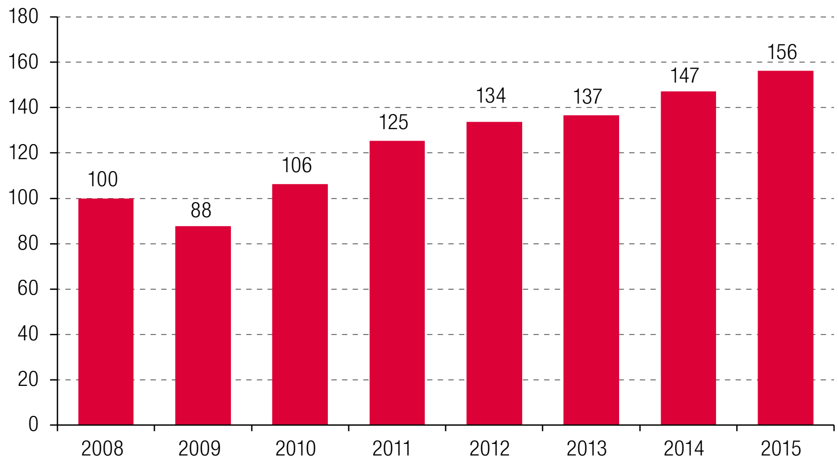
Multimodal transport and container shipping are two factors that have developed simultaneously over the same period of time. Analysis of containerized goods therefore faithfully reflects the development of infrastructure for the consumer logistics chain. The use of container shipping, combined with economies of scale, has led to mega container vessels being built, that now have a capacity of 24,000 TEU. In addition, the driver of intermodal transport has undoubtedly been the container, which permits easy handling between modal systems (Rodrigue, Comtois and Slack, 2013).

The volume of goods handled in the period 2008–2015 in each of the analysed ports on the west coast of Latin America is expressed in TEU (ECLAC, n/d).

TEU moved at these ports are included in the econometric model as an indicator, since when producing the estimates, the variables must be expressed in the same units. For this reason, absolute values have not been used (Guisan, 2008). The TEU variable is expressed in thousands and values range from 8,151 in the port of Balboa (Panama) to a minimum of 0 in the port of Coronel (Chile).

Figure 1 shows the trend in containerized cargo movements in the 2008–2015 period. An index has been calculated taking 2008 as the base year with a value of 100. According to available information, container movements fell by 12 percentage points to 88 in 2009. However, from 2010 onward container movements in the countries of the west coast of Latin America followed a path of growth; despite some fluctuations, variation rates remained positive. In 2010, the TEU movement indicator reached 106.27, with a growth rate of 20.46%. This two-digit growth was maintained in 2011, with 17.92%, and the absolute value continued to rise in 2012, hitting 134, although the growth rate slowed to 7.2%. Growth decelerated further in 2013, falling to 2.23%; however, the absolute values climbed to 147 in 2014 and 2015 —the most recent years analysed— with growth rates of 7.30% and 6.12%, respectively.

Figure 1
Latin America (10 countries): TEU indicator, 2008–2015[a]
(Base year 2008 = 100)



Source: Prepared by the authors, on the basis of data from Economic Commission for Latin America and the Caribbean (ECLAC), *Maritime and Logistics Profile of Latin America and the Caribbean*, n/d [online] http://perfil.cepal.org/l/en/start.html.

[a] The countries included are: Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama and Peru.

(c) Unemployment rate

The unemployment rate is expressed as the percentage of the economically active population in each of the countries studied that is seeking employment and has not found it, for each of the years analysed (World Bank, n/d). The unemployment rate reflects the labour market situation.

Table 3 shows the unemployment rate of these countries for the 2008–2015 period. If the last year of the series is not included, the maximum value is 12.07% in 2009 in Colombia and the minimum value is 2.79% in 2008 in Guatemala. In 2015, the highest unemployment rate was in Costa Rica (9.61%), while Guatemala continued to have the lowest rate (2.42%).

Table 3
Latin America (10 countries): unemployment rate, 2008–2015
(Percentages)

	2008	2009	2010	2011	2012	2013	2014	2015
Chile	7.80	9.69	8.14	7.12	6.43	5.93	6.39	6.21
Colombia	11.27	12.07	11.83	10.88	10.43	9.70	9.15	8.95
Costa Rica	4.78	7.71	8.92	10.31	10.17	9.38	9.62	9.61
Ecuador	7.30	6.47	5.02	4.21	4.12	4.15	3.80	4.77
El Salvador	5.88	7.33	7.05	6.62	6.07	5.93	5.92	6.18
Guatemala	2.79	3.08	3.74	4.13	2.87	2.99	2.91	2.42
Mexico	3.90	5.38	5.33	5.19	4.92	4.94	4.83	4.34
Nicaragua	6.20	8.20	8.00	7.42	6.74	5.30	5.27	5.61
Panama	5.60	6.60	6.50	4.48	4.05	4.10	4.82	5.35
Peru	6.64	4.40	4.00	3.90	3.60	4.00	4.08	4.42

Source: Prepared by the authors, on the basis of data from World Bank, "Indicators", n/d [online] https://data.worldbank.org/indicator?tab=all.

(d) Competitiveness index

The Global Competitiveness Index (GCI) is produced and published by the World Economic Forum (Schwab, 2016) and seeks to rank the competitiveness of each country according to a common global scale. The range for this indicator is 1–7, where 1 is the lowest possible value and 7 the highest. To obtain this indicator, different aspects of the country are analysed, grouped under 12 pillars:

- Pillar 1: Institutions
- Pillar 2: Infrastructure
- Pillar 3: Macroeconomic environment
- Pillar 4: Health and primary education
- Pillar 5: Higher education and training
- Pillar 6: Goods market efficiency
- Pillar 7: Labour market efficiency
- Pillar 8: Financial market development
- Pillar 9: Technological readiness
- Pillar 10: Market size
- Pillar 11: Business sophistication
- Pillar 12: Innovation

Worldwide, the highest value in the Global Competitiveness Index in 2016 was that of Switzerland, with 5.81. Within the group of countries analysed, the top place is held by Chile, with 4.64, putting the it thirty-third globally, followed by Panama, with 4.51, in forty-second place.

Table 4 gives the competitiveness index values for the countries covered by this study for the 2008–2015 period. In 2008, the values ranged from 4.75 for Chile to 3.32 for Nicaragua. Over the period under review, the indicator improved in almost all the countries, with the exception of Chile, where it gradually worsened, reaching 4.60 in 2015; although Chile remains the best positioned country in relative terms. In 2015 Nicaragua still had the lowest competitiveness index score of the group; however, its situation has consistently improved, with an index value at 3.82. The scores for the remaining countries lie between these maximum (Chile) and minimum (Nicaragua) values, ranging from 4.01 for El Salvador to 4.43 for Panama.

Table 4
Latin America (10 countries): competitiveness index, 2008–2015
(Scores on a scale from 1 to 7)

	2008	2009	2010	2011	2012	2013	2014	2015
Chile	4.75	4.70	4.72	4.69	4.70	4.65	4.61	4.60
Colombia	4.03	4.05	4.05	4.14	4.20	4.18	4.19	4.23
Costa Rica	4.20	4.25	4.23	4.31	4.27	4.34	4.35	4.42
Ecuador	3.36	3.56	3.58	3.65	3.82	3.94	4.18	4.22
El Salvador	4.00	4.02	3.99	3.89	3.99	3.80	3.84	4.01
Guatemala	3.92	3.96	4.04	3.94	4.00	4.01	4.04	4.10
Mexico	4.18	4.19	4.19	4.29	4.23	4.34	4.36	4.27
Nicaragua	3.32	3.44	3.57	3.41	3.61	3.73	3.84	3.82
Panama	4.18	4.21	4.24	4.33	4.35	4.49	4.50	4.43
Peru	3.93	4.01	3.95	4.11	4.21	4.28	4.25	4.24

Source: Prepared by the authors, on the basis of data from K. Schwab (ed.), The Global Competitiveness Report 2016–2017, Geneva, 2016 [online] http://www3.weforum.org/docs/GCR2016-2017/05FullReport/TheGlobalCompetitivenessReport2016-2017_FINAL.pdf.

(e) Trade agreements

As stated above, trade has been a determining factor in the economic growth of the group of countries under analysis. While trade was buoyant in 2009–2011, thanks to higher commodity prices (ECLAC, 2014), international trade is now sluggish, mainly owing to falling demand for commodities from China. However, growth is beginning to pick up on the back of South-South trade, fuelled by the fourth industrial revolution (big data and e-commerce) (UNCTAD, n/da).

Given that trade is extremely important to the economies analysed, it is necessary to study how they have opened up to trade, with a shared goal of liberalizing commerce and eliminating barriers, to promote trade with countries in the region and those outside it. A descriptive analysis is therefore needed of the policies on free trade agreements of the countries considered in this study.

Latin America and the Caribbean has pursued a multitude of regional agreements to expand the market for goods and services by removing barriers between neighbouring countries. However, these projects —such as the Andean Community (CAN), established in 1969 as the Andean Pact; the Amazon Cooperation Treaty Organization (ACTO), created in 1978; and the Latin American Integration Association (LAIA), set up in 1980— have not achieved the expected results. The most important prevailing trade integration mechanisms are the Southern Common Market (MERCOSUR), set up in 1991; the Bolivarian Alliance for the Peoples of Our America – Peoples' Trade Agreement (ALBA-TCP), established in 2004; and the Pacific Alliance, created in 2011.

These agreements seek to form economic blocs that favour trade relations and support the development of the signatory countries. However, when it comes to making decisions, positions differ considerably, ranging from the openness of the Pacific Alliance to the protectionism of ALBA-TCP.

The member countries of the Pacific Alliance (Chile, Colombia, Mexico and Peru) follow a clear model of openness and liberalization. These States have ratified free trade agreements with various economies outside the region. These agreements are trade policy tools that help to develop competitive export and import exchanges, while producing economic, employment and social improvements. They often boost foreign investment by providing certainty and stability to investors.

Analysis of the free trade agreements that these countries have ratified shows that, in recent years, those with Asian countries have had the greatest impact on their economies. In conclusion, it can be said that:

- Latin American countries have entered into a multitude of regional agreements. Many have not succeeded, and others have promoted trade among member countries (for example, MERCOSUR). In this context, the Pacific Alliance has emerged as a trading bloc that promotes exchanges among its member countries and also exports outside the region.
- Most of the free trade agreements that Latin American countries have ratified have been with countries in the same region, with European partners and with the United States. However, in the period under review, the Asian economies, specifically China and Japan, have risen the most in the ranking of these economies' key trading partners.

2. Econometric model

A sample of 23 ports along the west coast of Latin America is used, with 8 observations over the 2008–2015 period. The ports are: Antofagasta, Arica, Coronel, Iquique, Lirquén, Mejillones, San Antonio, San Vicente and Valparaíso (Chile); Buenaventura (Colombia); Caldera (Costa Rica); Esmeraldas and Guayaquil (Ecuador); Acajutla (El Salvador); Puerto Quetzal (Guatemala); Ensenada, Lázaro Cárdenas and Manzanillo (Mexico); Corinto (Nicaragua); Balboa (Panama); Callao, Matanari and Paita (Peru). As there are more units of cross-sectional data available (23 ports) than time series (8 years), panel data estimates (N>T) are used, instead of time series data (N<T).

Greene (2003) states that the fundamental advantage of a panel data set over cross-sectional data is that it will allow greater flexibility in models, while taking into account the differences between the units that make up the model. Their main advantages include the fact that:

- No rigid assumptions are needed for panel data, while in the case of cross-sectional data, especially for the maximum likelihood estimation (MLE) model, distribution assumptions for each error component are needed to separate technical inefficiency from statistical noise. In addition, MLE analysis requires that technical inefficiency be independent of regressors.
- The technical efficiency for each unit can be estimated consistently with panel data. Although it is also possible to produce estimates using cross-sectional data, this is not consistent.
- Panel data provide more information about the behaviour of units over time, which cannot be analysed with cross-sectional data —such as changes in structure and factors that vary or do not vary over time— through fixed and random effects analysis.

The model specification is based on the basic structure proposed by Greene (2003):

$$Y_{it} = x'_{it}\beta + z'_i\alpha + \varepsilon_{it}$$

Where:

Y_{it} is the variable to be explained;

x'_{it} is a vector of explanatory variables ($K \times 1$);

$z'_i\alpha$ are the individual effects, where z_i contains a constant term and a set of individual or group variables, which may be observable or not;

β is the slope vector of the equation;

t is the time series up to period T ($t=1, 2, ..., T$);

i refers to individuals, the last one being individual N ($i=1, 2, ..., N$);

ε_{it} is the error term.

Based on the structure of the proposed econometric model, the following specification is presented:

$$LpcGDP_{it} = \beta_0 + \beta_1 \cdot LTEU_{it} + \beta_2 \cdot LUnemp_{it} + \beta_3 \cdot LGCI_{it} + \beta_4 \cdot T_{it} + \varepsilon_{it}$$

Where:

$LpcGDP_{it}$ is the natural logarithm of per capita GDP at purchasing power parity expressed in constant 2011 dollars of the country where port i is located in year t (World Bank, n/d);

$LTEU_{it}$ is the natural logarithm of TEUs handled at port i in year t (ECLAC, n/d);

$LUnemp_{it}$ is the natural logarithm of the unemployment rate of the country where port i is located in year t (World Bank, n/d);

$LGCI_{it}$ is the natural logarithm of the competitiveness index of the country where port i is located in year t (Schwab, 2016);

T_{it} is the dummy variable with a value of 1 for a country that signs an outward-looking trade agreement (Pacific Alliance) or that ratifies a free trade agreement with an Asian country in a given year, or with a value of 0 otherwise, at port i in year t;

β_m represents each of the coefficients of explanatory variables m;

t is the 2008–2015 period;

i is each of the analysed ports;

ε_{it} is the error term.

The fixed effects model is the most widely used model in economics and political science (Schurer and Yong, 2012). In addition, according to Wooldridge (2010), the fixed effects transformation is useful for policy analysis and economic programme evaluation. Brüderl and Ludwig (2015) argue that standard regression models provide biased estimates if there are unobserved intrinsic characteristics, while fixed effects regression is a method that can provide unbiased estimates under the same circumstances.

Before producing estimates by means of a fixed effects model (Brüderl and Ludwig, 2015; Gangl, 2010; Allison, 2009), random effects model or panel-corrected standard errors (PCSE) model (Rodríguez, 2017; Marques and Fuinhas, 2012; Reed and Webb, 2010), statistical tests must be performed to determine the characteristics of the data in the sample and to correctly select both the appropriate specification and econometric method.

The tests verify whether there is heteroscedasticity, temporal autocorrelation or contemporaneous correlation between cross-sectional units. Furthermore, if the presence of heteroscedasticity is detected (modified Wald test for groupwise heteroscedasticity), this means that the initial fixed effects estimate is not accurate and, therefore, a fixed effects estimate is calculated with a heteroscedasticity-robust error estimator of variance.

Lastly, the presence of autocorrelation and contemporaneous correlation ultimately leads to the use of the PCSE method specified by Beck and Katz (1995). This method is used to calculate the standard errors and the estimates of variance-covariance; errors are assumed to be heteroscedastic by default with contemporaneous correlation between panels (entities).

The variables in the model are expressed in logarithms, with the exception of the variable for treaties, which is included as a dummy variable.

(a) The Hausman test

The statistical test proposed by Hausman (1978) is based on a chi-square test to determine whether there are systematic and significant differences between two given estimates. The Hausman test has been widely used to determine the appropriateness of using a fixed effects or a random effects estimator in the context of specifications for panel data (Wooldridge, 2010; Greene, 2001). Fixed effects model specifications are, in principle, more appropriate when using a set of observations divided into cross-sectional units, as is the case with panel data. However, according to Baltagi (2008), if the number of cross-sectional units is too high in relation to the number of temporal units, a fixed effects model estimation will cause a significant loss of degrees of freedom, which will generally entail a higher variance of the estimated parameters; in such cases, it is proposed that the random effects estimator be used.

Table 5 presents the results of the Hausman test to determine whether a random effects model should be used.

Table 5
Results of the Hausman test

	Fixed coefficients (b)	Random coefficients (B)	Difference (b-B)	Standard error
LTEU	0.0298407	0.0303932	-0.0005525	0.0029095
LUnemp	-0.2317544	-0.1801522	-0.0516022	0.0077272
LGCI	0.521414	0.8465897	-0.3251758	0.0417249
Treaties	0.0640417	0.1101613	-0.0461196	0.0072828
Test: H_0: Non-systematic difference in coefficients				
χ^2 (7) = (b-B)'[(V_b-V_B)^(-1)](b-B) = 64.28				
Prob>χ^2 = 0.0000				

Source: Prepared by the authors.
Note: Calculations performed in Stata 13. LTEU: natural logarithm of TEUs (twenty-foot equivalent units) handled; LUnemp: natural logarithm of the unemployment rate; LGCI: natural logarithm of the competitiveness index.

The results obtained allow us to reject the null hypothesis ($p<0.05$) of equality with a 95% confidence level and, therefore, we must assume that the fixed effects estimation is appropriate.

(b) Wooldridge test for autocorrelation in panel data

Autocorrelation in a time series of a process X_t is the correlation of that process with a time-shifted version of the time series itself. According to Drukker (2003), autocorrelation in panel data models biases the standard errors and causes the results to be less efficient. Autocorrelation must therefore be identified in the idiosyncratic error term in the model. Baltagi and Wu (1999) set out a test similar to that of Wooldridge (2003), which was shown to have optimal power with a series of assumptions concerning the individual effects of the model being tested. However, according to Drukker (2003), the Wooldridge test should be less powerful than more highly parametrized tests because it requires relatively few assumptions and is easy to implement, but it should be more robust.

Under the null hypothesis of no serial correlation, the regression residuals of the first differences should have an autocorrelation of -0.5. This means that the coefficient of a regression based on the lagged residuals over current residuals should be -0.5. The results of this test are shown in Table 6.

Table 6
Wooldridge test results

H_0: No first-order autocorrelation
F(1.22) = 133.025
Prob>F = 0.0000

Source: Prepared by the authors.
Note: Calculations performed in Stata 13.

The null hypothesis of no first-order correlation is rejected, and it is assumed that first-order autocorrelation exists in the model.

(c) Testing for groupwise homoscedasticity

In order to use a statistical inference based on the ordinary least squares (OLS) covariance matrix, it must be assumed that, in addition to no autocorrelation, that there is homoscedasticity in the data. The difference in variance of each of the model's entities (or panels) must be tested to accept or reject the hypothesis of homoscedasticity.

In Table 7, a modified Wald test is run to test for groupwise heteroscedasticity in the residuals of the specific fixed effects regression model, as proposed by Greene (2003). The null hypothesis $\sigma^2_i = \sigma^2$ is proved for $i = 1, 2, ..., N_g$, where N_g is the number of cross-sectional units. The result of this modified Wald test will be distributed as an $\chi^2[N_g]$, under the null hypothesis of homoscedasticity. According to Baum (2001), the power of this test is low for small samples when N>T, so the results obtained should be taken with caution.

Table 7
Modified Wald test for groupwise heteroscedasticity

H_0: $\sigma^2_i = \sigma^2$, for all $i = 1, 2, 3, ..., 34$
χ^2 (23) = 1374.93
Prob> χ^2 = 0.0000

Source: Prepared by the authors.
Note: Calculations performed in Stata 13.

The null hypothesis of groupwise heteroscedasticity in the regression residuals is rejected.

(d) Pesaran's cross-section dependence test

According to De Hoyos and Sarafidis (2006), panel data models are likely to exhibit substantial cross-sectional dependence (or contemporaneous correlation) which may arise because of the presence of common shocks and unobserved components that ultimately become part of the error term. The same has been argued in the studies by Robertson and Symons (2000), Anselin (2001), Pesaran (2004) and Baltagi (2008).

Pesaran's test (see table 8) tests the hypothesis of cross-sectional independence in panel data models with N>T, by implementing the parametric testing procedure proposed by Pesaran (2004). It is for this reason that the Breusch-Pagan test was ruled out as a possible means of detecting contemporaneous correlation in the model residuals, in favour of the Pesaran's alternative approach.

Table 8
Pesaran test

H_0: Cross-sectional independence
Pesaran's cross-section dependence test = 18.156, Pr = 0.0000
Average absolute value of off-diagonal elements = 0.594

Source: Prepared by the authors.
Note: Calculations performed in Stata 13.

The null hypothesis of cross-sectional independence is rejected and, therefore, the existence of cross-sectional dependence (contemporaneous correlation) is assumed.

IV. Results

The tests performed detected that the sample presents the following characteristics: heteroscedasticity, autocorrelation and contemporaneous correlation. In addition, the Hausman test indicates that between a fixed effects and a random effects estimation, the fixed effects estimation is preferable (Wooldridge, 2010; Greene, 2001).

In the research carried out by Rodríguez (2017), a sample of data with the same characteristics is presented and certain estimates are made; he finds that PCSE estimation is the most appropriate in these circumstances. Lastly, in this research the estimation method that offers the best results is the PCSE model, applying the Prais-Winsten transformation (Prais and Winsten, 1954) beforehand, to correct first-order autocorrelation. It is also possible to calculate an autoregressive coefficient for each panel (known in the literature as panel-specific AR(1)) or to calculate a common autoregressive coefficient across all panels. It could be assumed a priori —since the sample is of a heterogeneous group of countries, although all are developing countries, with the exception of Chile and Mexico— that there is a different autoregression coefficient for each port. However, based on Beck and Katz (1995), it is suggested, as in the cross-sectional and panel time series models where the parameters of interest β do not vary for each cross-sectional unit, that the autocorrelation parameter should not vary either.

Since the sample's panel data are balanced, the strategy that has been followed to calculate the covariance is based on using all the observations that are common to each pair of panels to compute each element of the covariance matrix. Calculation of autocorrelation of time series has been selected as the method for calculating the autocorrelation parameter, all other alternatives being consistent and asymptotically equivalent.

Table 9 contains the results of the three estimations: basic fixed effects, which is the fixed effects estimator without any correction; fixed effects with a heteroscedasticity-robust error estimator of variance; and the PCSE model, with sample characteristics, meaning corrected for autocorrelation, contemporaneous correlation and heteroscedasticity. The estimation is performed for all 23 ports over 8 years, making a total of 184 observations. All of the model's variables are expressed as logarithms, except the variable that refers to trade agreements, which is treated as a dummy variable.

The data obtained from the model estimations allow us to identify some significant differences. In the two fixed effects estimations, Rho assumes a value of 0.98535966, while, in the case of PCSE, its value is reduced to 0.7022694. So, while the fixed effects estimations have the highest Rho value, when considering R^2 within (0.5868), between (0.2488) and overall (0.2346), these values are much lower than the R^2 of the PCSE model (0.9955).

In the fixed effect estimations, the variables analysed (LTEU, LUnemp, LGCI and trade agreements) are significant with a 95% confidence level and the estimated coefficients do not show variations. The results show that a 1% increase in the TEU indicator represents 0.0298% growth in per capita GDP. A 1% increase in the unemployment rate translates into a reduction in per capita GDP of 0.2318%. With regard to the competitiveness index, an improvement of 1% leads to an increase in per capita GDP of 0.5214%. Lastly, the existence of an outward-looking trade policy results in an increase in per capita GDP of 0.0640%.

Fixed effects estimates are consistent, but not efficient, given the characteristics of the sample's variables. Therefore, the PCSE estimation is carried out, with LUnemp as the only variable that does not appear as significant; this may be because —as stated in the research by Cipoletta Tomassian, Pérez and Sánchez (2010)— investments in infrastructure in the countries under analysis have been low and, therefore, have not influenced the labour market.

Table 9
Fixed effects model and panel-corrected standard errors model (PCSE)

$$Lpc\ GDP_{it}=\beta_0+\beta_1 \cdot LTEU_{it}+\beta_2 \cdot LUnemp_{it}+\beta_3 \cdot LGCI_{it}+\beta_4 \cdot T_{it}+\varepsilon_{it}$$

			Fixed effects	(Robust) fixed effects	PCSE
β_0			8.982853	8.982853	5.400565
Standard error			0.2009241	0.4333786	0.6216013
P>|t|			0.000	0.000	0.000
LTEU		β_1	0.0298407	0.0298407	0.0155947
		Standard error	0.0083282	0.0130366	0.0074627
		P>|t|	0.000	0.032	0.037
LUnemp		β_2	-0.2317544	-0.2317544	0.0383143
		Standard error	0.0241899	0.059507	0.0508677
		P>|t|	0.000	0.001	0.451
LGCI		β_3	0.521414	0.521414	2.612246
		Standard error	0.1267077	0.2265887	0.4352533
		P>|t|	0.000	0.031	0.000
T		β_4	0.0640417	0.0640417	0.2836674
		Standard error	0.0231973	0.0117699	0.0508644
		P>|t|	0.006	0.000	0.000
N			184	184	184
F			55.74	538.78	
P>F			0.000	0.000	
Wald Chi^2					164.79
P>Chi^2					0.000
COV(v_j,$x_{i,j}$)			0.2739	0.2739	
Rho			0.98535966	0.98535966	0.7022694
R^2					0.9955
R^2	Within		0.5868	0.5868	
	Between		0.2488	0.2488	
	Overall		0.2346	0.2346	
Estimated covariance					276
Estimated autocorrelation					1
Estimated coefficients					5

Source: Prepared by the authors.
Note: Calculations performed in Stata 13.

Regarding the PCSE model estimation, the LTEU, LGCI and trade agreement variables, in addition to being significant, have positive signs. In quantitative terms, a 1% increase in the TEU indicator results in 0.0156% growth in per capita GDP. A 1% increase in the competitiveness index results in a 2.61% rise in per capita GDP. In addition, the existence of an economic policy based on outward-looking free trade agreements or treaties with Asian countries results in an increase in per capita GDP of 0.2837%.

The results show that the competitiveness index has a significant impact on per capita GDP. This percentage is justified, primarily, by the configuration of the variable, since the index is prepared through analysis of different aspects of each country and the values range from 1 to 7. Specifically, in the 10 countries analysed, the values of the variable range from 3.32 to 4.75 in the period studied (2008–2015). In short, its limited variation and the grouping of so many aspects under a single indicator means that a slight increase in the index indicates that the country has improved considerably and, therefore, the effect of this on per capita GDP is clearly evident.

Lastly, the increase in per capita GDP resulting from the existence of outward-looking trade agreements or treaties with Asian countries, means that the outward-looking trade policy implemented toward the end of the twentieth century has boosted the development of Latin American countries. In addition, these economies did not suffer as severely from the effects of the global financial crisis.

V. Conclusions

Maritime transport accounts for 80% of world trade (UNCTAD, n/db). This research focuses on only one part of maritime transport: that which transports goods in containers. This is done for two important reasons: firstly, because of the trade boom in the logistics of containers with standardized measurements (TEU); and, secondly, because containerized goods is the form of freight trade with the highest added value. In short, containerized transport is a faithful reflection of the form of trade in goods with the most added value in the countries analysed. Therefore, such transport has very significant effects on these economies, by promoting considerable socio-economic development.

The results of the estimation support the hypothesis that an increase in containerized trade through ports has an impact on the growth of a country's economy and therefore that this type of trade benefits the entire population. Specifically, with regard to the estimation, the TEU indicator, competitiveness index and trade agreements variables, in addition to being significant, all have positive signs, meaning that their effects on per capita GDP are positive. In quantitative terms, a 1% increase in the TEU indicator results in 0.0156% growth in per capita GDP, while a 1% increase in the competitiveness index brings about a 2.61% rise in per capita GDP.

The trade agreements variable is intended to measure the effect of an outward-looking trade policy. Such approaches were boosted in the analysed period by trade with Asian countries, with whom a number of countries on the west coast of Latin America have free trade agreements. The existence of such a policy results in an increase in per capita GDP of 0.2837%.

The results show that the competitiveness index is the variable with the greatest impact on per capita GDP. This can be explained by how the index is obtained and by the limited variability of the sample analysed (with values between 3.32 and 4.75); consequently, a slight rise in the index translates into a considerable impact on per capita GDP.

Lastly, in the period analysed —2008 to 2015— the economies of the countries on the west coast of Latin America have been boosted by the trade policy instruments they have developed and by high commodity prices. The effects of these two factors can be measured through the volume of containerized goods transported, which is a faithful estimator of trade. However, it can also be concluded that these countries must increase investment in port infrastructure and modernize and adapt it to today's needs, since such facilities generate long-term economic benefits for the economy, and therefore also for the population.

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A regional approach to the study of industrial diversity in Argentina (1996–2012)[1]

Andrea Belmartino and Carla Daniela Calá

Abstract

The aim of this paper is to quantify the productive diversity of the manufacturing industry in the provinces of Argentina, to analyse trends in productive diversity between 1996 and 2012, and to identify the main related economic factors. A diversity index is calculated based on official data on total registered wage employment from the Dynamic Employment Analysis Database (BADE). An analysis is then performed of trends in diversity in the different provinces over the period. Lastly, an econometric panel data model is estimated to identify the main related economic factors. The industrial diversity of the provinces is negatively associated with withdrawal of firms and positively associated with level of development, region size, higher levels of urbanization and greater territorial capabilities. The results of this study can be used to design policies to promote regional diversity.

Keywords

Industry, industrial enterprises, manufacturing enterprises, manufactures, econometric models, industrial statistics, Argentina

JEL classification

L60, R11

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I. Introduction

Productive diversity is key to the design of countries' development strategies. In particular, the variety of goods produced and exported is directly related to economic development, in its early stages (Imbs and Wacziarg, 2003; Klinger and Lederman, 2004; Hidalgo and Hausmann, 2010). Diversity in productive structures generates additional benefits, such as promoting innovation and knowledge transmission (Duranton and Puga, 2000; Frenken, Van Oort and Verburg, 2007), reducing vulnerability to external shocks (Ghosh and Ostry, 1994; Kosacoff and Ramos, 1999; Haddad, Lim and Saborowski, 2010), incentivizing the entry of new firms (Guesnier, 1994; Reynolds, Storey and Westhead, 1994) and increasing investment opportunities (Al-Marhubi, 2000; Herzer and Nowak-Lehnmann, 2006; Hesse, 2009).

These empirical findings give productive diversity a central role in the design of industrial policies on local development. It is therefore important to know how diverse regional production structures are, how their diversity has changed over time, and what the related economic factors are. This article offers a regional view of this phenomenon based on a twofold analysis: firstly, it describes the trend in productive diversity of industry in the Argentine provinces between 1996 and 2012; and secondly, it examines the relationship between industrial diversity and some characteristics of the regions, such as their degree of development, level of urbanization, presence of resources and capabilities, and variables of business dynamics. Based on this, the aim is to generate meaningful information that can be used in the design of industrial development policies at the regional level.

The results obtained enable a deeper understanding of productive diversity, which the Economic Commission for Latin America and the Caribbean (ECLAC) has called a key mechanism for developing new technological capabilities in the framework of implementation of selective industrial policies (Lavarello and Sarabia, 2015). In this regard, and in keeping with the 2030 Agenda for Sustainable Development, ECLAC affirmed in 2017 the need to move towards more knowledge-intensive sectors that facilitate productive diversification, to generate new opportunities for social integration and inclusion.[2]

In Argentina, this issue has also been highlighted in the lines of action of the 2020 Strategic Plan for Industry (Ministry of Industry, 2011), which underscore the importance of actions that promote a more diversified production in order to achieve sustainable growth with equity (Porta, 2016). However, this growing interest contrasts with the limited number of academic contributions that address the phenomenon empirically, from a regional perspective. The papers that study productive diversity in Argentina mainly focus on analysing exports at the country level (Bebczuk and Berrettoni, 2006), or the distribution of employment in certain geographical areas (Fritzsche and Vio, 2000; Rojo Brizuela and Rotondo, 2006; Mazorra and Beccaria, 2007).

The article is structured as follows: first, it summarizes the main theoretical and empirical works that help to identify and understand the economic factors linked to regional productive diversity. Next, the data source, diversity index and estimation method are described. The results are then outlined, followed by some reflections and possible future lines of research.

II. Theoretical framework

This work falls within the field of regional science, meaning the set of studies that encompass the territorial dimension and its heterogeneities in economic analysis (Moncayo Jiménez, 2001). Although this field of science has provided theoretical models that allow for rigorous study of certain issues such as regional growth or the territorial concentration of economic activity (Capello, 2006), there are not

[2] Bielschowsky, Izam and Mulder (2011) summarize the evolution of ECLAC thinking on productive diversification and international integration from 1950 to the present.

yet any models that adequately describe the phenomenon of regional productive diversity. That is why empirical studies on the subject (see section III) often use ad hoc econometric specifications, incorporating elements from different theoretical frameworks. In particular, this paper draws on arguments from two approaches: (i) new economic geography (Krugman, 1991, 1995, 1998 and 1999); and (ii) resources and capabilities (Penrose, 1959; Teece, 1980; Montgomery, 1994).

1. New economic geography

This approach consists of a set of general equilibrium models in a structure of imperfect competition that take into account the existence of increasing returns to scale, transport costs and the possibility of territorial movement of production factors and consumers (Krugman, 1991; Fujita and Krugman, 2004). While these models generate a wide variety of results depending on specific assumptions, new economic geography highlights a number of elements that may explain productive diversity in large urban areas (Bishop and Gripaios, 2007).

Krugman (1998) suggests that there are two opposing forces: centripetal forces (which concentrate economic activity geographically and centrifugal forces (which dissipate it). Centripetal forces originate from circular causation: workers find better quality infrastructure, higher real wages and a greater variety of goods in large urban areas, while firms select locations in large markets to benefit from internal and external economies of scale. Similarly, within the concept of external economies there is often differentiation between the forces of localization and those of urbanization. The forces of localization are the benefits derived from the proximity of firms in the same industrial sector (specialized labour market, suppliers and technological spillovers), while the forces of urbanization are independent of the industrial sector (public, financial and commercial services, knowledge transfer) (Hoover, Jr., 1936). Evidence indicates that localization economies are particularly important for traditional manufacturing, while urbanization economies have a greater impact on services and high-tech manufacturing (Henderson, Kuncoro and Turner, 1995). In this regard, a more urbanized environment that facilitates knowledge transfers and innovation, will also be more conducive to productive diversity (Glaeser and others, 1992; McCann and Van Oort, 2009).

2. Regional resources and capabilities

The resource-based view arises from Penrose's (1959) contribution to the analysis of firms. Under this approach, firms are analysed on the basis of their "inherited" resources (Teece, 1980; Montgomery, 1994). This theory can also be applied to regions, which can be defined by their resource endowments, either tangible (such as infrastructure) or intangible (such as the human capital of their workers or the quality of their institutions) (Lawson, 1999; Boschma, 2004; Neffke and others, 2014; Boschma and Capone, 2015). Since resource endowments and capabilities determine which production activities can be carried out by firms in a region, they must be included as a factor that is associated with the degree of regional productive diversity and its evolution.

In this regard, the more modern approach proposed by Hidalgo and others (2007) analyses the network of relatedness between products and industries, originating from input-output links, technological sophistication and the use of similar capabilities or infrastructure. Under this approach, the development of greater capabilities, in a broad sense (such as productive, organizational and institutional capabilities), makes it possible to expand the product range and even produce more complex goods. This is why countries tend to diversify into products that are comparable to those they already export, i.e. goods that require similar capabilities. At the regional level, diversification also tends to occur in industries that are related to existing activities (Neffke, Henning and Boschma, 2011). The process is affected by the local industrial history, the territory's accumulated capabilities and the path dependence of the region (Martin and Sunley, 2006; Neffke and others, 2014).

III. Empirical background

The subject of productive diversity has been studied in the context of multiple disciplines and paradigms (Ramanujan and Varadarajan, 1989). In this regard, there are at least three dimensions of analysis: firm, region and country. In particular, work at the regional level has grown considerably in recent years (Frenken and others, 2004), especially in developed countries.[3]

Empirical evidence indicates that there is a positive correlation between a region's productive diversity and its size (Duranton and Puga, 2000; Monastiriotis, 2000; Beckstead and Brown, 2003; Bishop and Gripaios, 2007) and level of urbanization (Dewhurst and McCann, 2002; Bishop and Gripaios, 2007). In other words, as is to be expected in accordance with the elements indicated in new economic geography, the largest and most densely populated urban areas are also the most diverse.

Moreover, empirical studies that adopt a resources- and capabilities-based approach are faced with the difficulty of proper identification. Existing research quantifies regional capabilities by using proxy variables such as research and development (R&D) intensity (Aw and Batra, 1998; Parteka and Tamberi, 2011); the ratio of managers or technical personnel to total industry employment (Baldwin and others, 2000); number of employees in science- and technology-based industries (Baldwin and others, 2000; Bishop and Gripaios, 2007); or the educational level of the population (Parteka and Tamberi, 2011).

Some empirical studies link the degree of diversity of a region or country with its level of development, measured in terms of per capita gross domestic product (GDP). In this regard, De Benedictis, Gallegati and Tamberi (2009), and Parteka and Tamberi (2011) conclude that regions with lower per capita GDPs have a lower degree of relative production heterogeneity. In this regard, Imbs and Wacziarg (2003) show that the relationship between per capita GDP and diversity at the country level is non-linear, meaning that there is a positive correlation between growth and a more diverse production and export structure until countries reach certain income levels, at which point the relationship reverses and countries begin to specialize again.

A final group of papers draws on elements related to business dynamics to explain changes in regional productive diversity. These studies affirm that an increase in regional diversity can be evidenced by:

- the creation of new firms in existing industries but with a lower relative share of regional employment ("non-traditional" sectors), or growth of existing firms in those industries (Neffke, Henning and Boschma, 2011);
- the exit of firms or a contraction in employment in industries that account for a larger proportion of employed persons in the region ("traditional" sectors);
- the entry of new production industries (Kamien and Schwartz, 1975).

In short, a positive correlation is expected between regional productive diversity and the degree of regional development, the size of the region, higher levels of urbanization and the level of capabilities in the territory. Likewise, productive diversity is expected to be associated with certain variables of business dynamics (entry and exit of firms), although it is not possible to establish the direction of the relationship, a priori.

[3] For example, Beckstead and Brown (2003) in Canada; Rodgers (1957); Monastiriotis (2000) and Essletzbichler and Rigby (2007) in the United States; Boschma, Minondo and Navarro (2013) in Spain; Bishop and Gripaios (2007) in the United Kingdom; and Boschma and Iammarino (2007) and Marra, Carlei and Paglialunga (2011) in Italy. The number of empirical studies in developing countries is small, owing to the lower quality and availability of data (Nachum, 2004; Hammouda and others, 2006).

IV. Methodology

1. Data source

The main source of information is the Dynamic Employment Analysis Database (BADE), compiled by the Employment and Business Dynamics Observatory (OEDE), part of the Ministry of Labour, Employment and Social Security of Argentina. The unit of analysis is firms, identified by Unique Tax Identification Codes (CUIT). The database is constructed from firms' filings with the Integrated Retirement and Pension System and therefore contains data on total registered wage employment in the private sector in Argentina (Castillo and others, 2004). Industrial employment data have been used, disaggregated at the two-digit level of the International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 3.1, (see annex 1) and at the regional level in the 24 administrative areas that make up the territory of Argentina (23 provinces and the city of Buenos Aires).

To characterize the provinces, various data sources were also consulted, namely the National Population and Housing Census, the statistical yearbooks of the National Institute of Statistics and Censuses (INDEC), provincial statistics departments and data published by the Ministry of Industry and the Ministry of Science and Technology, as well as those on BADE.

2. Productive diversity index

The use of regional diversity indices allows a great volume of information to be easily summarized and interpreted. As is customary in the specialized literature (Aw and Batra, 1998; Duranton and Puga, 2000; Hammouda and others, 2006; Klinger and Lederman, 2004; Parteka and Tamberi (2011); Cadot, Carrère and Strauss-Kahn, 2011), this paper uses the inverse of the Herfindahl-Hirschman index (HHI) as a measure of diversity, constructed from data on regional registered wage employment in manufacturing.[4] HHI is defined as the sum of each sector's share of regional employment, squared (Duranton and Puga, 2000). The inverse of the index is as follows:

$$PD_i = 1/HHI = 1/\sum_{j=1}^{J} \left(\frac{E_i^j}{E_i} \right)^2 \qquad (1)$$

where E_i^j is the number of employees in sector j in region i and E_i is the total number of the industry's employees in the region.

3. Model

To examine the relationship between the productive diversity in manufacturing and the associated economic factors, an econometric panel data model is estimated. One of the main advantages of using this type of model is that it controls heterogeneity, both between individuals and over time (Baltagi, 2008). It is thus possible to control some characteristics of the provinces (whether observable or not) that do not change to a great extent over the period (such as natural resource endowments or institutional arrangements).

[4] Alternatively, the index can be calculated from product or value added data, but such information is not available at the regional level in Argentina.

The model specification is presented in equation (2), which includes fixed effects by province and dummy variables by year to capture time effects (θ_t). The dependent variable (PD_{it}) is the productive diversity index defined in equation (1).

$$PD_{it} = \beta_0 + \beta_1 pcGGP_{it} + \beta_2 Density_{it} + \beta_3 R\&D\_expend_{it} + \beta_4 Sh\_expo_{it} + \beta_5 Entry_{it} - \beta_6 Exit_{it} + \beta_t \theta_t + \varepsilon_{it} \quad (2)$$

The subindices refer to region i and time t. Table 1 lists the explanatory variables of the model, their expected sign and the data source. This information is summarised in table 1 and the correlation matrix is shown in annex 2.

Table 1

Argentina: factors associated with regional productive diversity: definition, data source, expected sign and descriptive statistics

Associated factor	Variable		Expected sign	Data source	Descriptive statistics			
					Mean	Deviation	Minimum	Maximum
Development	Per capita gross geographic product (in millions of pesos at constant 1993 values)	*pcGGP*	+	CEP PS	0.007	0.005	0.002	0.034
Level of urbanization	Population density	*Density*	+	INDEC	0.581	1.843	0.015	11.888
Resources and capabilities	Public expenditure on R&D (current values - log)	*R&D_expend*	+	INDEC	10.535	1.504	6.968	15.481
	Share of exports	*Sh_expo*	+	INDEC	3.978	8.010	0.036	39.447
Business dynamics	Entry of industrial firms (number of firms)	*Entry*	+/-	OEDE	199.394	415.620	2.000	2 946.00
	Exit of industrial firms (number of firms)	*Exit*	+/-	OEDE	180.666	392.213	4.000	2 540.00

Source: Prepared by the authors.
Note: CEP: Production Research Centre; PS: provincial statistics departments; INDEC: National Institute of Statistics and Censuses; OEDE: Employment and Business Dynamics Observatory.

Firstly, a region's degree of development, estimated on the basis of the per capita gross geographic product *(pcGGP)* is expected to have a positive correlation with its productivediversity (De Benedictis, Gallegati and Tamberi, 2009; Parteka and Tamberi, 2011). Provincial gross geographic product (GGP) data have been used, as published by the Production Research Centre (Ministry of Industry) and by the provincial statistics departments. The data have been deflated using the implicit price index (IPI) for Argentina and the Buenos Aires province IPI (in the robustness analysis), since there are no constant price pcGGP data (or price indices) for all provinces over the period analysed.

In addition, in order to evaluate the relationship between the degree of diversity and the level of urbanization of each region, a density variable is included, measured as the quotient between the population of each province and its area in square kilometres. As a measure of regional capabilities, public expenditure on research and development *(R&D_expend)* is included, as is each province's percentage share of the country's total exports *(Sh_expo)*. According to Castellacci (2007), Filipescu and others (2013), and Artopoulos, Friel and Hallak (2013), entry into the external market can be understood as a result of development of productive, organizational or institutional capabilities. Thus, a region that is oriented towards the international market requires greater learning and sophistication in its exporting firms and local suppliers, to adjust to the characteristics of the new demand. Stimulation of external demand can also encourage development of new products and processes, boosting diversity through "demand-pull" (Schmookler, 1966; Crépon, Duguet and Mairesse, 1998).

Lastly, it is not possible to establish a priori the direction of the correlation between the degree of diversity and the variables of business dynamics (number of industrial firms that are established or closed during the year). There will be a positive correlation between diversity and the entry of firms when they enter less traditional sectors. It will be negative if the entry is into traditional activities, i.e. those that account for a high share of regional employment (Dumais, Ellison and Glaeser, 2002; Noseleit, 2010). Conversely, there is a negative (positive) correlation between the exit of firms and diversity if closures occur in less (more) traditional sectors in each region (Duranton and Puga, 2000; Noseleit, 2010). The data on business dynamics are from BADE, published by OEDE.

V. The manufacturing industry in Argentina

The manufacturing industry in Argentina accounted for 67% of exports (33% agricultural and 34% industrial), 22.5% of GDP and 20% of employment in 2012. Each region has a different industrial profile, depending on the relative importance of industry in each province and the type of specialization (see table 2).

Table 2
Argentina: industrial sector's share of total provincial employment

Provincial groups	Province	Percentage of industrial employment		Major manufacturing industries (ISIC division[a] - 2012)[b]		
		1996	2012	1	2	3
1. Production and consumption hub	City of Buenos Aires	18.8	13.7	15	26	22
	Buenos Aires	33.6	26.5	15	24	25
	Santa Fe	31.0	26.1	15	29	28
	Córdoba	26.7	21.1	15	34	29
2. Promotes industry	San Luis	51.9	34.7	15	17	25
	San Juan	26.6	17.3	15	26	24
	Catamarca	27.1	21.5	15	17	18
	La Rioja	44.1	33.9	15	17	19
	Tierra del Fuego	28.4	36.9	32	34	25
3. Agro-industrial complex	Tucumán	25.6	16.0	15	17	28
	La Pampa	13.9	11.5	15	17	26
	Entre Ríos	21.1	18.8	15	20	28
	Salta	16.0	14.2	15	16	24
	Río Negro	10.6	8.9	15	24	26
	Mendoza	25.3	19.3	15	26	29
	Jujuy	29.8	22.0	15	27	16
	Santiago del Estero	15.4	10.7	15	17	26
4. Oil and fishing complexes	Neuquén	11.3	7.9	15	28	29
	Chubut	17.3	11.6	15	17	27
	Santa Cruz	6.5	5.4	15	29	28
5. Forestry and textile complexes	Chaco	16.9	12.0	15	17	26
	Formosa	11.6	7.3	15	24	36
	Corrientes	18.4	15.1	15	20	17
	Misiones	30.5	21.2	15	20	21

Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).
[a] ISIC, Rev. 3.1.
[b] In terms of employment.

In the provinces that are the country's main production and consumption hubs (Buenos Aires, Santa Fe and Córdoba), industry is relatively more important in terms of employment: the proportion of industrial employment in these administrative areas is higher than the national average (20%). The city of Buenos Aires specializes in services, mainly owing to the diseconomies of the urban area for industrial production. In these administrative areas, as in the rest of the country's provinces (except Chaco and Tierra del Fuego), the main sector is the manufacture of food products and beverages (division 15). It is followed in order of importance by industries linked to the population (such as publishing and printing, division 22 or to the agricultural sector (machinery and equipment, division 29).

Another group of provinces with industrial activity levels higher than the national average comprises the regions that benefit from frameworks to promote industrial activity (Tierra del Fuego, San Luis, La Rioja and Catamarca).[5] In these provinces, the activities with the greatest relative weight are those fostered by promotion policies (such as the manufacture of radio, television and communication equipment and apparatus (division 32) in Tierra del Fuego, or the manufacture of textiles (division 17)).

A third group of provinces has a markedly agro-industrial profile (Tucumán, La Pampa, Entre Ríos, Salta, Río Negro, Mendoza, Jujuy and Santiago del Estero). Food and beverage manufacturing accounts for more than 50% of registered industrial employment. Neuquén, Chubut and Santa Cruz are characterized by activities related to oil and fishing complexes. Lastly, the fifth group comprises provinces where industries (sawmilling, group 201; furniture, division 36; and textiles, division 17) are linked to the natural resources present in the region (Chaco, Corrientes, Formosa and Misiones).

VI. Results

1. Productive diversity of industry at the national and regional levels (1996–2012)

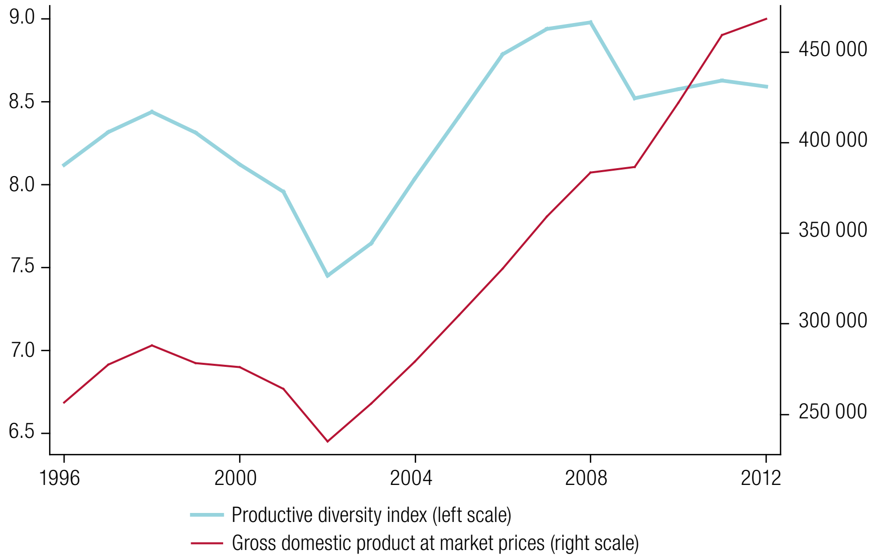
The productive diversity of Argentine industry is closely related to the macroeconomic fluctuations of the past 20 years, which affected the economy in general and the manufacturing industry in particular. Figure 1 shows that industrial diversity is a clearly procyclical phenomenon, meaning that it follows a similar pattern to GDP (measured on the right scale). The diversity indicator declined continuously from 1998 onward, bottoming out in 2002 following the emergence of the political, economic and social crisis in Argentina in late 2001. During the period of economic recovery that began in 2003, industrial diversity increased steadily, even surpassing pre-crisis values, peaking in 2008. From that year onward, industrial diversity declined again, mirroring the international financial crisis and the gradual appreciation of the exchange rate, and failed to recover in subsequent periods. The positive correlation between the industrial diversity indicator and gross domestic product at market prices (GDPmp) is statistically significant, with similar results for the GDPmp growth rate (see table 3).[6]

However, within Argentina, is diversity also a procyclical phenomenon in all the regions? Are all the provinces equally diverse? What economic factors can be associated with a greater or lesser degree of industrial productive diversity?

[5] The provinces with frameworks to promote industrial activity are La Rioja (Law No. 22.021/79), San Luis and Catamarca (Law No. 22.702/82) and San Juan (Law No. 22.973). Tierra del Fuego is considered a Special Customs Area (Law No. 19.640/72).

[6] From 2007 onward, the markedly positive correlation between the two variables was interrupted. This may be because of an overestimation of GDP in real terms as a result of action in 2007 by the official statistics body (INDEC).

Figure 1
Argentina: industrial diversity (1/HHI) and gross domestic product at market prices (GDPmp), 1996–2012
(Millions of pesos at constant 1993 prices)



Source: Prepared by the authors, on the basis of the National Institute of Statistics and Censuses (INDEC) and the Dynamic Employment Analysis Database (BADE).
Note: HHI: Herfindahl-Hirschman index.

Table 3
Argentina: correlation between gross domestic product at market prices (GDPmp) and the diversity index

Variables	Pearson correlation coefficient
GDPmp/diversity index	0.746*
GDPmp growth rate/diversity index	0.551**

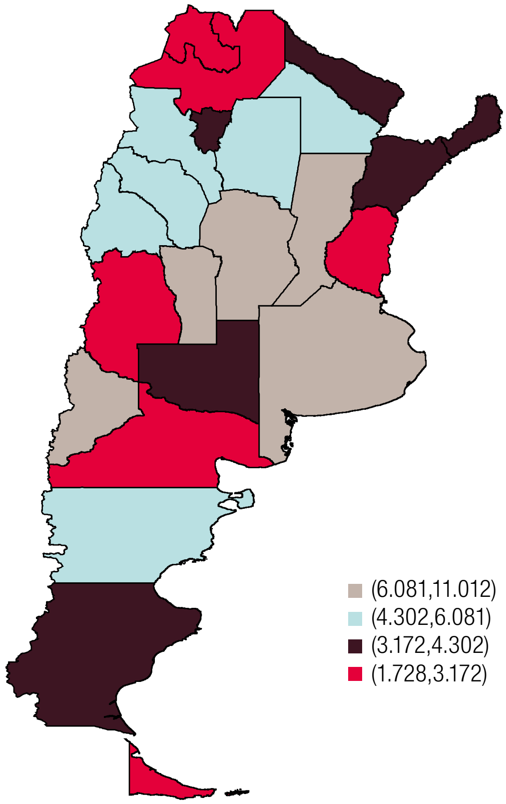
Source: Prepared by the authors, on the basis of the National Institute of Statistics and Censuses (INDEC) and the Dynamic Employment Analysis Database (BADE).
Note: Statistically significant relationships: ** 0.05; * 0.10.

Far from being homogeneous, the Argentine territory shows marked structural heterogeneity, reflected in historical economic and territorial inequality. This, in turn, is a result of diversity of resources, population density, industrial localization and urbanization of certain geographical areas (Zalduendo, 1975; Gatto, 2007). These inequalities can also be seen in industrial productive diversity (see map 1).

The major administrative areas of the country —the city of Buenos Aires, and the provinces of Buenos Aires, Santa Fe and Córdoba— are the most diverse, along with San Luis and Neuquén. In contrast, some of the agro-industrial provinces —Salta, Jujuy, Entre Ríos, Mendoza and Río Negro— are the least diverse, as the food industry accounts for around 60% of industrial employment.[7] The situation is similar in Tierra del Fuego, where the radio and television manufacturing industry accounts for 60% of industrial employment.

[7] Considering the degree of production development of some provinces (such as Mendoza or Entre Ríos), it is possible that there is high diversity within the food industry (related diversity), which cannot be captured by the diversity indicator used (inverse of the Herfindahl-Hirschman index (HHI)) with employment data disaggregated at the two-digit level of ISIC, rev. 3.1.

Map 1
Argentina: degree of productive diversity (1/HHI), 2012



Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).

The high diversity of the city of Buenos Aires and the central provinces (Buenos Aires, Santa Fe and Córdoba) has been a structural and relatively stable feature in recent years (see table 4). Conversely, in the provinces with frameworks to promote industrial activity (San Luis, San Juan, La Rioja and Catamarca) diversity has decreased, possibly owing to the declining impact of such frameworks on the less traditional sectors in each region (Donato, 2007). In Tierra del Fuego, diversity has dropped sharply since 2009, as a result of the relative increase in employment in the sectors benefiting from special frameworks over the period (radio and television equipment, textiles, leather and footwear).

Figure 2 shows the evolution of average diversity by the provincial groups listed in table 4, together with the national index. The national trend is set by the most diverse regions, which are the ones with the greatest relative weight in terms of employment. The other groups show a similar trend, i.e. they show procyclical patterns, except for the provinces with industrial promotion policies, whose diversity has declined steadily.[8]

An increase in the degree of diversity may be associated with one of two phenomena: either growth in employment in less traditional sectors (with steady or slackening growth in traditional sectors); or a fall in employment in the main sectors. One example of the former is the province of Chubut, where the increase in diversity is linked to growth in non-traditional sectors such as metal products (division 28) or non-metallic minerals (division 26). Chaco is an example of the latter, where the increase in diversity is the result of a fall in employment in the textile industry (division 17) (see figure 3). The causes and effects of diversity are likely to change in both cases and future research on the subject should consider this.[9]

[8] The evolution of the productive diversity index by province is set out in annex 3.

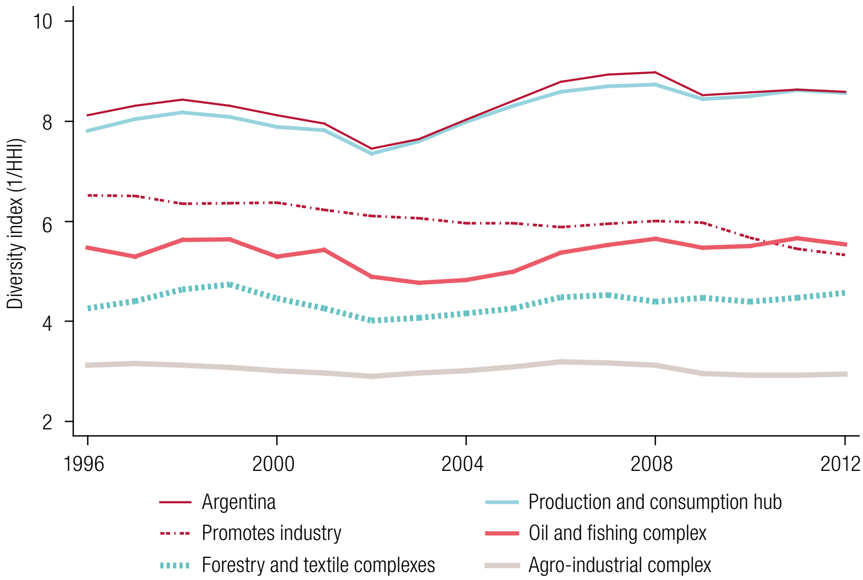
[9] In the models in section VI.2 it was not possible to incorporate this, since Chaco is the only province with a pattern linked to the second group. It is therefore not possible to estimate different regressions for each group or to incorporate a binary variable into the fixed-effects panel data regressions.

Table 4
Argentina: provincial productive diversity index, 1996–2012

Provincial classification	Province	Productive diversity index, 1996	Productive diversity index, 2012	Change (1996–2012)	Coefficient of variation (1996–2012)
Production and consumption hub	City of Buenos Aires	9.65	11.01	↑	0.07
	Buenos Aires	10.29	10.14	↓	0.03
	Santa Fe	5.73	6.99	↑	0.06
	Córdoba	5.57	6.09	↑	0.06
Promotes industry	San Luis	10.45	7.52	↓	0.09
	San Juan	5.55	5.94	↑	0.04
	Catamarca	6.58	5.41	↓	0.08
	La Rioja	5.68	5.19	↓	0.05
	Tierra del Fuego	4.33	2.57	↓	0.15
Agro-industrial complex	Tucumán	3.43	3.44	↑	0.03
	La Pampa	4.68	3.23	↓	0.17
	Entre Ríos	2.61	3.10	↑	0.08
	Salta	2.75	2.77	↑	0.04
	Río Negro	2.53	2.54	↑	0.09
	Mendoza	2.45	2.33	↓	0.06
	Jujuy	2.27	1.72	↓	0.11
Oil and fishing complex	Neuquén	6.57	6.58	↑	0.04
	Chubut	4.59	5.98	↑	0.10
	Santa Cruz	5.25	4.06	↓	0.15
Forestry and textile complexes	Santiago del Estero	4.28	4.43	↑	0.04
	Chaco	4.55	6.06	↑	0.08
	Formosa	4.85	4.17	↓	0.13
	Corrientes	3.74	4.06	↑	0.08
	Misiones	3.88	4.00	↑	0.05

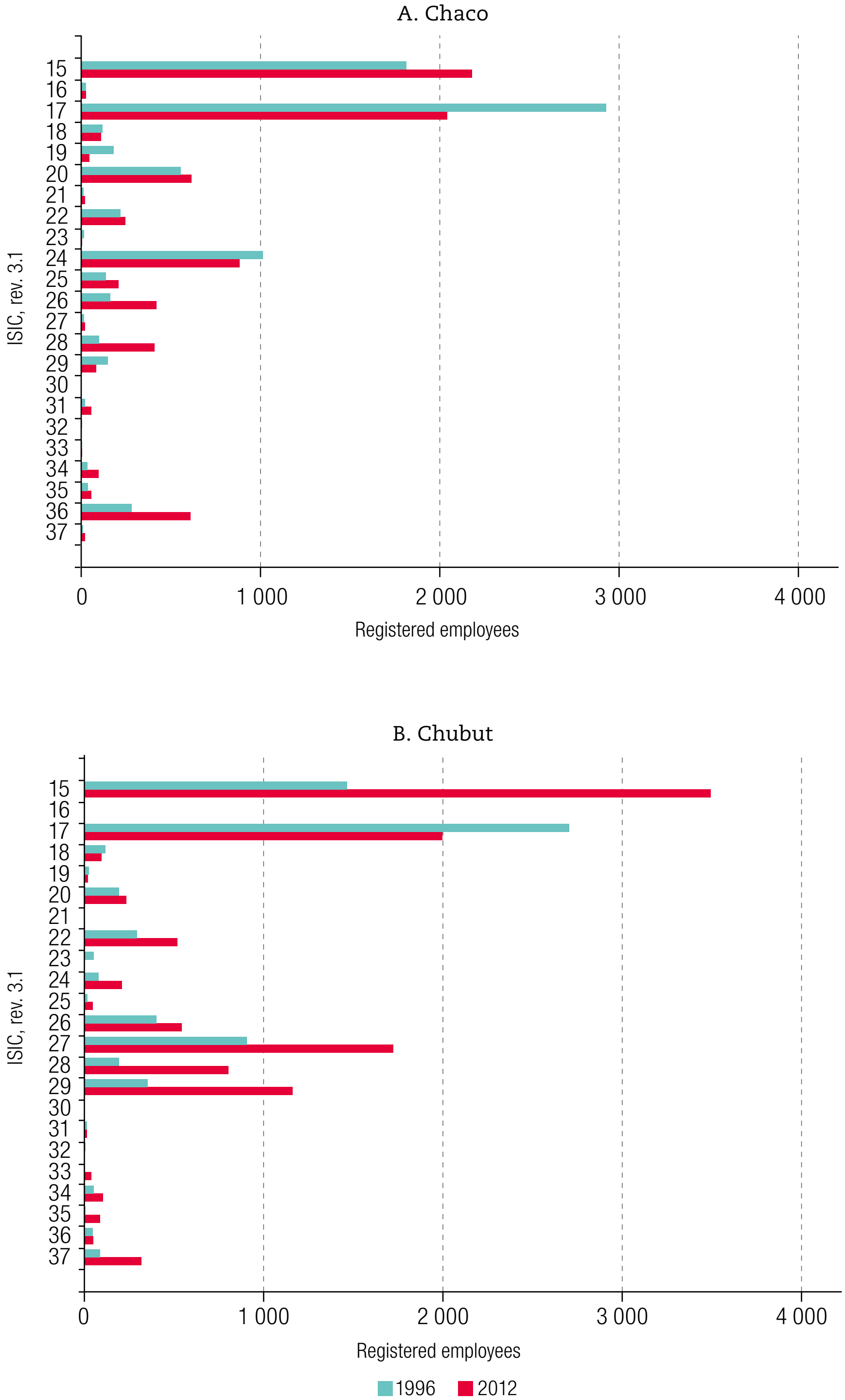
Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).

Figure 2
Argentina: industrial diversity (1/HHI) by groups of provinces



Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).

Figure 3
Argentina (Chubut and Chaco): economic activities by share of total industrial employment, 1996 and 2012



Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).
Note: Only two cases are included that contrast the two described causes of increased regional diversity: (a) employment growth in less traditional sectors and (b) declining employment in traditional sectors.

2. Economic factors linked to regional productive diversity

To identify the economic factors associated with the degree of regional diversity, a fixed-effects panel data model is estimated. This type of model was preferred to a random-effects model since the null hypothesis of the Hausman test (Hausman, 1978) was rejected.[10] Table 5 shows the results of the estimation, which include dummy variables by year to capture the time effects. The explanatory variables used have been lagged by one period as a strategy to deal with the potential problem of endogeneity (Bebczuk and Berrettoni, 2006).

Most of the estimated coefficients are statistically significant and with the expected sign, in accordance with the specialized literature. Firstly, there is a direct relationship between the regions' per capita products and their productive diversity. This confirms that the degree of regional development is positively associated with regional productive diversity.[11]

Table 5
Argentina: factors associated with the diversity of regional industry
(model 1)

Factors	Model 1
Per capita GGP	84.8968*
	(34.8276)
Density	0.9827***
	(-0.1433)
R&D expenditure	0.2095
	(-0.1533)
Share of exports	0.0552*
	(-0.0211)
Entry of industrial firms	0.0000
	(-0.0002)
Exit of industrial firms	-0.0008*
	(-0.0003)
Constant	2.0581
	(1.5958)
F-test	57.89***
R^2 (w)	0.36

Source: Prepared by the authors.
Notes: Significance: * p<0.05; ** p<0.01; *** p<0.001; 378 observations; fixed effects by province, dummy variables by year; dependent variable: productive diversity index; variables lagged by one period; robust standard errors in parentheses.

Population density (a proxy variable for the level of urbanization) is directly correlated with diversity. This is evidence that urbanization economies may be a factor associated with regional industrial diversity. There is also a positive and significant relationship between each province's share of national exports and its degree of diversity. The interpretation is that provinces with greater involvement in the external market have more capabilities and resources, increasing possibilities to expand the product range of local industry.

[10] The key assumption means that in the random-effects model it cannot be assumed that the explanatory variables are independent of the error term, so if the null hypothesis is rejected, it is suggested to use a fixed-effects estimator, which always provides consistent estimates (Wooldridge, 2010). The random-effects estimates are available for consultation.

[11] Alternative specifications also included the quadratic term (pcGGP2) to determine whether there is a non-linear relationship between regional diversity and development, such as that observed at the country level by Imbs and Wacziarg (2003). The term was not statistically significant. This could be because Argentine regions are much more homogeneous in terms of development than the countries analysed by these authors.

While a positive correlation was expected between R&D spending and diversity, the coefficient is positive but not significant. This may be because public spending on R&D at the provincial level in Argentina is not sufficient to encourage a change in the production structure.

Examination of the variables that capture regional industrial dynamics shows that the exit of firms decreases diversity. This indicates that exits are most frequent in the less traditional sectors of each region, either because they have fewer localization economies, limited productive or institutional capabilities to keep firms in the market, or infrastructure that is not suited to their development. In contrast, the entry of firms is not statistically significant, possibly because firms enter both traditional and non-traditional sectors in each region, thus offsetting the impact of such entries on diversity. Greater disaggregation of the business dynamics data could allow the effective identification of the sectors firms enter and exit at the provincial level, and corroborate these interpretations.

Table 6 shows the results of an alternative specification, which includes a measure of the size of the region —GGP— to analyse whether, as suggested by the specialized literature, the largest regions are also the most diverse (the measure of degree of development (pcGGP) is omitted owing to high multicollinearity). The relationship between the size of the regions and diversity is positive and significant. The rest of the results remain the same.

Table 6
Argentina: factors associated with the diversity of regional industry
(model 2)

Factors	Model 2
GGP	0.00001*
	(0.000)
Density	0.8387***
	(0.118)
R&D expenditure	0.2237
	(0.181)
Share of exports	0.0600*
	(0.030)
Entry of industrial firms	-0.0001
	(0.000)
Exit of industrial firms	-0.0007**
	(0.000)
Constant	2.3717
	(1.747)
F-test	343.27***
R^2 (w)	0.33

Source: Prepared by the authors.
Note: Significance: * p<0.05; ** p<0.01; *** p<0.001; 378 observations; fixed effects by province, dummy variables by year; dependent variable: productive diversity index; variables lagged by one period; robust standard errors in parenthesis.

To verify the robustness of the results, various alternative specifications of the models are presented in table 7. Firstly, since price indices are not available for all provinces, as an alternative to Argentina's IPI, the IPI of the city of Buenos Aires is used to deflate the GGP data (see table 7). The results remain the same, using GGP both as a measure of development (per capita GGP – model 3) and as a proxy for size (GGP – model 4).

Table 7
Argentina: factors associated with the diversity of regional industry (models 3 and 4)

Factors	Model 3	Model 4
Per capita GGP (deflated based on the IPI for the city of Buenos Aires)	87.6756*	
	(32.6031)	
GGP (deflated based on the IPI for the city of Buenos Aires)		0.0001*
		(0.000)
Density	1.0064***	0.839***
	(-0.1425)	(0.118)
R&D expenditure	0.2134	0.224
	(-0.151)	(0.181)
Share of exports	0.0549*	0.061*
	(-0.0213)	(0.030)
Entry of industrial firms	0.0000	0.000
	(-0.0002)	(0.000)
Exit of industrial firms	-0.0008*	-0.001**
	(-0.0003)	(0.000)
Constant	1.9886	2.375
	(1.5798)	(1.746)
F-test	58.70***	354.07***
R^2 (w)	0.38	0.33

Source: Prepared by the authors.
Note: Significance: * p<0.05; ** p<0.01; *** p<0.001; 378 observations; fixed effects by province, dummy variables by year; dependent variable: productive diversity index; variables lagged by one period; robust standard errors in parentheses.

Another test of robustness consists of estimating regressions excluding provinces whose main activity accounts for more than 50% of regional industrial employment (Tucumán, La Pampa, Entre Ríos, Salta, Río Negro, Mendoza, Jujuy and Tierra del Fuego). It is possible that in these provinces the pattern in the index is related to factors that affect the trend in the main sector and not factors linked to diversity. As in the base estimated regression, most of the explanatory variables remain statistically significant and show the expected signs (see table 8). The results are presented taking the constant pcGGP, deflated by the IPI of Argentina (model 5) and by the IPI of the city of Buenos Aires (model 6).

Table 8
Argentina: factors associated with the diversity of regional industry (excluding provinces with highly concentrated employment)

Factors	Model 5	Model 6
Per capita GGP (deflated based on the IPI for Argentina)	101.409**	
	(29.3258)	
Per capita GGP (deflated based on the IPI for the city of Buenos Aires)		98.9882**
		(30.6885)
Density	4.6024**	4.5532**
	(1.4499)	(1.5046)
R&D expenditure	0.4071*	0.4008*
	(0.1698)	(0.1712)
Share of exports	0.0399*	0.0407*
	(0.0208)	(0.0206)
Entry of industrial firms	0.0001	0.0001
	(0.0002)	(0.0002)
Exit of industrial firms	-0.0007*	-0.0007*
	(0.0003)	(0.0003)
Constant	0.1987	0.2928
	(1.9722)	(1.9928)
F-test	6.96***	9.28***
R^2 (w)	0.42	0.42

Source: Prepared by the authors.
Note: Significance: * p<0.05; ** p<0.01; *** p<0.001; 256 observations; fixed effects by province, dummy variables by year; dependent variable: productive diversity index; variables lagged by one period; robust standard errors in parentheses.

In order to control possible path dependence in the diversification process, a dependent variable lagged by one period is included as an independent variable, modelled on the Arellano-Bond estimator for dynamic panels. Although the generalized method of moments (GMM) model is globally significant, the variables included are not statistically significant, which may be evidence of multicollinearity between the variables mentioned (see table 9). Although instrumental variables estimation could be appropriate in this case, it cannot be used because of the low number of observations.[12]

Table 9
Argentina: factors associated with the diversity of regional industry (dynamic model)

Factors	Model 7
Diversity index (lagged one period)	-0.5481
	(0.7465)
Per capita GGP	-17.06
	(441.1592)
Density	-13.8913
	(14.1142)
R&D expenditure	0.4415
	(0.9466)
Share of exports	-0.0098
	(0.0468)
Entry of industrial firms	0.0003
	(0.0004)
Exit of industrial firms	-0.0004
	(0.0005)
Constant	7.3263
	(4.5333)
Wald test	1904.06***

Source: Prepared by the authors.
Note: Significance: * $p<0.05$; ** $p<0.01$; *** $p<0.001$ GMM; 378 observations; Lag (1) dummy variable by year; dependent variable: productive diversity index; variables lagged by one period; robust standard errors in parentheses.

VII. Concluding remarks

The specialized literature considers productive diversity to be key to the design of industrial policies for regional development. A more diverse productive structure is associated with an environment that is conducive to new investment, greater innovation and the transfer of knowledge, among other positive effects. This article contributes empirically to the study of productive diversity through a regional approach with updated data for all Argentine provinces. In particular, it analyses industrial diversity in both static and dynamic terms: on one hand, it describes and quantifies the degree of regional productive diversity in Argentina and how it evolved in the 1996–2012 period; and on the other, it examines the relationship between this phenomenon and some associated regional economic factors.

In static terms, the most diverse administrative areas in the country are the city of Buenos Aires and the provinces of Buenos Aires, Santa Fe, Córdoba, San Luis and Neuquén. This result may be associated with the higher level of urbanization in these regions, with greater productive, institutional and organizational capabilities that encourage the establishment of a large number of enterprises in various sectors, or with the existence of specific industrial policy incentives. In contrast to this group, the

[12] For example, He (2009) uses data from 20,035 firms; Elhiraika and Mbate (2014) work with information from 53 countries; Cadot, Carrère and Strauss-Kahn (2011) use export data for 79 countries.

provinces with a less diverse industrial structure are those with an agrifood base (Tucumán, La Pampa, Entre Ríos, Salta, Río Negro, Mendoza and Jujuy), where the food and beverage sector accounts for more than half of industrial employment.

In dynamic terms, productive diversity is a procyclical phenomenon, both at the national level and in most regions. This result, together with the negative impact on diversity of firms' exits, highlights the need for a stable growth path to achieve structural change based on productive diversity. This also raises a number of questions about the impact of macroeconomic policies (exchange rate, trade protection and fiscal policies, among others) on productive diversity, at the national and regional levels.

The provinces that have frameworks to promote industrial activity (San Luis, Catamarca, San Juan, La Rioja and Tierra del Fuego) are a special case, in which industrial diversity is not procyclical but is in steady decline. In some instances, this may be linked to the current inability of such frameworks to drive changes in the production structure that entail growth in non-traditional sectors, while in others the greater specialization is related to the sizeable incentives recently received to develop certain industries, such as radio and television equipment manufacturers in Tierra del Fuego.

The results of the econometric estimations indicate that the industrial diversity of the provinces is positively associated with their level of development, the size of the region and a higher level of urbanization. This restricts the ability of specific policies to promote productive diversification, given that these structural characteristics are difficult to change in the short term. Regional industrial diversity is also directly related to territorial capabilities, which may be boosted through medium-term industrial policies.

Conversely, the exit of firms is negatively associated with the degree of diversity. This may be because of the closure of firms in non-traditional sectors, whose external economies (such as specialized labour market and suppliers) and supporting institutions are not sufficiently consolidated. In this regard, policies to retain firms in less traditional sectors may be more effective in increasing diversity than those focused on the entry of new businesses in those sectors.

Some dimensions that have not been addressed in this article may give rise to future research on the subject. Firstly, greater disaggregation of the data (three or four digits in ISIC, rev. 3.1), or study of the primary, commercial and service sectors would provide a more in-depth understanding of the phenomenon, given that the relative importance of industry differs sharply between provinces. Another point of interest is whether diversity occurs in related or unrelated industries, since international literature indicates that these two types of diversity are driven by different sources and have different effects. In the same vein, the availability of business demography data with greater sector disaggregation would make it possible to determine the sectors (traditional or not) that businesses actually enter and exit.

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Annex A1

Table A1.1
International Standard Industrial Classification of All Economic Activities (ISIC), rev. 3.1

Code	Division
15	Manufacture of food products and beverages
16	Manufacture of tobacco products
17	Manufacture of textiles
18	Manufacture of wearing apparel; dressing and dyeing of fur
19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
21	Manufacture of paper and paper products
22	Publishing, printing and reproduction of recorded media
23	Manufacture of coke, refined petroleum products and nuclear fuel
24	Manufacture of chemicals and chemical products
25	Manufacture of rubber and plastics products
26	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment n.e.c.[a]
30	Manufacture of office, accounting and computing machinery
31	Manufacture of electrical machinery and apparatus n.e.c.[a]
32	Manufacture of radio, television and communication equipment and apparatus
33	Manufacture of medical, precision and optical instruments, watches and clocks
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment
36	Manufacture of furniture; manufacturing n.e.c.[a]
37	Recycling

Source: Prepared by the authors, on the basis of United Nations, "International Standard Industrial Classification of all Economic Activities, ISIC Rev 3.1", *Statistical Papers*, No. 4, New York, 2002.

[a] Not elsewhere classified.

Annex A2

Table A2.1
Argentina: correlation matrix

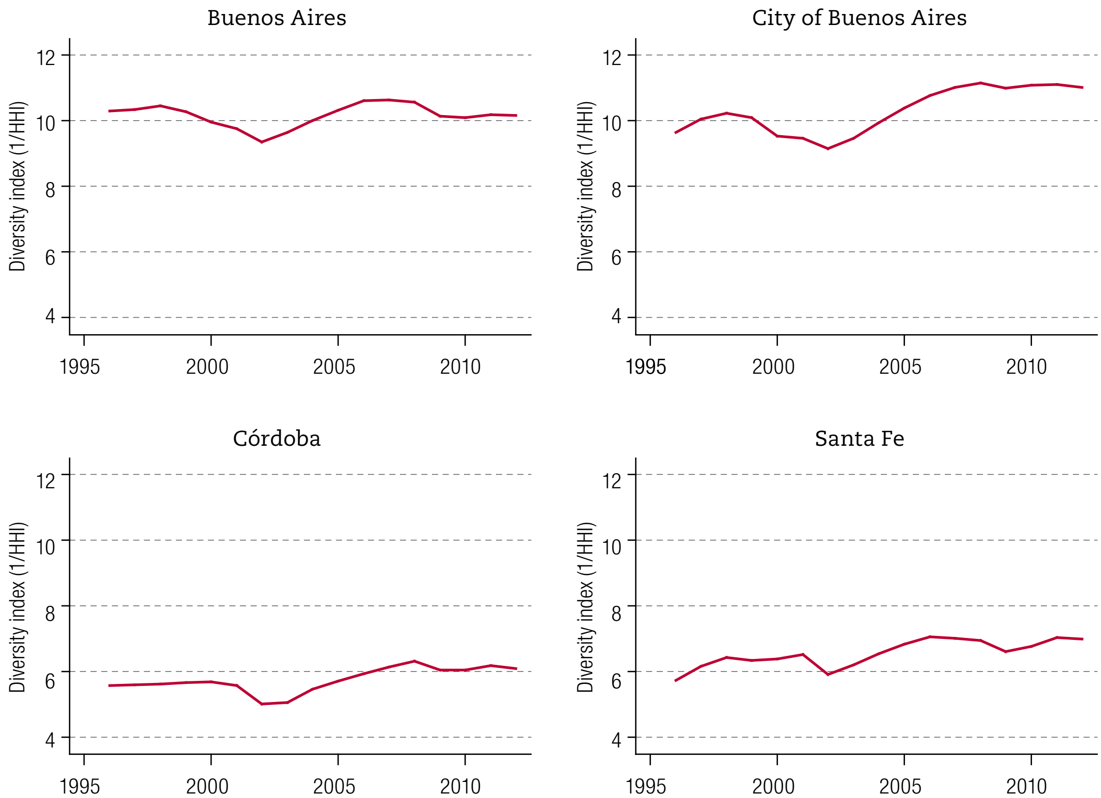
	PD[a]	GGP[b] (IPI BA)[c]	pc_GGP[d] (IPI BA)	GGP (IPI Arg)[e]	pc_GGP (IPI Arg)	Density	R&D[f] expend	Sh_expo	Entry	Exit
PD	1.00									
GGP (IPI BA)	0.69	1.00								
pc_GGP (IPI BA)	0.40	0.34	1.00							
GGP (IPI Arg)	0.69	1.00	0.34	1.00						
pc_GGP (IPI Arg)	0.40	0.34	1.00	0.34	1.00					
Density	-0.07	-0.12	0.38	-0.12	0.38	1.00				
R&D_expend	0.49	0.72	0.26	0.72	0.25	-0.18	1.00			
Sh_expo	0.50	0.74	0.01	0.74	0.01	-0.10	0.53	1.00		
Entry	0.65	0.91	0.22	0.92	0.22	-0.12	0.67	0.79	1.00	
Exit	0.65	0.90	0.25	0.90	0.24	-0.12	0.63	0.75	0.84	1.00

Source: Prepared by the authors.
[a] Productive diversity.
[b] GGP.
[c] Buenos Aires IPI.
[d] Per capita GGP.
[e] IPI for Argentina.
[f] R&D expenditure.

Annex A3

Figure A3.1
Argentina: productive diversity index by provinces, 1996–2012

A. Production and consumption hubs



B. With frameworks to promote industrial activity

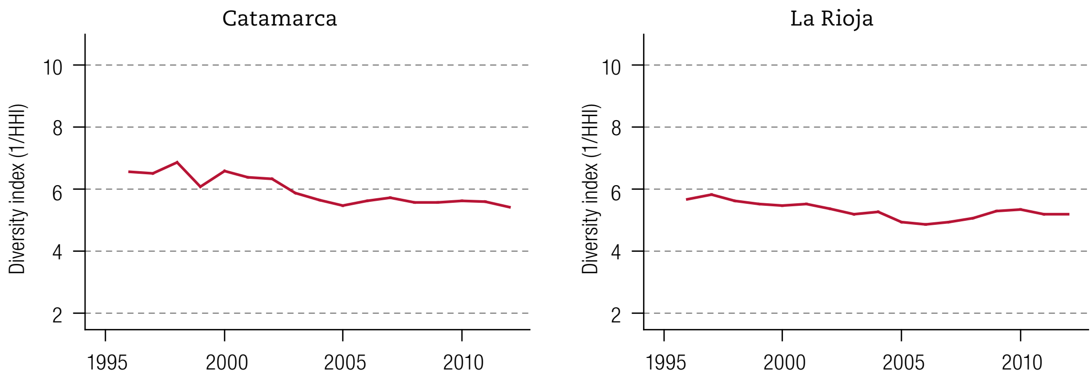
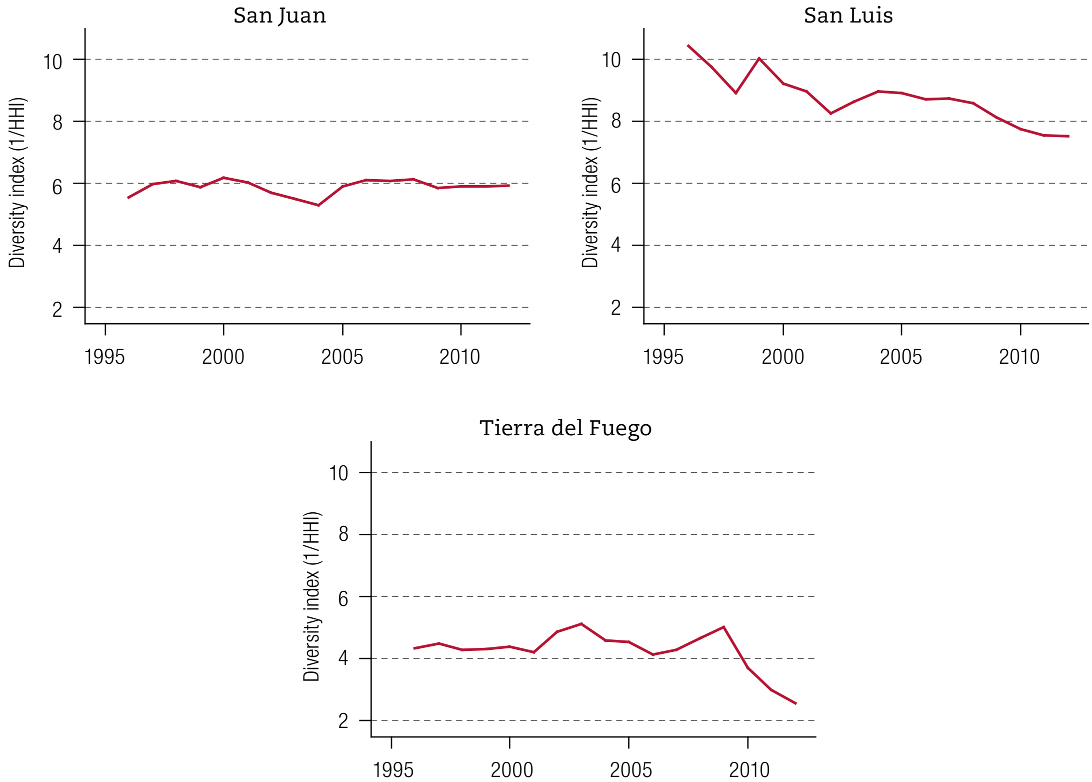
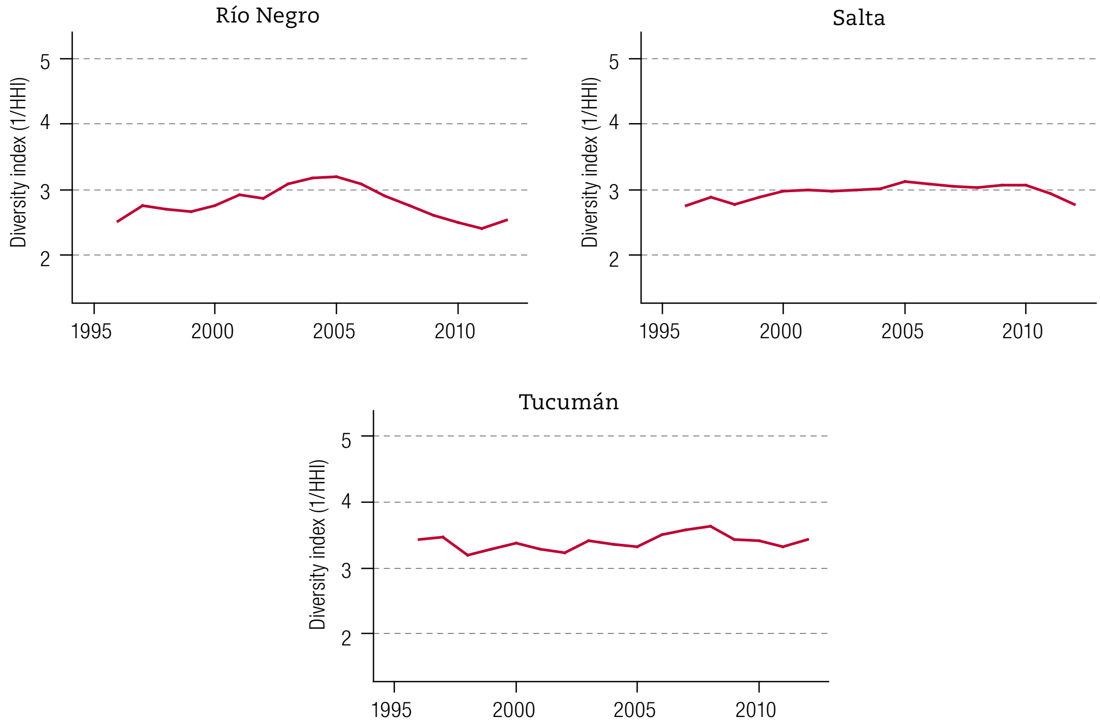


Figure A3.1 (continued)



C. Agro-industrial complexes

Figure A3.1 (continued)



D. Oil and fishing complexes

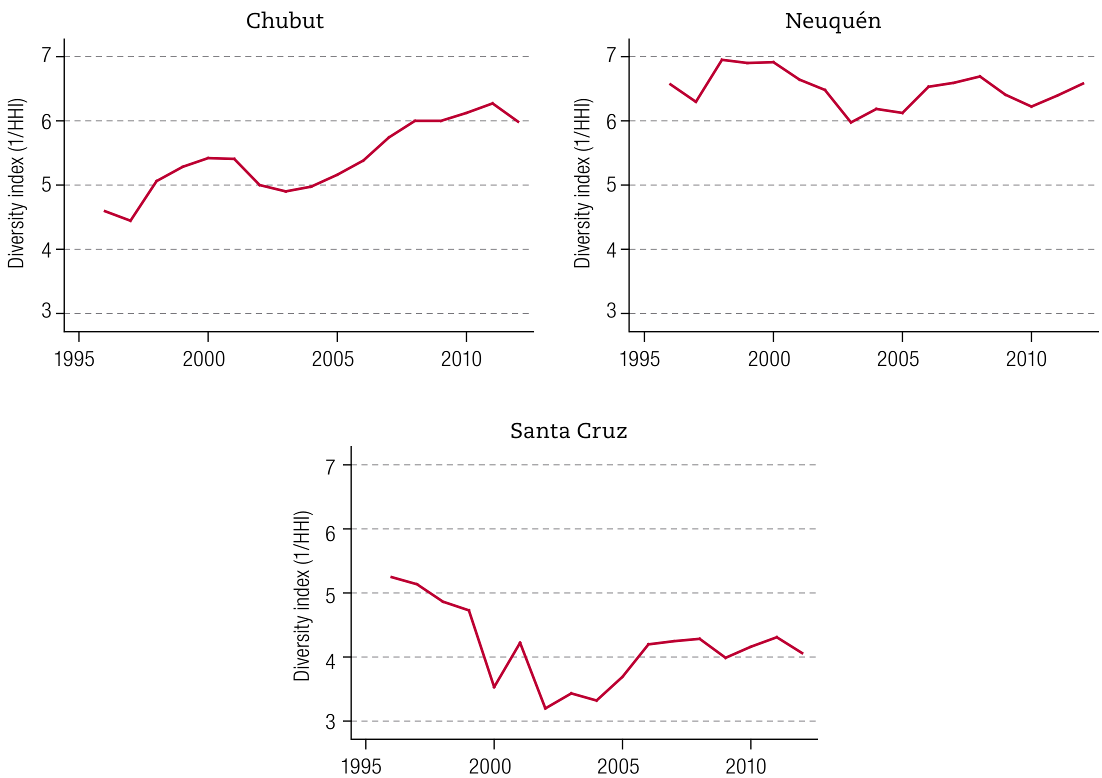
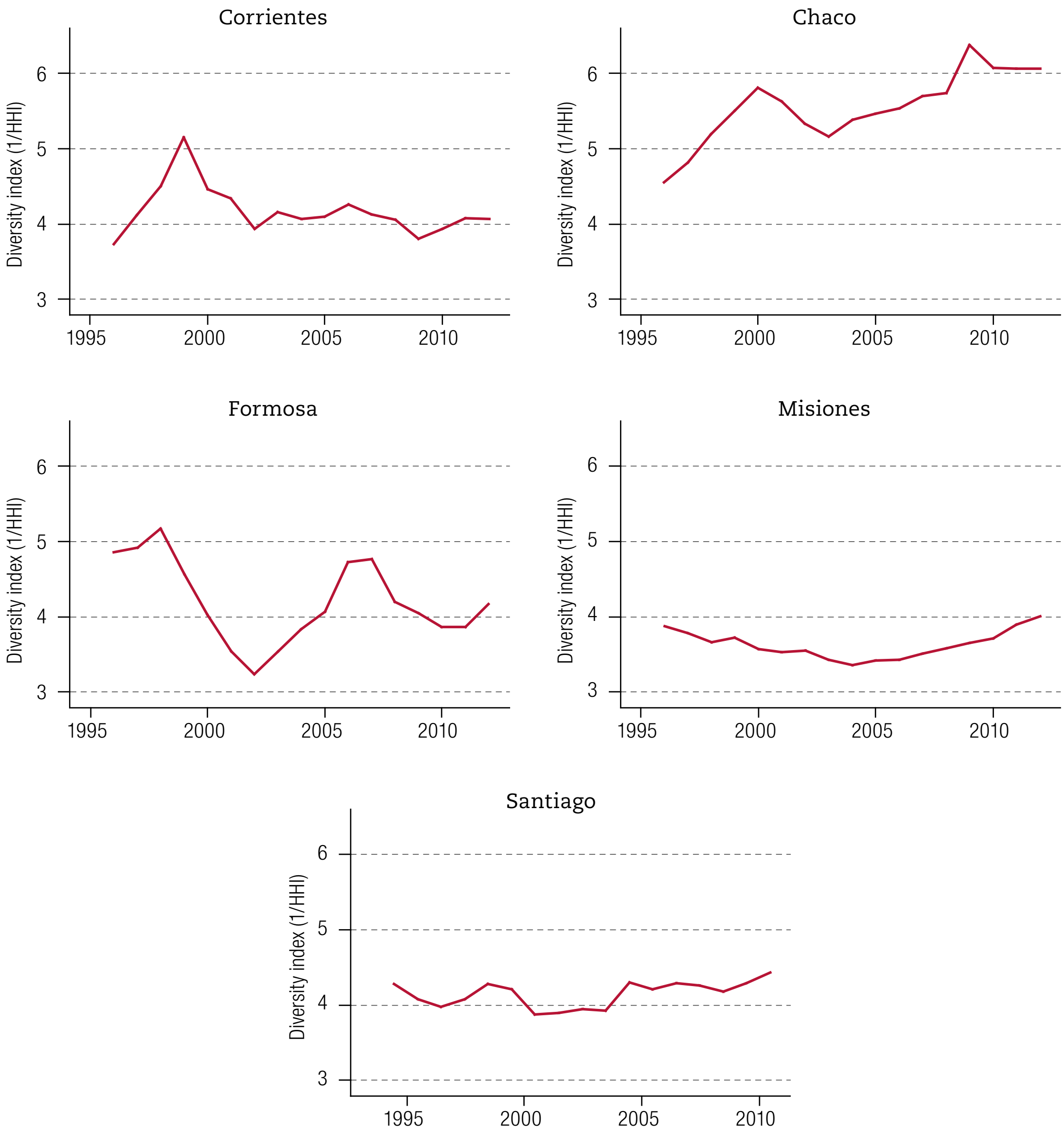


Figure A3.1 (concluded)

E. Forestry and textile complexes



Source: Prepared by the authors, on the basis of the Dynamic Employment Analysis Database (BADE).

Anatomy of the Brazilian middle class: identification, behaviours and expectations

Matthieu Clément, Yves-André Fauré, Jean-Philippe Berrou, François Combarnous, Dominique Darbon and Éric Rougier

Abstract

This article aims to analyse the composition of the Brazilian middle class and its main behaviours and expectations. Combining a quantitative analysis based on the National Household Sample Survey (PNAD) and a qualitative survey carried out among households belonging to the middle class, it reveals the following characteristics. First, the Brazilian middle class is heterogeneous and a substantial part of it remains vulnerable to poverty. Second, the middle class exhibits consumer behaviour largely sustained by credit. Third, in terms of expectations, the Brazilian middle class prioritizes health, education, security and housing and is particularly critical of the quality of public services, all the more so as it faces a high tax burden. While the upper middle class is able to bypass these failures via private services, the most vulnerable elements of the middle class remain very dependent on these low-quality public services.

Keywords

Middle class, social structure, social classes, economic conditions, social conditions, social surveys, social statistics, Brazil

JEL classification

I31, O54

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I. Introduction[1]

Brazil has long been known for a polarized social structure with a very small elite, a mass of poor or very poor people and only a modest-sized intermediate class composed of senior administrative and commercial executives, engineers and senior technicians, often in the public sector or in private sector companies close to power. With recent social transformations, the country has seen a marked increase in the number and the proportion of individuals who have escaped poverty and joined the middle class. Indeed, the rise of the Brazilian middle class accelerated in the 2000s so that it now represents some 45% to 65% of the population, according to different estimates. This expansion has mainly resulted from economic growth, an increase in formal employment, the rise in real wages following the end of hyperinflation (subsequent to the 1994 Real Plan) and large-scale social programmes implemented in the 2000s, such as Bolsa Família. It has also been sustained by the expansion of credit, especially during the years of Dilma Rousseff's presidency. However, Brazil is now suffering a severe economic crisis marked by a collapse in economic growth (-3.8% in 2015 and 2016) whose main trigger has been the decline in demand for commodities from China, Brazil's main trading partner. This crisis has led to an upsurge in unemployment and poverty, as well as to an increase in the number of households that are overindebted, all of which could threaten the Brazilian middle class.

Experience from Western countries has shown that the emergence of middle classes contributes to the acceleration of economic development, particularly because of its effects on consumption (Banerjee and Duflo, 2008). From a social perspective, there is evidence that the development of the middle class breaks the dualism between a vast mass of poor and a small elite, thus helping to strengthen social cohesion and political stability. The new requirements expressed by the middle class can also help to promote democratization (Easterly, 2001).

From an academic point of view, the idea of the "middle class" is a transdisciplinary one whose use and definition remain highly controversial. Broadly speaking, four approaches can be identified: (i) an income-based economic approach, (ii) a sociological approach (based on education, occupation and social status more generally), (iii) a subjective approach (based on class consciousness) and (iv) a managerial approach (based on consumption habits). This great diversity of approaches means that the use of the term "middle class" is sometimes confusing.

The Brazilian authorities have made much of the topic, seeing in it a simple and effective means of demonstrating the legitimacy and efficacy of the policies they have adopted over the last 10 years. From an international viewpoint, it is also a way of proving that Brazil is a full member of the club of emerging countries and, as such, in a position to demand the establishment of a new order in international relations. The sensitivity of these issues explains why the federal government has increased the volume of rhetoric both in Brazil and in the international arena, boasting of this Brazilian success, as former President Dilma Rousseff did at the World Economic Forum in Davos in January 2014.

It was in this quite euphoric atmosphere that the government created, in July 2008, a ministerial-level Secretariat of Strategic Affairs. The Secretariat was made responsible for helping the government to formulate long-term public policies and has subsequently focused more particularly on defining the Brazilian middle class and monitoring actions to consolidate this social group. The Secretariat bases its measure of the middle class on gross monthly income per capita and links it to the notion of vulnerability, i.e. the probability of the identified classes remaining poor or returning to poverty. The class C thus identified (on a spectrum of five classes from A to E) has been shown to consist now of nearly 54% of the Brazilian population and to have a purchasing power of a trillion reais (SAE, 2012a). For the authorities, the preponderance of this category represents the face of a new Brazil and is proud

[1] This study derives from a comparative research project funded by the French Development Agency (AFD) and analysing "the implications of the rise of the middle classes in developing and emerging countries". The project covered four different countries: Brazil, Côte d'Ivoire, Turkey and Viet Nam.

evidence of progress that demonstrates the effectiveness of the social policies implemented since 2003 and the presidency of Lula da Silva. The Social Policy Centre of the Getúlio Vargas Foundation and its founder Marcelo Neri also had a pioneering role in the study of the "new middle class" (Neri, 2012; Neri and De Melo, 2008), as did the Brazilian Institute of Geography and Statistics (IBGE) and the Brazilian Association of Research Companies (ABEP). For IBGE, the middle class, defined as individuals belonging to households whose per capita income is between half and five times the minimum wage, represented 63% of the population in 2014. Finally, comparative studies applied to Latin American countries have also highlighted the rise of middle-income categories on the continent in general and in Brazil in particular (Franco, Hopenhayn and León, 2011; Ferreira and others, 2013).

Despite the enthusiasm of this literature, more critical studies stress the vulnerability of the supposed "new middle class" (Xavier Sobrinho, 2011; Pochmann, 2012; Scalon and Salata, 2012). Pochmann (2012) explains that 94% of jobs created between 2004 and 2010 paid no more than 1.5 times the minimum wage. In addition to still being low-paid, most of these new jobs, the bulk of them in the service sector, are very low-skilled, have very poor conditions of employment and are subject to high levels of instability. In other words, households recently lifted out of poverty as a result of real wage increases and social policies aimed at helping the poor will not have the characteristics of socioeconomic stability traditionally associated with membership of the middle class. The economic crisis currently faced by Brazil is obviously likely to increase the vulnerability of a large part of the population.

The rise of the middle class is an important and topical issue in today's Brazil and is of great interest to policymakers. This article, which contains three sections after the present introduction, aims to analyse the composition of this intermediate category and its behaviours and aspirations. It has two main objectives: (i) to propose a method for identifying the Brazilian middle class that highlights its heterogeneity and (ii) to analyse the behaviours and aspirations of this middle class. Methodologically, we adopt a two-step empirical approach. First, section II carries out a quantitative analysis based on data from the National Household Sample Survey (PNAD) to identify and characterize the Brazilian middle class. The second step, in section III, is to use a qualitative survey conducted among middle-class households from two contrasting regions, the Rio de Janeiro and Fortaleza metropolitan areas, to understand the dynamics of this group, but also to highlight its main aspirations in terms of public policies. Section IV presents the conclusion.

II. Identification and characterization of the Brazilian middle class

1. Method and data

The purpose of the quantitative analysis is to identify the Brazilian middle class, reveal its potential heterogeneity and describe its main socioeconomic characteristics. To do this, we rely on household survey data and adopt a sequential method that broadly follows the approach proposed by Bonnefond, Clément and Combarnous (2015). This approach is multidimensional and combines an economic definition of the middle class (based on income) and a sociological definition (based on employment and education). The idea in this first step is to delimit a middle-income group. The main issue is not to identify precisely the number or percentage of people in the middle class (given the lack of consensus on the choice of income range) but rather to delimit a group of individuals located in the middle of the income distribution. In the second step, the approach consists in mobilizing more qualitative information on employment and education to identify the different components of the middle-income class identified in the previous step and thence highlight the potential heterogeneity of this intermediate group.

(a) First step: identification of the middle-income class

The aim in this step is to test and compare most of the intervals used in the economic literature to identify the middle-income class. In the literature, the statistical identification of the middle class relies primarily on an income-based definition whereby households falling within a specific income range are considered to belong to the middle-income class. Three broad approaches should be distinguished.

First, the relative approach defines the middle class as the population located in the middle of the income distribution. Relative intervals are most often constructed from median income or average income: between 75% and 125% of median income (Birdsall, Graham and Pettinato, 2000), between 50% and 150% of median income (Castellani and Parent, 2011) or between 100% and 250% of average income (Song and others, 2016). In Brazil, IBGE also adopts a relative approach, using a range from 0.5 to 5 times the official minimum wage. Second, the absolute approach is primarily used for international comparisons. It is based on intervals expressed in purchasing power parity (PPP) dollars. Many intervals are constructed with a lower bound of US$ 2 per capita per day (in PPP). The underlying idea is that the middle class starts where poverty ends. The following intervals can be found in the literature: US$ 2 to US$ 10 (Barnerjee and Duflo, 2008), US$ 2 to US$ 13 (Ravallion, 2010) and US$ 2 to US$ 20 (AsDB, 2010; Castellani and Parent, 2011). However, as the Asian Development Bank (AsDB, 2010) acknowledges, households with per capita incomes just above US$ 2 remain highly vulnerable to a return to poverty in the case of socioeconomic shocks. This has led other authors to use a lower limit of US$ 10. Ranges often used now are US$ 10 to US$ 20 (Milanovic and Yitzhaki, 2002), US$ 10 to US$ 50 (Ferreira and others, 2013) and US$ 10 to US$ 100 (Kharas, 2010). Third, the mixed approach consists in combining an absolute lower bound and a relative upper bound. The interval proposed by Birdsall (2010) has a lower limit of US$ 10 and an upper limit corresponding to the ninety-fifth percentile of the income distribution. Overall, the objective of this first step is to compare different income intervals and select one for its ability to accurately trace the development of social stratification in Brazil.

(b) Second step: cluster analysis and characterization of the middle class

To explore the heterogeneity of the middle-income class identified in the previous step from a multidimensional point of view, we applied a mixed classification procedure to several variables describing the occupational and educational status of households in this group. Specifically, we selected four categorical variables related to the education and employment characteristics of the household head: (i) education (highest level attained), (ii) occupation, (iii) employment status and (iv) institutional sector.

Setting out from these four variables, the statistical procedure classified a large set of individuals characterized by their first factorial coordinates, themselves generated by an initial factor analysis procedure (in this case, a multiple correspondence analysis of the four variables). A first classification was obtained by cross-referencing several basic partitions built around moving means, after which the stable classes thus formed were aggregated by a hierarchical classification method. We chose to use the Ward aggregation criterion. The partition used (the number of groups retained within the middle-income class) was selected by analysing the aggregation node values and the dendrogram (the diagram that synthesizes the successive aggregation stages). This process yielded a classification into homogeneously composed, clearly distinct groups. Lastly, the better to characterize these groups, we compared the distributions of the different classification variables mentioned above and refined the analysis by comparing the distribution or average values of a set of additional variables, called characterization variables.

The quantitative analysis was based on the PNAD survey conducted by IBGE. The baseline survey was carried out in 2014 and covered approximately 115,000 households. PNAD data for the years 2001, 2004, 2007 and 2011 were also used to determine the change in the percentage of the population represented by the middle-income class over time.

2. The size of the middle-income class

Income is defined as monthly per capita household income, going by PNAD data. The various income intervals selected produced very disparate results. For the year 2014 (see table 1), the proportion of the population represented by the middle-income class ranged from 20% to 73%, depending on the criterion. The changes identified are also very heterogeneous (see table 2). The first two criteria (US$ 2 to US$ 10 and US$ 2 to US$ 20) yield a decrease in the size of the middle class in Brazil, while all the others show a more or less marked increase. This is explained by the variety of intervals, with many overlapping only very partially, if at all. For instance, the US$ 2 to US$ 10 interval does not intersect any of the intervals starting at US$ 10. This great disparity obviously raises the problem of the choice of the most relevant criterion.

Table 1

Comparison of different criteria for defining the middle-income class, 2014

Criterion	Income range		Poor	Middle-class	Rich
	Monthly per capita reais *(2014 prices)*	Monthly per capita dollars *(2011 PPP, 2014 prices)*[a]	*(percentages of the population)*		
[US$ 2 to US$ 10]	[R$ 104.4 to R$ 522]	[US$ 60 to US$ 300]	3.1	30.5	66.4
[US$ 2 to US$ 20]	[R$ 104.4 to R$ 1,044]	[US$ 60 to US$ 600]	3.1	63.9	33.0
[US$ 4 to US$ 20]	[R$ 208.8 to R$ 1,044]	[US$ 120 to US$ 600]	8.4	58.6	33.0
[US$ 10 to US$ 20]	[R$ 522 to R$ 1,044]	[US$ 300 to US$ 600]	33.6	33.4	33.0
[US$ 10 to US$50]	[R$ 522 to R$ 2,610]	[US$ 300 to US$ 1,500]	33.6	57.4	9.0
[US$ 10 to US$ 100]	[R$ 522 to R$ 5,220]	[US$ 300 to US$ 3,000]	33.6	63.4	3.0
[75% to 125% of median income]	[R$ 543 to R$ 905]	[US$ 312 to US$ 520]	34.9	26.1	39.0
[50% to 150% of median income]	[R$ 362 to R$ 1,086]	[US$ 208 to US$ 624]	19.4	48.8	31.8
[100% to 250% of mean income]	[R$ 1,226 to R$ 3,065]	[US$ 705 to US$ 1,762]	73.0	20.0	7.0
[US$ 10 to percentile 90]	[R$ 522 to R$ 2,471]	[US$ 300 to US$ 1,420]	33.6	56.4	10.0
[US$ 10 to percentile 95]	[R$ 522 to R$ 3,875]	[US$ 300 to US$ 2,227]	33.6	61.4	5.0
[0.5 to 5 times minimum wage]	[R$ 362 to R$ 3,620]	[US$ 208 to US$ 2,080]	21.4	73.1	5.5

Source: National Household Sample Survey (PNAD), 2014.

[a] The purchasing power parity (PPP) conversion coefficient used (2011 PPP adjusted to 2014 prices) is 1.74, as calculated by the World Bank.

Table 2

Evolution of the size of the middle income-class on different criteria, 2001–2014

(Percentages of the population)

Income range	2001	2004	2007	2011	2014
[US$ 2 to US$ 10]	50.3	51.8	42.6	35.7	30.5
[US$ 2 to US$ 20]	70.4	73.0	71.1	67.8	63.9
[US$ 4 to US$ 20]	54.1	57.9	59.4	60.4	58.6
[US$ 10 to US$ 20]	20.1	21.2	28.5	32.1	33.4
[US$ 10 to US$ 50]	33.1	34.4	44.5	51.9	57.4
[US$ 10 to US$ 100]	37.0	38.2	48.9	57.0	63.4
[75% to 125% of median income]	15.8	16.7	23.2	25.1	26.1
[50% to 150% of median income]	36.5	38.7	43.0	46.3	48.8
[100% to 250% of mean income]	11.1	11.1	13.3	16.4	20.0
[US$ 10 to percentile 90]	32.8	33.9	43.9	51.4	56.4
[US$ 10 to percentile 95]	35.8	36.9	47.6	55.3	61.4
[0.5 to 5 times minimum wage]	51.2	53.3	61.0	68.0	73.1

Source: National Household Sample Survey (PNAD), 2001, 2004, 2007, 2011 and 2014.

Note: Incomes for 2001, 2004, 2007 and 2011 have been converted to 2014 prices using the extended national consumer price index (IPCA). The purchasing power parity (PPP) conversion coefficient used (2011 PPP adjusted to 2014 prices) is 1.74, as calculated by the World Bank.

It seems imperative to select a lower bound that is neither too low (to avoid the risk of capturing households that are poor rather than middle-class) nor too high (to ensure that non-poor households which remain potentially vulnerable to a return to poverty are included). Accordingly, we follow Birdsall (2010) and Ferreira and others (2013) in using a lower limit of US$ 10 per day. It is interesting to note that this US$ 10 threshold represents approximately 70% of the Brazilian minimum wage, slightly above the 50% of the minimum wage that is the lower limit used by IBGE to identify the middle class. It can be assumed that this relatively low threshold makes it possible to capture households that are relatively vulnerable to a risk of returning to poverty. The upper bound is set at the ninety-fifth percentile of the income distribution (P95), in line with Birdsall (2010), who considers this relative limit to exclude "that portion of the population within a country whose income is most likely to be from inherited wealth or based on prior or current economic rents (…) and thus less associated with productive and primarily labour-based activity than for the non-rich" (Birdsall, 2010, p. 7). In a nutshell, our identification of the middle-income class in Brazil is based on an interval ranging from US$ 10 per day to the ninety-fifth percentile of the distribution, i.e. from 522 reais to 3,875 reais per month at 2014 prices.

With the interval [US$ 10; P95], the middle-income class represents 61.4% of the Brazilian population, a level close to previous estimates (mainly falling into the 45% to 65% bracket). The expansion of this middle-income group since the beginning of the 2000s is also confirmed, insofar as it represented only 35.8% of Brazilian households in 2001.

We then set out to characterize the three groups identified on the basis of this income criterion ("poor", "middle-class" and "rich") using the different classification variables selected (see table 3). Broadly speaking, table 3 shows that for most education and employment characteristics, heads of households belonging to the middle class occupy an intermediate position between "poor" and "rich". However, it can be seen that the proportions of household heads with secondary education, working as manual workers and working in the formal private sector are highest for the middle class. All this suggests that there are strong markers of membership of Brazil's middle class and that this middle class is probably heterogeneous in terms of socioeconomic characteristics.

Table 3

Characteristics (classification variables) of poor, middle-class and rich household heads, 2014

(Percentages)

	Poor	Middle-class[a]	Rich	Total
Education				
No education	12.4	7.7	0.2	8.9
Primary education	58.0	44.7	8.6	47.4
Secondary education	26.3	31.1	16.9	28.7
Tertiary education	3.3	16.6	74.4	15.0
Occupation				
No job (retiree, inactive, unemployed)	34.2	30.0	21.8	31.0
Managers, executives	2.0	11.0	51.5	10.0
Intermediate occupations	2.1	6.7	11.9	5.4
Service workers	25.4	24.7	8.3	24.1
Workers	19.0	20.1	3.8	18.9
Farmers	17.3	7.5	2.8	10.6
Employment status				
No job (retiree, inactive, unemployed)	34.2	30.0	21.8	31.0
Paid employees	40.0	45.6	46.7	43.8
Self-employed without employees	20.5	18.2	15.3	18.8
Self-employed with employees	0.6	3.9	15.5	3.4
Unpaid workers	4.7	2.3	0.7	3.0

Table 3 (concluded)

	Poor	Middle-class[a]	Rich	Total
Institutional sector				
No job (retiree, inactive, unemployed)	34.2	30.0	21.8	31.0
Private formal	46.4	52.3	49.1	50.2
Private informal	15.3	7.7	3.3	10.0
Public	4.1	10.0	25.8	8.8

Source: National Household Sample Survey (PNAD), 2014.

[a] The middle class is defined as households whose per capita daily income ranges from US$ 10 to the ninety-fifth percentile of income distribution.

3. The heterogeneity of the Brazilian middle class

In the second step, we isolate households belonging to the middle-income class and analyse the heterogeneity of the group by carrying out the multidimensional cluster analysis described above. The results of this classification lead us to identify seven distinct groups within the Brazilian middle-income class. Going by the analysis of the comparative distributions of the classification variables and a set of characterization variables (see tables 4 and 5, respectively), we can describe these seven groups.

Table 4

Characteristics (classification variables) of clusters derived from the mixed classification procedure, 2014

(Percentages)

	Group 1 (30)	Group 2 (7)	Group 3 (10)	Group 4 (2)	Group 5 (24)	Group 6 (20)	Group 7 (7)	Total
Education								
No education	16.2	0.0	0.3	29.7	4.7	2.5	7.4	7.7
Primary education	55.8	5.0	9.7	58.8	58.6	38.3	59.4	44.7
Secondary education	18.6	60.4	18.1	8.3	33.2	48.6	28.9	31.1
Tertiary education	9.4	34.6	72.0	3.2	3.6	10.7	4.3	16.6
Occupation								
No job (retiree, inactive, unemployed)	100.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0
Managers, executives	0.0	0.0	89.1	2.5	2.8	0.0	3.6	11.0
Intermediate occupations	0.0	94.9	0.4	0.6	1.0	0.0	0.8	6.7
Service workers	0.0	0.0	9.6	6.1	0.0	100.0	54.3	24.7
Workers	0.0	5.0	0.4	5.4	76.5	0.0	28.5	20.1
Farmers	0.0	0.1	0.5	85.4	19.8	0.0	12.9	7.5
Employment status								
No job (retiree, inactive, unemployed)	100.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0
Paid employees	0.0	85.0	69.0	0.0	47.9	71.8	100.0	45.6
Self-employed without employees	0.0	14.2	6.4	0.0	48.1	27.7	0.0	18.2
Self-employed with employees	0.0	0.8	24.6	0.0	4.1	0.5	0.0	3.9
Unpaid workers	0.0	0.0	0.0	100.0	0.0	0.0	0.0	2.3
Institutional sector								
No job (retiree, inactive, unemployed)	100.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0
Private formal	0.0	49.5	58.8	100.0	98.4	88.4	0.0	52.3
Private informal	0.0	4.9	3.0	0.0	0.0	0.0	100.0	7.7
Public	0.0	45.6	38.2	0.0	1.6	11.6	0.0	10.0

Source: National Household Sample Survey (PNAD) 2014.

Note: The shaded cells identify the modalities that are statistically (at 5% level) more heavily represented in the group considered than in the rest of the middle class.

Table 5
Characteristics (characterization variables) of clusters derived from the mixed classification procedure, 2014
(Percentages)

	Group 1 (30)	Group 2 (7)	Group 3 (10)	Group 4 (2)	Group 5 (24)	Group 6 (20)	Group 7 (7)	Total
Area of residence								
Urban	91.6	97.4	96.1	49.4	82.1	96.3	87.6	90.0
Rural	8.4	2.6	3.9	50.6	17.9	3.7	12.4	10.0
Region								
North	**9.7**	13.3	13.6	10.5	11.8	12.1	12.9	11.6
North-east	24.4	21.9	20.8	33.0	**17.9**	21.2	21.6	21.7
South-east	36.2	34.2	31.7	**20.5**	34.3	34.6	32.7	34.2
South	19.8	19.1	20.8	28.2	22.7	19.0	17.5	20.4
West-central	**9.9**	11.4	13.1	7.9	13.4	13.1	15.2	12.1
Gender								
Female	58.2	27.8	37.5	40.2	9.3	45.6	43.7	38.6
Male	41.8	72.2	62.5	59.8	90.7	54.4	56.3	61.4
Skin colour								
White	59.3	60.0	65.6	55.0	54.2	55.3	52.0	57.5
Black	39.8	39.1	**33.3**	44.3	45.1	44.0	47.2	41.7
Yellow	0.5	0.5	1.0	0.4	0.4	0.3	0.3	0.5
Brown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indigenous	0.4	0.4	0.1	0.3	0.4	0.3	0.5	0.3
Retired								
Yes	63.4	3.2	5.0	77.8	11.6	5.8	12.2	26.3
No	36.6	96.8	95.0	22.2	88.4	94.2	87.8	73.7
Multi-activity								
Yes	0.0	6.3	8.5	0.4	3.0	4.1	3.6	3.2
No	100.0	93.7	91.5	99.6	97.0	95.9	96.4	96.8
Housing								
House	88.4	78.3	74.5	97.9	93.6	86.7	91.1	87.4
Apartment	11.3	21.6	25.4	2.0	6.1	12.9	8.2	12.3
Other	0.2	0.1	0.1	0.1	0.3	0.4	0.7	0.3
Equipment goods								
Freezer	**17.4**	**17.1**	22.0	30.3	21.1	**15.7**	**12.9**	18.4
Washing machine	**61.7**	78.4	82.9	**37.5**	**60.9**	66.8	**51.3**	64.7
Computer	**39.2**	82.2	87.8	**22.0**	**51.6**	59.1	**38.8**	53.8
Motorized vehicle	**44.7**	75.8	83.4	**51.2**	71.1	**58.0**	**48.0**	60.2
Mean of quantitative variables								
Household size	**2.423**	2.898	3.033	**2.298**	2.884	2.769	2.556	2.704
Number of rooms	5.947	6.110	6.815	6.246	**5.702**	**5.532**	**5.196**	5.872
Age of household head	64.679	**41.396**	**42.859**	65.616	**46.049**	**43.298**	**45.161**	50.817
Household participation rate	**0.222**	0.686	0.674	0.837	0.735	0.760	0.797	0.583
School enrolment in public sector	0.580	**0.455**	**0.388**	0.716	0.715	0.648	0.741	0.596
Monthly per capita household income	**1 141**	1 535	1 839	**1 010**	**1 143**	**1 125**	**1 017**	1 232

Source: National Household Sample Survey (PNAD), 2014.
Note: The shaded cells identify the modalities that are statistically (at 5% level) more heavily represented in the group considered than in the rest of the middle class. The bold cells identify the modalities that are statistically (at 5% level) less heavily represented in the group considered than in the rest of the middle class. For quantitative variables, shaded and bold cells identify respectively the means that are significantly higher and lower than the mean for the whole middle class.

Group 1: Retired and inactive middle class (30% of the middle-income class)

This first group mainly includes households headed by retired individuals, who are also less well educated than household heads in other middle-class groups. These households are slightly overrepresented in the north-east region and underrepresented in the north and west-central regions. They are smaller than other groups' and more often headed by women. Their incomes and level of durable goods equipment are quite low compared to the rest of the middle class.

Group 2: Intermediate occupations and public sector middle class (7%)

This group is overwhelmingly made up of employees in intermediate occupations, particularly in the public sector, whose level of education is relatively high overall. These households are almost all urban, more likely than others to live in apartments, rarely headed by a woman and more often than not multi-active. They are quite large households whose heads are very young and whose incomes are high compared to those of other middle-class households. They are significantly better equipped with durable goods (washing machine, computer or motor vehicle) and are more likely to enrol their children in private schools.

Group 3: Employer, managerial and executive middle class (10%)

Household heads in this group are mainly managers, employers and senior executives from the formal private and public sectors whose level of education is very high overall. Almost entirely urban, many of these households live in apartments and more often than not they are multi-active. Whites are overrepresented in this group and blacks underrepresented. The households considered are large and their heads rather young. Their incomes are the highest among the different middle-class groups. This is also the group with the highest level of durable goods equipment and that which most frequently sends its children to private schools.

Group 4: Active retired middle class (2%)

This subset of the middle class is of limited size and composed of very specific households. These are mainly households headed by retired individuals who remain active and do unpaid work, most of them in agriculture. We can legitimately think here of small-scale subsistence agriculture carried out to compensate for small pensions. They are poorly educated and overrepresented in the north-east region (the poorest) and rare in the south-east region (the richest) and almost all live in houses. Their incomes are on average among the lowest in the middle class, despite an extremely high labour market participation rate. They are also less well equipped with durable goods than the rest of the middle class.

Group 5: Worker and farmer middle class (24%)

This group includes employees and a very high proportion of the self-employed. It consists of a large majority of workers and most farmers, all of them working in the formal private sector. Their average level of education is quite low. This class is relatively underrepresented in the north-east region and is overwhelmingly male. Households in this group are quite small and their per capita incomes quite low for the middle class. In terms of ownership of durable goods, they occupy an intermediate position, being better equipped than average for certain goods (freezers and motor vehicles) but less well for other goods (washing machines and computers).

Group 6: Service worker middle class (20%)

Household heads in this group are mainly employees and self-employed with a relatively high level of education. They work quasi-exclusively in the formal private service sector, they are urban and women are overrepresented by comparison with other subsets of the middle class. The mean income of this group is rather low despite a relatively high labour market participation rate. These households have an intermediate level of durable goods equipment, with relatively high rates of washing machine and computer ownership but low rates of freezer and motor vehicle ownership.

Group 7: Informal employee middle class (7%)

The last group is made up entirely of wage-earning household heads working in the informal private sector. Whether they are employed in the service sector or as workers or even farmers, they are clearly less well educated than other subsets of the middle class. Households in this group have the smallest dwellings and very low incomes, despite a very high labour market participation rate. This group also has one of the lowest durable goods equipment levels.

4. The vulnerability of the Brazilian middle class

The cluster analysis highlights the great heterogeneity of the Brazilian middle class and indicates a form of bipolarization, with a rather affluent and urban middle class in stable, high-skilled jobs coexisting with a more fragile, less well-educated and lower-income middle class whose jobs are less stable, of lower quality (informal, agriculture) or both.

Indeed, groups 2 and 3 have significantly higher education levels and average incomes than the rest of the Brazilian middle class. They could therefore be seen as constituting the upper middle class, accounting for a limited proportion (17%) of the whole middle class in Brazil. These groups include most civil servants, often perceived as Brazil's historical middle class, although they also contain private sector employees and self-employed individuals. The two groups also stand out clearly from the rest of the middle class in terms of durable goods equipment levels and their greater propensity to enrol their children in private schools. These are strong markers for membership of the upper middle class in Brazil, thus emphasizing the role of consumption-related behaviour in social differentiation.

The other five groups (83% of the middle class) have lower and fairly similar average incomes. The percentage of vulnerable households is difficult to estimate, however. It is important to note that some households belong to groups with a relatively stable occupational status: formal workers in the primary and secondary sectors (24%) and formal tertiary sector workers (20%). If we consider that the stability of their jobs moves them away from the vulnerable zone, the proportion of genuinely vulnerable households in the middle class can be put at 39%. Whatever the percentage chosen, there is no doubt that the proportion of vulnerable households in the Brazilian middle class is high. Some of the literature points this out, suggesting that such households are difficult to equate with the middle classes in the Western sense of the concept and that they belong rather to the working class (Xavier Sobrinho, 2011; Pochmann, 2012; Scalon and Salata, 2012).

Birdsall, Lustig and Meyer (2014), working in the Latin American context, call individuals making up this vulnerable class "strugglers". According to these authors, two phenomena heighten the vulnerability of this group. First, within the redistributive system, strugglers are "net payers" like the upper middle class and the wealthy class and unlike the poorest. They benefit much less from public transfer programmes than the poorest and, at the same time, are subject to high indirect taxation. In addition, lacking the income level of the upper middle class and the rich class, strugglers are more dependent on low-quality public services, especially in the fields of education and health, which could restrict their prospects of upward mobility.

III. Trajectories, behaviours and aspirations of the Brazilian middle class: lessons from a qualitative household survey

To complete the characterization of the Brazilian middle class, a qualitative survey was carried out among households judged to be characteristic of the different groups identified during the quantitative analysis. The main objective of this qualitative survey was to examine intergenerational changes in the living conditions of the Brazilian middle classes and to identify their behaviours and aspirations and the expectations they had of the public authorities.

1. Survey methodology

The quantitative analysis applied to the PNAD data identified seven distinct groups within Brazil's middle class. This structure served as a sampling basis for the qualitative survey. Given its small size (2% of the middle-income class), group 4, composed of the "active retired", was merged with group 1, "retired and inactive". A total of 30 interviews were conducted with household heads from these different groups in two contrasting regions of Brazil: the Rio de Janeiro metropolitan area (Rio de Janeiro State, south-east region) and the Fortaleza metropolitan area (Ceará State, north-east region). The former has much more favourable socioeconomic indicators than the latter. In addition, we took care to distribute the interviews between urban and rural areas in a way that reflected the high rate of urbanization in Brazil (around 86%).

Table 6 shows the distribution of interviews based on the relative size of each group in the Brazilian middle class. The qualitative survey was conducted in April and May 2017. The interview grid included about 100 questions (closed and open).[2] Because of the limited sample size, it was not possible to arrive at robust results at the group scale. However, the qualitative survey yields interesting results about the intergenerational mobility, priorities and aspirations of the Brazilian middle class as a whole that complement those derived from the quantitative analysis.

Table 6
Sampling scheme

Group	Share *(percentages)*	Theoretical number of interviews (out of 30)	Number of interviews conducted	Rio de Janeiro	Fortaleza
1. Retirees and inactive	32	9.6	9	3	6
2. Intermediate occupations and civil servants	7	2.1	3	1	2
3. Employers, managers and executives	10	3.0	3	1	2
5. Workers and farmers	24	7.2	7	4	3
6. Service workers	20	6.0	6	3	3
7. Informal employees	7	2.1	2	1	1
Total	100	30	30	13	17

Source: Prepared by the authors.

The qualitative survey made it possible to estimate the incomes of the households surveyed. The average monthly per capita income of the households in the sample was 2,433 reais. It should be noted that these incomes are expressed at 2017 current prices and are therefore not directly comparable to incomes from the quantitative analysis (2014 prices).

[2] The questionnaires in Fortaleza and Rio de Janeiro were administered, respectively, in collaboration with Janaina Araújo, who holds a master's degree in economics from the Federal University of Ceará, and Caroline Miranda, a master's student in economics at the Institute of Economics of the Federal University of Rio de Janeiro.

A methodological requirement in the administration of the questionnaires was never to use the term “class” or “social class” in order not to influence respondents’ answers. However, in Brazil, these expressions have been part of everyday language since the mid-2000s. In particular, the term “middle class” has gone from being an academic concept to a tool for political communication. Results from household surveys, especially those of the IBGE, have also been widely reported by the media. It is therefore not surprising that most of the respondents themselves spoke of class. Of the 30 households surveyed, 25 stated that they belonged to the middle class, while only two said they belonged to the rich class and three to the poor class. This means that there is a strong correlation between objective identification of the middle class and subjective perceptions.

2. Intergenerational mobility

The first dimension addressed in the interviews is the respondents’ assessment of their situation both in relation to their parents’ and to their own more or less recent past. Going by the different expressions used by the respondents, three types of judgment were conveyed. In 11 cases out of 30, respondents stated that there had been a marked improvement in their situation compared to earlier periods; a simple improvement was indicated in 17 out of 30 cases; and in two cases the change was considered to have been negative. The “positive change” responses appear to be well correlated with average monthly income per capita. Household heads who considered the change in their situation to have been very positive had higher incomes than the average for the sample (2,982 reais compared to 2,433 reais).

The survey also examined the living conditions of the direct ascendants (only 50% of whom were still alive at the time of the surveys) of the heads of families surveyed. Out of 58 first generation respondents (two of the household heads interviewed did not know their fathers), it was possible to collect information on place of residence, employment, education and living conditions.

The interview analysis reveals clear trends between generations. Living environments have changed significantly: while rural origins were fairly common in the first generation, migration resulted in the generation surveyed settling in metropolitan urban areas (Rio de Janeiro and Fortaleza). In the field of education, intergenerational changes are no less notable, with, for example, the near disappearance of illiteracy, a reduction in the number of individuals leaving school after only completing the primary level, a significant increase in the number completing the secondary level and, above all, a sharp rise in higher education. The education levels of the respondents (second generation) were as follows: 1 person had no education, 7 had only completed primary education, 9 had gone to secondary school and 13 had gone on to higher education. Regarding employment, lastly, while members of the first generation were primarily involved in agriculture and handicrafts and were therefore somewhat fixed in their type of work and where they did it, the next generation experienced greater job mobility. Of those surveyed, 30 people reported 53 job changes after the first position obtained, representing an average of 1.8 changes per household head interviewed. The survey also reveals that 22 of the 25 active (i.e. not retired) respondents were satisfied with their occupational activity. The ability to work unsupervised, flexible schedules, financial security and the opportunity to improve their professional know-how were the reasons given to justify these positive responses.

Our sample of middle-class households had thus benefited from intergenerational changes in living conditions. However, the current economic crisis is very likely to threaten this upward mobility. In fact, 22 of the 25 respondents who expressed an opinion on the subject deplored the current deterioration of the situation. There was, therefore, full awareness of current changes in relation to employment and wages.

3. Socioeconomic behaviour: consumerism sustained by credit

In line with the literature (SAE, 2012b; Kamakura and Mazzon, 2013), and as already mentioned in relation to the quantitative analysis, Brazilian middle-class households are distinguished by their consumption-oriented behaviour. The prevalence of such behaviour is confirmed by the qualitative survey, most particularly as regards high-technology equipment. Mobile telephony use in Brazil is among the highest in the world, and each of the 30 households in the sample owned at least one mobile phone, often a latest-generation model. Moreover, 27 had Internet access, 23 a computer and 17 a fixed-line telephone at home. Ownership of high-technology equipment would thus appear to be a strong marker of membership of the middle class.

Middle-class consumerism is also reflected in leisure consumption. The households surveyed were questioned about the purpose and nature of their occupations outside working hours. In order of frequency, their answers, which were not limited in number, were as follows: rest (14), sports, leisure, beach (11), culture, cinema, theatre (8), television and Internet (8), reading (4) and visiting family (4). The other 6 activities were very diverse. This suggests a strong demand for recreational activities among Brazilian middle-class families. In particular, 15 of the households interviewed reported travelling, some regularly, others infrequently. Travel for tourism or entertainment purposes or to visit relatives was mentioned by 13 out of 15 households, with the other two mentioning business trips.

A specific feature of Brazil's middle class is the massive use of credit to finance consumer expenditure. De la Torre, Ize and Schmukler (2012) explain that countries with characteristics close to those of Brazil have a level of consumer credit that is only half that prevailing in Brazil. In our survey, 21 of the 30 households surveyed used credit, including seven which had finished paying off a loan and did not have one at the time of the survey. The loans were made by banking institutions in 19 cases and by the companies employing the head of the household in the other 2 cases. Two of the cases involved loans with repayments automatically deducted at source from wages *(empréstimos consignados)*. This method, rare until the 2000s, was greatly expanded during Dilma Rousseff's presidency (2009-2016), characterized by the explosion of credit.

For the 12 households which still had outstanding debt, the interviews identified the level of repayments. These ranged from 7% to 30% of total monthly income. The average per capita monthly income of households currently borrowing was 1,938 reais, 500 reais less than the average per capita monthly income of the sample (2,433 reais). In other words, credit was used most at the lower end of the middle class and therefore appears to be a potential source of vulnerability. The explosion of consumer credit over the last 10 years, followed by an abrupt reversal in the country's economic fortunes, has placed many Brazilians in great difficulty. Whereas in 2005 only 18.4% of Brazilian families were indebted, by September 2016 the figure had reached 58.2%. A quarter of the indebted families were experiencing difficulties with repayments, and 9.6% of families were insolvent as of September 2016 (CNC, 2016). Although the households surveyed were not affected by insolvency, it is interesting to note that seven households in the sample reported having stopped using credit cards. There is thus growing caution about debt.

4. The priorities of the middle classes

Among the personal and family needs that respondents would most like to see satisfied, health was the most often cited (21 responses), before education (13), security (7), comfort and hobbies (5), etc. When respondents were asked about their expectations for infrastructure in the broadest sense, the health sector again came first (cited 11 times), ahead of education (9), security (9), roads (5), transport (5), etc. In other words, it is obvious that the priorities of the Brazilian middle class are primarily in the areas of health, education and security.

We then investigated the likely impacts of a potential improvement in household economic conditions. More specifically, the heads of household surveyed were asked what uses they would make of an increase in income of 50%. The most frequent responses were: buying an apartment, house or land (13 responses), helping family members (6) and financing education (6). Together with education, the purchase of a car and subscription to private health insurance plans were also included in this list (3 and 2 responses, respectively), confirming the importance of these elements in Brazilian middle-class "culture". Property ownership would clearly be the highest priority in the case of a significant increase in income. This shows interviewees' degree of attachment to housing and land, even though 25 of the 30 households were already property owners. Out of the 25 interviewees who owned their home, 21 considered their local environment to be acceptable or pleasant. For the four interviewees who did not say this, the reason given was the level of violence. Twenty-six of the households interviewed were satisfied with their accommodation; the other four considered their dwelling to be too small. Despite this high level of satisfaction, 10 of the households would have liked to move to a quieter neighbourhood or a larger dwelling, but financial obstacles made it difficult to fulfil this desire.

5. The middle class and the public sphere

The relationship to the public authorities can be part of class identity, particularly for the middle class. This is why the following paragraphs address the Brazilian middle class's main expectations in relation to four of the most important dimensions of public action: education, social protection and taxation, public security and corruption.

(a) The education system

Asked to assess the state of the education system, 17 of the 26 respondents who had some involvement with education expressed critical opinions. These negative judgments related exclusively to public primary and secondary education, and the main criticisms were that the system "leaves much to be desired", "has an inadequate presence in the region", delivered "poor-quality education", had "teachers lacking qualifications and commitment", had "deteriorated significantly", was "unfair", etc. Private establishments were considered to be of good quality and were seen as the only way to escape the mediocrity of the public sector. Although our survey respondents were involved with private education (15 had attended at least one private school during their education), it became much more significant with the next generation. When households with children were questioned about their choice of schools, two stated that they had chosen State schools, 12 a mix of State and private schools and 10 exclusively private institutions.[3] The private sector was therefore present in 22 of the 24 cases surveyed. As already pointed out in the quantitative analysis, this massive recourse to private education has become a strong marker of middle-class membership in Brazil. However, access to private institutions involves costs described by the individuals interviewed as sometimes abusive, thus tending to exclude families with lower incomes. This is one of the hypotheses put forward by Birdsall, Lustig and Meyer (2014): the most vulnerable components of the middle class are likely to have more difficulty using the private sector and thus remain dependent on a poor-quality public education service.

[3] The combination of public-private education results either from a single child attending both categories or different children from the same family attending different categories of school.

Among the other opinions expressed about the state of the education system, six household heads spoke spontaneously about higher education, judging it difficult to access and expressing the desire to see a greater number of places on bachelor's and master's degree courses. At public universities (especially federal universities and, to a lesser extent, state universities), the number of places is limited and entrance examinations are selective. This is why young people from private secondary institutions have the greatest chances of obtaining a high-quality public higher education. The strictly limited intake at public universities has the effect of driving large numbers of students into private universities, which thus represent a lucrative market, but whose official evaluations show them to be of lower quality.

(b) Social protection and taxation

As regards social security (sickness, occupational injury, old-age pensions), almost all the households surveyed (29 out of 30) were covered by the basic schemes, namely the general social security scheme and the public sector employees' scheme, with one household covered by the special scheme for military personnel). These basic schemes were severely criticized (27/30) by the households surveyed. Respondents' criticisms included: poor use of contributions, mismanagement of funds, delays in the payment of benefits and even embezzlement. In addition to these basic schemes, there are private health plans run by insurance companies for which premiums are particularly expensive. Such plans entitle subscribers to more rapid medical consultations and hospitalizations than the public health system, depending on the size of their contributions. Undoubtedly, subscription to these private health schemes is in many respects a distinctive feature of the Brazilian middle class, since 19 households in our sample had this type of insurance. However, a household's financial capacity is decisive in determining access to such private health insurance. Nine of the 11 households that did not have a private plan had a monthly per capita income of below 2,000 reais, significantly lower than the average income in the sample (2,433 reais). Once again, this tends to confirm the hypothesis of Birdsall, Lustig and Meyer (2014) that the more insecure members of the middle-income group cannot afford private insurance and therefore remain more dependent on lower-quality public health services.

Linked to these redistributive issues is taxation, considered too heavy by 26 households, which thus confirmed the essence of the criticisms regularly raised in Brazil. These are expressed in various ways but can be summarized as follows: a lack of "return" benefiting the population, mismanagement of public funds, misuse of taxes, poor public services and the absurdity of some taxes levied even on matches and books. Overall, since it mainly bears on goods and services, the Brazilian tax system places excessive pressure on poor and intermediate social groups (Silveira and others, 2011). In 2013, of the total tax collected by the three levels of government, 51.3% was levied on goods and services, 18.1% on income and 3.9% on property. This tends to confirm the hypothesis of Birdsall, Lustig and Meyer (2014) that high indirect taxation contributes to the continuing vulnerability of part of the middle class.[4]

(c) Public security

The Atlas of Violence recorded 59,627 homicides for the year 2014, an increase of nearly 22% on 2003 (IPEA/FBSP, 2016). The rate of 29.1 homicides per 100,000 inhabitants this works out at is the highest in Brazil's history and places it among the 10 most dangerous countries in the world. Besides the human tragedy, the economic cost is considerable. A study by the Inter-American Development Bank (IDB) estimates the cost of crime at nearly 4% of Brazil's GDP. What did households in the sample feel about these worrying questions? When asked about their assessment of public security in the area

4 Afonso and Castro (2012) refer to a recent study from the University of São Paulo showing that 49% of the income of households in the bottom income decile is taken by the tax authorities, compared to just 26% of the income of households in the top income decile. Tax deductions tend mechanically to increase the benefits of rich taxpayers.

where they lived, the respondents' opinion was almost unanimously negative. Of the 30 respondents, 28 felt unsafe: "We walk down the street constantly fearing attack", "There's nothing we can do about the criminals", "Crime is lurking everywhere", "Violence is taking over streets and neighbourhoods", etc. Furthermore, 28 respondents said that they themselves or members of their family had already been victims of violence, mostly attacks and robberies, plus one case of kidnapping for ransom and two cases of homicide. The recriminations focused on the failings of the public security forces and included "a very sluggish police force which leaves much to be desired", "inefficient", "deficient", "disorganized and bewildered", "in crisis", "non-existent", "contributing to the chaos", etc.

(d) Politics and corruption

Our survey was carried out in a national political context tarnished by multiple corruption scandals involving a number of politicians at all three levels of government (federal, state and municipal), including the two most recent former presidents, Lula da Silva and Dilma Rousseff, as well as business leaders. While Brazilians' opinion of politics has worsened with the current proliferation of "cases", they have had a very negative image of their representatives and authorities for a long time, regardless of which government has been in power. Respondents spoke freely and spontaneously, using their own words and expressions. The adjectives frequently associated with politics defined it as "dreadful", "corrupt", "awful", "dishonest", "filthy", "wrong", "getting worse by the day", "the exact opposite" of what it should be. Several respondents said they were "saddened" and "disgusted". They criticized politicians for "forgetting their promises", "not being serious" and "diverting public funds".

An important dimension of politics and governance is corruption. The Corruption Perceptions Index of Transparency International, a non-governmental organization, ranked Brazil seventy-ninth out of 176 countries for the year 2016. Moreover, 78% of Brazilian people think that corruption is endemic and increasing in their country (Transparency International, 2017). The existence of corruption in Brazil was affirmed by all 30 households. Among them, 14 said that it was ubiquitous in all or most sectors (the most often cited were education, health, social security and transport), but 16 households of the 30 said that it was concentrated in the political sphere or, more precisely, within the political parties, Congress, the executive and the legislature, with several citing the capital Brasilia as the focal point of these practices. The reality of small-scale, everyday corruption in administrative formalities was recognized by 23 of the 30 households, with 13 stating they had been victims of it. Lastly, several respondents said that the general population contributed to the frequency of such practices, as minor everyday lawbreaking *(o jeitinho)*[5] provided a climate conducive to the development of illicit practices.

IV. Conclusion

Following this in-depth analysis of Brazil's growing middle class and its relationship to public policies, we can identify a number of stylized facts.

We estimate that the middle-income class accounted for over 61.4% of the population in 2014, a level consistent with previous estimates. The significant increase in the size of this middle-income group since the early 2000s is also confirmed. Our study also shows that the middle-income class in Brazil is particularly heterogeneous in terms of education, occupation and employment status, since seven distinct groups were identified within that class. Our typology tends to emphasize the existence of a degree of bipolarization within the Brazilian middle class, with a limited upper middle class holding

[5] The term *jeitinho* is commonly used in Brazil to describe small, everyday methods of getting around the law such as bribes, tips, exchanges of services, etc.

stable and highly skilled jobs (especially in the public sector) and a large, vulnerable middle class with lower income and education levels and more unstable, lower-quality jobs. Although this latter category is often depicted as the "new middle class" in Brazil, it is clear that people in this group have not attained to the stability and living conditions traditionally associated with membership of the middle class. Moreover, they are directly threatened by the collapse of the job market and the problems of overindebtedness linked to the current economic crisis.

The Brazilian middle class is also characterized by its consumption-oriented behaviour. The purchase of durable goods, housing and leisure appears to be a strong marker of middle-class membership. This consumerism has been largely fuelled by easier access to credit. In terms of its expectations and aspirations, Brazil's middle class cites health, education, public security and housing as priorities. The middle class judges the quality of public infrastructure and services very harshly, all the more so because it is aware that the Brazilian tax system is pro-rich. It is true that the upper middle class is distinguished by its ability to circumvent the failings of the public sector by using the private sector, particularly in education and health. However, the most vulnerable families in the middle class remain highly dependent on poor-quality public services. Lastly, like the rest of the Brazilian population, the middle class expresses its repudiation of the political system at all levels of power, stressing its inability to work for the general interest. In particular, the country's endemic corruption is severely criticized.

Although this study provides interesting insights into the size, composition, behaviours and expectations of the Brazilian middle class, further research is still needed. Without being exhaustive, three lines of research could be envisaged.

First, the vulnerability of the Brazilian middle class needs to be better analysed, particularly by focusing on the distinction between objective and subjective vulnerability. Our method of identifying the Brazilian middle class takes into account such important dimensions of vulnerability as income and labour market status. Nonetheless, in line with Stampini and others (2016), we suggest that our objective identification of the middle class could be complemented by a measure of objective vulnerability based on the probability of falling into poverty. As for subjective vulnerability, our qualitative survey of members of the middle class provides some evidence for perceived difficulties regarding education, health and credit in the current context of economic crisis. Further research could be conducted to arrive at a better understanding of how the objective and subjective dimensions of vulnerability interact. It may be argued that there is a potential gap between the two dimensions of vulnerability, with the subjective fear of downgrading being greater than objective vulnerability.

Second, the heterogeneity of the Brazilian middle class has potentially important implications for social cohesion that should be addressed. As already explained, the middle class is bipolarized, with a large and vulnerable component that remains dependent on poor-quality public services and an upper component that can afford private mechanisms and thus avoid depending on those public services. In many respects, this well-off middle class shares characteristics and behaviours with the richest class. This could indicate that the culture of privilege, historically rooted in Brazilian society, spills over into the upper middle class. Moreover, increasing recourse to market mechanisms obviously challenges the idea of a social State that could have emerged with the social policies implemented during the past decade.

Third, the heterogeneity of the Brazilian middle class also has implications for political and civic commitment. Examining the capacity of this fragmented middle class for collective action is a particularly important area for future research. Members of the Brazilian middle class, especially the most vulnerable, have recently proven their ability to mobilize and demonstrate, as they did during mass gatherings from March to June 2013 (Fauré, 2014). Although the initial message was their opposition to the tremendous expenditure associated with the 2014 FIFA World Cup and the 2016 Rio Olympics, the protests then broadened out greatly to include the denunciation of corruption, public insecurity and failures in public services. These expressions of discontent can be analysed as a new wave of citizen-based activism, strongly supported by the large-scale use of social networks on the Internet. However, this activism has been primarily driven by new entrants into the middle class who remain highly vulnerable (Biekart, 2015). Although the different components of the Brazilian middle class share common expectations, the fragmentation of that class might limit its capacity to mobilize collectively over shared demands. More specifically, the upper middle class's ability to afford market mechanisms means it is probably less interested than the rest of the group in demanding improved public services. Examining the extent to which the weak cohesion of the Brazilian middle class may obstruct policies that would favour its most vulnerable components would be a promising avenue for future research.

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Determinants of labour productivity in Mexico: an approach from the endogenous growth theory using artificial neural networks

Héctor Eduardo Díaz Rodríguez and Fidel Aroche Reyes

Abstract

The widespread adoption of information and communications technology (ICT) has increased research on the link between such technology and economic growth. The use of ICT has a significant impact on growth, but studies tend to ignore the determinants of this use and the differing conditions across the companies, industries and countries that adopt them. In this study, we analyse the determinants of the differentiated impact of ICT on labour productivity growth in Mexican companies, using microdata from the ICT survey of the National Institute of Statistics and Geography (INEGI) and based on factor analysis and artificial neural network techniques. The results indicate that the strength of companies' links with the external sector and their capacities (educational level of staff and organizational maturity) determine the impact of ICT on labour productivity in Mexico.

Keywords

Employment, labour, labour productivity, innovations, information technology, communication technology, computer networks, Mexico

JEL classification

C46, O47, O33

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I. Introduction

The past 20 years have seen a boom in research on the impact of the adoption of technologies worldwide, in particular information and communications technology (ICT), as well as on their increasing importance in production processes. These studies began to multiply shortly after the emergence in the 1990s of endogenous growth theories (known as *AK* models), which hold that, in addition to technology, investment in human capital is an important driver of productivity growth. Paradoxically, however, most early analyses of the impact of ICT overlooked the importance of workforce education and training as a determinant of the benefits of technology (Brynjolfsson, 1993 and 1996; Brynjolfsson and Hitt, 1996; Bresnahan, 1997 and 1999; Lichtenberg, 1995; Jorgenson and Stiroh, 2000). In other words, product and technology innovation have played a major role in this regard.

Only recently have some studies recognized that the differences in the initial conditions various agents (companies, industries or countries) encounter are key to understanding the relationship between ICT and productivity; however, there remains a dearth of such studies in the existing literature and they focus primarily on developed economies (Schreyer, 2000; Daveri, 2000; Dutta and Bilbao-Osorio, 2012; Bilbao-Osorio, Dutta and Lanvin, 2013; ITU/UNESCO, 2013). Research on the impact of ICT on developing economies has been scarce at best, with little consideration given to the role of education in that nexus. This is evident from the few studies on the role of ICT and its impact on productivity in Mexico (Aravena, Cavada and Mulder, 2012; INEGI, 2013; UNCTAD, 2003). In view of the foregoing, this paper aims to add to the discussion on the role of workforce education and training as determining factors in the exploitation of technology in Mexico, drawing on some principles of endogenous growth theory. This is done through an analysis of microdata collected from the ICT survey (ENTIC) conducted by INEGI, using factor analysis and artificial neural networks methodologies (Haykin, 1999; Arrieta, Torres and Velásquez, 2009; Pitarque, Roy and Ruiz, 1998; Larrañaga, Inza and Moujahid, 2003).

The assumption is that while ICT is a prerequisite for labour productivity growth, it alone is insufficient for that growth to occur —organizations and workers must possess the requisite capacities that will enable them to incorporate technology into production and business processes and to fully exploit that technology. Without such capacities, ICT availability becomes moot.

The rest of the paper is organized as follows. Section II reviews the studies on the impact of ICT on productivity, with a view to describing some of the models derived from endogenous growth theory. Section III describes the factor analysis and artificial neural network methodologies used and section IV presents and analyses the results obtained from applying the method to the survey data. Section V concludes and presents possible public policy options.

II. Literature review

The well-known Solow model (1957) is one of the first approximations of the impact of technological change and factor growth on productivity, using a Cobb-Douglas production function that measures the efficiency with which factors are used in the production process. Thus, productivity growth is possible through two channels: as a result of an increase in the capital-per-worker ratio, or from the use of technology, which, in addition to widening that ratio, leads to more efficient use of the combination of factors. However, the model does not explain technological change or the reasons behind the improved exploitation thereof. The specific characteristics of the Solow model made it the model of choice for subsequent studies analysing the link between ICT and productivity.[1]

[1] This is because the model can break growth down into both the underlying factors (capital, labour and more efficient use of combinations of the two) and the type of capital (ICT or non-ICT investment) that drive growth.

Because of the inability of the Solow model to explain the sources of technical change, in the early 1990s a new wave of studies emerged which are based on that model but incorporate the role of investment in education as a catalyst of technical progress (Romer, 1990 and 1994; Aghion and others, 1998).

Early research on the effect of computer use on productivity in the United States economy found no direct link between the two. This gave rise to what was known as the "productivity paradox", prompting further research (based on longer and more reliable data series as well as more refined methods), with notable studies by Brynjolfsson (1993 and 1996), Brynjolfsson and Hitt (1996), Bresnahan (1997 and 1999), Lichtenberg (1995) and Jorgenson and Stiroh (2000). This collection of work pointed to a significant change in productivity resulting from the use of ICT. To differentiate the impact of the exponential use of ICT in organizations and from the adoption of other types of technology, this series of studies (based on the Solow model) identified a fundamental difference between investments in ICT and in other types of capital, which is that the former has a dual role. First, like other types of capital, ICT can be seen as a new production technology that improves labour productivity; second, it can also be considered a transformative element of production processes.

The impact of that second aspect, which triggers changes in business processes both within and between organizations, has been shown to be greater in studies by Bresnahan, 1997; Gurbaxani and Whang, 1991; Malone, Yates and Benjamin, 1989; Hollenstein, 2004; Capel and Bosch, 2004; Inklaar, O'Mahony and Timmer, 2005; Bayo-Moriones and Lera-López, 2007; Carrera Portugal, 2010; Tödtling, Grillitsch and Höglinger, 2012; and Peppard and Ward, 2016. In this sense, this body of research credits ICT with promoting changes in business processes and, with them, in multifactor productivity. Greenan, Mairesse and Topiol-Bensaid (2001) analysed the impact of ICT on some French companies and their findings were similar to those of Bresnahan (1997) and Lichtenberg (1995).

In contrast, Lal (2001) found no link between ICT investments and productivity in the Indian textile industry. There is a general pattern of contrasting findings in studies on firms located in developed economies and those in developing economies, as shown by Kraemer and Dewan (2000) and Pohjola (2001), whose observations indicate that, at the firm level, ICT tends to bring about productivity changes in developed countries but not in developing countries. Kraemer and Dewan (2000) and Pohjola (2001) posit that these differences are attributable to labour costs in the two groups of countries. In developing countries, labour costs tend to be lower and the costs of access to capital high, making the substitution of labour by capital relatively more onerous. The opposite is true of developed countries.[2]

However, the plethora of studies based on the Solow model has failed to explain why, despite the exponential increase in ICT adoption worldwide, patterns of productivity and economic growth —which should follow therefrom— have diverged so markedly. More often than not, there has been a tendency towards stagnation, as exemplified by the Mexican economy. Consequently, more recent studies have begun to analyse factors associated with the context of economies and enterprises, as well as differences in their initial conditions, with a view to accounting for such disparate productivity outcomes despite similar levels of ICT uptake. These include papers by Aramendia-Muneta and Ollo-López (2013), Tarutė and Gatautis (2014) and a series of analyses conducted by international development and cooperation agencies (World Bank, 2011 and 2012; Dutta and Bilbao-Osorio, 2012; Bilbao-Osorio, Dutta and Lanvin, 2013; and OECD, 2012), which conclude that inflexible institutional factors which make it difficult to take full advantage of the potential benefits of ICT are the reason why technology has failed to create an impact on economies or the firms operating therein. The conclusion of these agencies has not changed from that drawn 30 years ago: general conditions for high and sustained growth must be created and these include openness to trade and capital flows, an appropriate institutional and legal

[2] In this study, we posit that the variations in how ICT affects countries and economic activities are owed mainly to differences in the level of education of the workforce, in the maturity of the companies in each group, and in the sectoral composition of the companies.

framework, flexibility in the production structure and efficient markets (World Bank, 2011 and 2012; Dutta and Bilbao-Osorio, 2012; Bilbao-Osorio, Dutta and Lanvin, 2013; OECD, 2012).

This paper does not establish a direct link between ICT availability and economic performance, which is seen as a change in factor productivity or aggregate economic growth; rather, that link is potential and is contingent on the economies, industries or firms involved possessing a set of characteristics and capacities to leverage the use of ICT infrastructure. How these determinants influence productivity depends on the situation, the economy in question, the possession of a set of skills concomitant with workers' educational level and organizational maturity and which is reflected in the ability to incorporate technology into production processes, and the very nature of the economic activities conducted.

Despite their focus on developed economies, the aforementioned Solow model and the studies reviewed in this section are incapable of explaining the differences in productivity associated with the adoption of ICT; in the case of developing economies, the paucity of research on this issue reinforces the need for a different perspective. In the specific case of the Mexican economy, the widespread adoption of ICT by companies has not led to increased productivity and it is worthwhile to consider possible explanations in that regard.

III. Methodology and characteristics of data

To understand why the adoption and expansion of ICT have not had a positive effect on productivity in Mexico, this paper analyses the database created from the ICT survey (ENTIC) published by INEGI in 2013. It contains information on 389 variables on ICT use for a sample of 6,468 companies, representative of 157,611 organizations that have ten employees or more and which were classified in 76 subsectors the previous year, based on the North American Industry Classification System (NAICS). With a view to applying the model presented below, 34 variables were selected to measure how organizations incorporate information and communications technology into their production and business processes: 13 variables were used directly and 21 variables were used to construct two indices, one on Internet use and the other on software use.[3]

The following criteria were used to group the variables in these indices: each of the available variables on Internet, software and cloud use was sorted based on the skills required; a rating was then applied to each variable,[4] with a lower rating for uses classified as basic[5] and a higher rating for advanced uses. Through this procedure, the 21 variables representing the various uses of the Internet and software were narrowed down to two: the Internet usage index and the software usage index. These indices are included as variables for factor analysis.

[3] Use and exploitation is a concept that describes the ways in which organizations use available technology and benefit from its advantages. The concept of use is not linear, since there are different levels at which the use of technology is incorporated into production processes; the more these uses affect the development of processes and lead to organizational change, the greater the impact of the technology.

The aim of the proposed classification is not to assign a specific qualification for each use, but simply to rank them according to the level of skills required for a specific use.

[4] The variables and the respective scores used to construct the Internet use index are as follows: general information search (4), information transfer (6), financial transactions (8), access to government portals (10), payment of non-government services (12), supplier care (14), recruitment and staffing (16), customer care (18), corporate advertising (20) and distance training (22). The variables and the respective scores used to construct the software use index are as follows: programs for invoicing (4), accounting (6), payroll administration (8), purchasing and payment management (10), human resources (12), sales (14), inventory (16), business administration (18), information analysis (20), design (22) and logistics (24).

[5] A use is considered basic if it requires little skill; the more complex the use, the greater the skill required. For example, in the case of Internet use, the variable for general information search demands little capacity from human resources and organizations. In comparison, the distance training variable requires greater capacities, such as the development of a culture that promotes training, the necessary infrastructure, and technological know-how on the part of the workforce, among others.

1. Factor analysis

Factor analysis can be used to group correlated variables and find homogeneous groups, particularly in databases with a high number of series. In principle, these groups are independent of each other. Using factor analysis, it is possible to find the minimum number of dimensions capable of explaining the maximum amount of information contained in the data. Put another way, a factor is a qualitative dimension on a coordinate axis, which defines how entities (observations) differ, just as the size or taste of an object defines its qualitative dimensions (Domínguez and Brown, 2004).

In formal terms, factor analysis is a multivariate method that expresses p observable variables as a linear combination of hypothetical or latent variables (m), called factors. These variables or common factors are obtained and interpreted from the matrix of correlations between the variables:

$$R = \begin{pmatrix} 1 & r12 & \cdots & r1p \\ r21 & 1 & \cdots & r2p \\ \vdots & \vdots & \ddots & \vdots \\ rp1 & \vdots & \cdots & 1 \end{pmatrix} \tag{1}$$

In the case of multifactor models, the p observable variables (variables from the ICT survey) depend on m latent variables or common factors, in addition to unique factor p, as denoted by the following linear model:

$$X_1 = a_{11}F_1 + \cdots + a_{1m}F_m + d_1U_1 \tag{2}$$

$$X_2 = a_{21}F_1 + \cdots + a_{2m}F_m + d_2U_2 \tag{3}$$

$$\cdots$$

$$X_p = a_{p1}F_1 + \cdots + a_{pm}F_m + d_pU_p \tag{4}$$

The multifactor analysis model is based on two fundamental assumptions:

(i) Common factors and unique factors are not correlated, i.e:

$$Cor\left(F_i, U_j\right) \quad i = 1, \ldots, m \quad j = 1, \ldots, p \tag{5}$$

(ii) The common factors and the unique factors have a mean of 0 and variance of 1:[6]

$$\mu = 0, \sigma = 1$$

In the factor analysis model, overall variance is explained by two groups of factors —common factors and unique factors— as illustrated below:

$$Var\left(X_i\right) = a_{i1}^2 + \cdots + a_{im}^2 + d_i^2 \tag{6}$$

That is, a_{ij}^2 is the share of variation of X_i that is explained by the existence of a common factor (F_j), while d_i^2 is interpreted as the share that is explained solely by the unique factor U_i.

The share of the pooled variance of variable X that is explained by common factors is called the commonality variable and is derived from the following function:

$$h_i^2 = a_{i1}^2 + \cdots + a_{im}^2 \tag{7}$$

6 However, since common factors are independent dimensions in the linear sense and both common and unique factors are conventional variables, there is a possibility that independent (common) vectors may not have a mean of 0 and a variance of 1 (Cuadras, 2007).

2. Artificial neural networks

A neural network is a massively parallel distributed processor [...] which has a natural propensity for storing experiential knowledge and making it available for use (Haykin, 1999). The author notes that it resembles the brain in two respects:

(i) Knowledge is acquired by an artificial neural network, like its biological counterpart, through a learning process.

(ii) Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

The knowledge acquired in an artificial neural network is applied to estimate the behaviour of a given variable using variables with input information; between the input variables (input layer) and the output variables (output layer) is an intermediate area called the hidden layer, in which the information and the model used to analyse it are processed.

While a regression model can be described as a specific type of network, in the sense that regression coefficients can acquire and store knowledge, regression has a rigid model structure and an underlying structure to assumptions, which are both imposed from the outset. This is in contrast to an artificial neural network model, where the form of the relationships is determined during the learning process. If a linear relationship between dependent and independent variables is adequate, the results of the neural network should match those of the linear regression model as closely as possible. If a non-linear relationship is more appropriate, the neural network will automatically approximate the "correct" model structure.

Larrañaga, Inza and Moujahid (2003) hold that artificial neural networks can be described as a directed graph with the following properties:

(i) Each node (neuron) i is associated with a state variable X_i.

(ii) Each synaptic connection (i, j) between nodes (neurons) i and j is assigned a weight $w_{ij} \in \mathbb{R}$.

(iii) Each node (neuron) i is associated with a threshold $\theta_i \in \mathbb{R}$.

(iv) For each node i, a function $f_i\left(X_i, \ldots, X_n, W_{i1}, \ldots, W_{in} \theta_i\right)$ is defined according to the connection weights, the threshold and the states of the nodes j that are connected to node i. The value of this function determines the new state of the node.

In an artificial neural network, the nodes are connected through contact between the neural functions in a process known as synapsis. The behaviour of an artificial neural network will ultimately be determined by the structure of the synaptic connections, known as the network architecture. This denotes the topology, structure or pattern formed by the synaptic connections of an artificial neural network. These networks can define both linear and non-linear parameters that are mapped from an input to an output, such as $Y=Y(X;W,A)$, which is a continuous function of both the inputs and the parameters (W) of the network architecture (A) (MacKay, 2003). Networks can be trained to perform regression, classification and prediction tasks.

The input layer of an artificial neural network is the layer composed of the set of neurons responsible for receiving data and information from the environment; in this layer of the structure, neurons do not have input synapses, only output synapses. Next are the hidden layers, which are not directly connected with the environment, but receive information and data from the input layer; it is here that the characteristics of the environment are estimated, modelled and represented. This is the only layer that is neither input nor output, and is formulated thus:

$$\text{Hidden layer: } a_j^1 = \sum\nolimits_l W_{jl}^1 X_l + \theta_j^1 \; ; \quad h_j = f^1\left(a_j^1\right) \tag{8}$$

Lastly, the output layer comprises the sets of neurons that provide the network response. The neurons in this layer do not have output synapses.

$$\text{Output layer: } a_j^2 = \sum\nolimits_l W_{jl}^2 X_l + \theta_j^2 \; ; \quad h_j = h^2\left(a_j^2\right) \tag{9}$$

One of the major differences between existing types of artificial neural networks is the number of layers used in the learning process (hidden layers). In general, using more layers makes it possible to model more complex processes. For the purposes of this study, we use a multilayer perceptron network.

(a) Multilayer perceptron

The multilayer perception is an artificial neural network that has one or more hidden layers, allowing for the detection of more complex patterns, which may or may not be separated by more than one hyperplane. The structure of this artificial neural network arguably makes it the most suitable for analysing the relationship discussed in this study as it can capture a wide range of functional relationships, even non-linear ones.[7] A multilayer perceptron is a feedforward network, meaning that it reacts to changes in its environment to maintain a specific state in the system. It has three fundamental elements (Bishop, 1995):

(i) Input layer (input variables)

(ii) Hidden layers

(iii) Output layer (output variables)

The hidden layers model the functional forms of the data obtained in the input layer through a process called neuron training. For this process, a subset of the data $D = \left\{X^{(n)}, t^{(n)}\right\}$ is used and the W of the input function is adjusted, minimizing the error function through the gradient descent method given by the backpropagation algorithm:

$$E_D(w) = \frac{1}{2} \sum n \sum i \left(t_i^{(n)} - y_i\left(x^{(n)}; w\right)\right)^2 \tag{10}$$

This minimization continually calculates the E_D gradient by means of the chain rule to find the derivatives through the following steps:

(i) Synaptic weights and initial thresholds are established.

(ii) One of the bases is processed to obtain a response from the network with respect to the r- th pattern.

(iii) Errors are interpreted as error signals associated with the process and are calculated by:

$$\left(\sum\nolimits_{k=1}^{S} \left(\sum\nolimits_{j=1}^{0} W'k_j Y_j^r - \theta_k\right) W_{kj}\right) \frac{\partial f\left(\sum\nolimits_{i=1}^{n} W_{ji} X_j^r - \theta_j\right)}{\partial\left(\sum\nolimits_{i=1}^{n} W_{ji} X_j^r - \theta_j\right)} \tag{11}$$

(iv) The total increase is calculated for all patterns of thresholds and weights $\Delta W'_{kj}$ and $\Delta W'_{ji}$.

(v) The weights and thresholds are updated.

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[7] The estimation of the two-layer artificial neural network model shows a better fit than the single-layer model when applied to data from the ICT survey. Only the best fitting results used in the model are reported here. Unused results are not reported.

(vi) The total error is recalculated at $t+1$. If that error is not "satisfactory", that is, if it is not the absolute minimum obtained through gradient descent, it is again interpreted as a process error signal and the third step is repeated until the minimum error is found.

In addition, an activation function, determined using the corresponding estimation algorithm, is calculated for each hidden layer and output layer. The activation function relates the weighted sum of units in a layer to the values of the units in the correct layer and differs for the hidden layers and the output layer. The following activation functions can be obtained in hidden layers:

(i) Hyperbolic tangent, which takes arguments from real values and maps them to a range of -1 to 1 using the function:

$$\gamma(c) = tanh(c) = \frac{e^c - e^{-c}}{e^c + e^{-c}} \tag{12}$$

(ii) Sigmoid, which takes arguments from real values and maps them to a range of 0 to 1 using the function:

$$\gamma(c) = \frac{1}{(1 + e^{-c})} \tag{13}$$

For output variables, the activation function relates the weighted sum of units in a layer to the values of the units in the correct layer. The following activation functions can be obtained for the output layer:

(i) Identity (or linear), which takes arguments from real values and returns them unchanged through the function:

$$\gamma(c) = c \tag{14}$$

(ii) Softmax, which takes a vector of arguments from real values and transforms it into a vector that has elements between the values 0 and 1, with the sum equal to 1. This function cannot be used when there are scaled output variables; it is only available when the dependent (input) variables are categorical variables. It is formulated thus:

$$\gamma(c_k) = exp(C_k) \Big/ \sum_j exp(C_j) \tag{15}$$

The process is considered complete once the algorithm has minimized errors and the activation functions of the hidden and output layers have been found. The best way to compare the results obtained is to analyse a set or batch of data separately. As this set is not part of the training data, it is a good indicator of the network's ability to estimate or recognize patterns.

IV. Analysis of the results

The first step in the factor analysis is to obtain the commonality coefficients of the analysed variables. If these coefficients are high (close to 1), this gives an approximation that a significant component of the variables can be explained by the existence of common factors. Otherwise (if coefficients are close to 0), it becomes evident that a large proportion of the variance can be explained by unique factors. The factors are obtained using the principal components method.

The commonality coefficients in the extraction column represent the proportion of the variance that can be explained by the factor solution model obtained. The commonalities explain most of the pooled variance of the variables (see table1).

Table 1
Results of factor analysis

Component	Initial eigenvalues	Percentage of variance of each component	Rotation sums of squared loading	Commonality Variable	
	Total		Cumulative percentage	Commonalities (extraction)	
1	3.684	24.562	24.562	Landlines	0.526
2	2.074	13.824	38.386	Mobile phones	0.452
3	1.259	8.395	46.781	Social networks	0.625
4	1.002	6.681	53.462	Computers	0.803
5	0.913	6.090	59.552	Software	0.631
6	0.892	5.948	65.500	Internet	0.807
7	0.847	5.648	71.148	Cloud computing	0.321
8	0.824	5.496	76.644	Innovation	0.491
9	0.733	4.886	81.530	Salaries of postgraduate degree-holders	0.512
10	0.646	4.310	85.840	Salaries of bachelor's degree-holders	0.671
11	0.587	3.914	89.754	Salaries of technicians	0.612
12	0.542	3.612	93.366	ICT training	0.671
13	0.465	3.100	96.465	Systems department	0.461
14	0.371	2.470	98.936	Internet use index	0.651
15	0.160	1.064	100.000	Software use index	0.984

Source: Prepared by the authors.
Note: The extraction method applied is the principal components analysis method, using the Statistical Package for the Social Sciences (SPSS 23) software.

Table 1 shows the set of eigenvalues of the variance and covariance matrix, as well as the percentage of the total variance that each eigenvalue represents. The eigenvalues obtained express the share of variance that is explained by each of the factors. The extraction method is capable of yielding both factors and eigenvalues above 1 for the matrix analysed (four, in this case). Thus, the four components extracted explain 53.5% of the total variance. The next step is to calculate the component matrix, which shows the number of variables that saturate each factor. To obtain a number of "simple structure" variables (Thurstone, 1947), which are variables that saturate a single factor, as well as factors containing a limited number of explicitly and exclusively saturated variables, the component matrix obtained through the initial solution can be rotated.[8] For the purposes of our analysis, the Varimax rotation method was used. The results of the rotated component matrix are shown in table 2.

These results indicate that the set of variables analysed can be grouped into three main factors: technology, capacity and innovation. Thus, six variables make up a factor termed "ICT infrastructure", which explains 25% of the pooled variance, while a second factor comprising a set of human resource capacities explains 14% of the that variance. Here, salaries by level of education are seen as an approximation of capacities since, in theory, they are commensurate with work experience, education, training and skills, among other things. The use of new technologies (social networking and cloud computing), as well as innovation in products or processes, make up a third factor, termed "innovation", which explains 8% of the pooled variance. Lastly, the software use variable explains 7% of the pooled variance.

[8] Various methods of rotation exist, based on the premise that there is no universal solution for determining the matrix of weights. Multiplication by an orthogonal matrix of order $k \times k$ can be used such that the new model verifies the properties and weights of the original matrix but makes it more easily interpretable in terms of determining the variables that saturate factors.

Table 2
Factors obtained through factor analysis

Factor	Percentage of variance explained	Variables	Rotated component matrix[a]			
			1	2	3	4
1. ICT infrastructure	24.5	Landline availability	0.724	0.008	-0.034	0.017
		Mobile phone availability	0.377	0.076	0.308	0.095
		Computer availability	0.896	0.010	0.035	0.009
		Software availability	0.469	0.069	0.032	-0.077
		Internet availability	0.893	0.019	0.095	0.013
		Internet use index	0.638	0.134	0.475	0.018
2. Human resource capacity	13.8	Salaries of postgraduate degree-holders	-0.004	0.698	0.158	-0.016
		Salaries of bachelor's degree-holders	0.073	0.802	0.149	0.006
		Salaries of technicians	0.047	0.780	-0.041	-0.002
		Systems department	0.243	0.460	0.436	0.003
		ICT training	0.037	0.573	0.205	-0.004
3. Innovation	8.4	Social networking	0.062	-0.063	0.562	0.034
		Cloud computing	0.028	0.033	0.564	-0.017
		Innovation	0.060	0.170	0.675	-0.053
4. Software use	6.7	Software use index	-0.019	-0.009	-0.015	0.991

Source: Prepared by the authors.
Note: The extraction method applied is the principal components analysis method, Rotation method: Varimax with Kaiser normalization. SPSS 23 software was used.
[a] Rotation converged in five iterations.

After identifying the factors into which the linear transformations of variables collapse, we can establish whether these are determinants of labour productivity. According to endogenous growth theory, besides factors related to workforce training, there are determinants of productivity related to capital intensity per worker and the capacity of organizations to absorb knowledge from competition (learning-by-doing). We use investment per employee as a proxy for capital stock per worker; we also use years of market experience and the exports-to-jobs ratio as operating variables in the competitive environment.

The next step of the analysis is to test, using artificial neural network methodology, whether the theoretical variables included are capable of explaining productivity behaviour, and whether that behaviour is associated with the capacities of organizations or, rather, the technology they use. We model a multilayer perception artificial neural network with two hidden layers. Thus, labour productivity is a function of the variables of the input layer (obtained through factor analysis): 1. ICT infrastructure; 2. Human resources capacity; 3. Innovation; 4. Software use; 5. Investment per employee; 6. Exports per employee; and 7. Firm experience, in years. The output layer denotes labour productivity.

1. Summary of processing

From a total of 6,210 observations, 1,622 were excluded from the analysis because they lacked one of the variables considered to be explanatory variables of productivity. The artificial neural network dataset was partitioned as follows: 78% of observations were used to train the network, 14% for validation and 8% used as the holdout set. The training process is performed in the hidden layer and is used to approximate the correct functional relationship. However, more data are sometimes required for neuron training, in which case the training dataset can pull data from the validation and holdout sets. The validation dataset is used to verify that the learning process has been performed appropriately with regard to error function minimization.

The partition of the sample allocated to the holdout set is excluded from the training and validation processes and is used to check how close productivity data estimated by the artificial neural network model are to real values to rule out the possibility of bias in the estimation. As these data were not used for training, they are a good indicator of the predictive strength of the model in terms of the proximity between estimated and real values. Table 3 shows the distribution of cases following network processing.

Table 3
Artificial neural network processing data

Summary of processing			
		N	Percentage
Sample	Training	3 556	78
	Validation	665	14
	Holdout	367	8
Valid		4 588	100
Excluded		1 622	
Total		6 210	

Source: Prepared by the authors.
Note: SPSS 23 software was used.

2. Input layer

The input layer comprises the independent variables which, theoretically, are capable of representing the behaviour of the dependent or output layer variable. The form that this representation takes is determined through a learning process within the network (hidden layers). The seven variables mentioned above were used in the artificial neural network selected for this study.

3. Hidden layers

It is in the hidden layers of an artificial neural network that the type of relationship that exists between the input variables and the dependent variable is estimated. This is done through a learning process known as “neuron training”. A significant proportion of the available data is needed for this training, which allows for the approximation of the correct functional relationship. Thus, 78% of the dataset was required to ensure that the learning process was carried out appropriately.[9] Specifically, the architecture of the selected artificial neural network comprises two hidden layers (maximum number of hidden layers) with a hyperbolic tangent activation function, which means that the input values are converted to values within a range of -1 and 1, starting with function 12. There are 20 units in the first hidden layer and 15 units in the second (see table 4).

9 A learning process is deemed “adequate” when it is determined that the error minimization process (using the gradient descent method, explained in the methodology section) is capable of finding the minimum error function. When the minimum error is found, the learning process in the hidden layers stops.

Table 4
Artificial neural network processing data, hidden layers

Network information, hidden layers		
Hidden layers	Number of hidden layers	2
	Number of units in hidden layer 1	20
	Number of units in hidden layer 2	15
	Activation function	Hyperbolic tangent
Training characteristics		
Initial learning rate		0.4
Lower boundary of learning rate		0.001
Learning rate reduction, in epochs		10
Momentum		0.9
Interval centre		0
Interval offset		± 0.5

Source: Prepared by the authors.
Note: SPSS 23 software was used.

4. Output layer

The output layer denotes labour productivity and, like the input layer, requires an activation function which makes it possible to compare the results obtained against what are considered to be the explanatory factors. For the artificial neural network modelled here, the output layer is an indicator of two things:

(i) Whether labour productivity is linked to input variables (ICT infrastructure and use, human resource capacities, innovation, software use, investment per employee, exports per employee and firm experience); this is determined through the error function.

(ii) The significance and order of significance of each independent variable over the dependent variable.

This is shown in table 5.

Table 5
Artificial neural network processing data, output layer

Training characteristics		
Output layer	Independent variables 1	Labour productivity
	Number of units	1
	Method of scale change for scale-dependent variables	Normalized corrected
	Activation function	Hyperbolic tangent
	Error function	Sum of squares

Source: Prepared by the authors.
Note: SPSS 23 software was used.

The table also shows information regarding the synaptic connections of the input layer, the hidden layers and the output layer. Each connection can denote an excitatory or inhibitory weight: in other words, this determines the signal that the independent variable fires in the dependent variable, and the strength of that impact. The results of the estimation by the network model can be analysed in terms of the model's predictive capacity. In this regard, the quality of the network model is ultimately validated —using the holdout sample— by comparing the values estimated by the model against real values to determine their proximity.

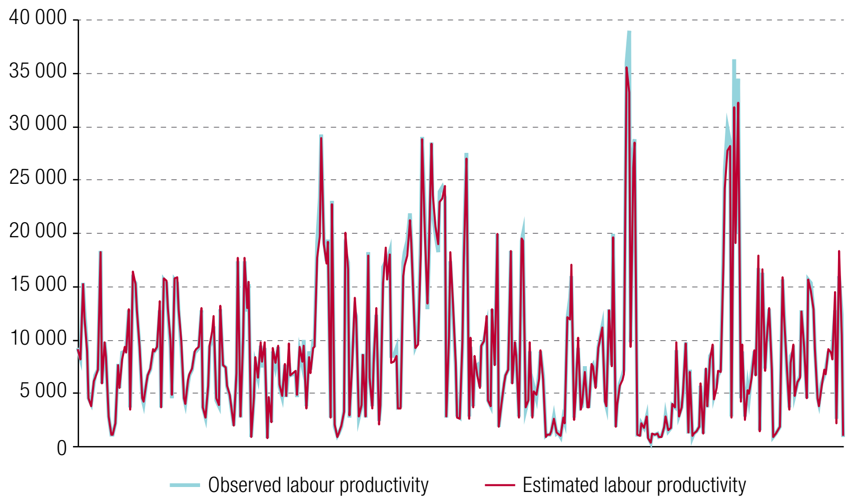
As can be seen in table 6, the errors in each process (thousands of pesos) are reasonably low, especially in the holdout sample. Based on the holdout dataset, this indicates that, on average, there is a difference of just over 1,900 pesos (equivalent to a 1.2% error) between the estimated and observed productivity data. Figure 1 shows how close the labour productivity values estimated by the artificial neural network model are to real labour productivity values, based on the holdout sample.

Table 6
Artificial neural network processing data (training, validation and holdout sets)

Model summary		
Training	Sum of squares error *(thousands of pesos)*	2.575
	Relative error *(thousands of pesos)*	1.006
	Stopping rule used	Maximum training time exceeded (15 minutes)
	Training time *(hours)*	27:48.7
Validation	Sum of squares error *(thousands of pesos)*	0.001
	Relative error *(thousands of pesos)*	1.862
Holdout	Relative error *(thousands of pesos)*	1.932

Source: Prepared by the authors.
Note: SPSS 23 software was used.

Figure 1
Observed labour productivity and labour productivity estimated by the artificial neural network model, holdout sample
(Thousands of pesos)



Source: Prepared by the authors, on the basis of data from the ICT survey (ENTIC).
Note: Estimation based on an artificial neural network with two hidden layers.

Figure 1 illustrates two interesting aspects: first, on average, for the entire holdout sample, the artificial neural network model is able to reasonably predict the behaviour of labour productivity; second, for companies with production per employee in excess of 10 million pesos, the model tends to underestimate the values. This could indicate that the factors that explain productivity in higher-income firms are more complex than the seven variables included as determinants of productivity in the model.

Unlike in econometric models, in artificial neural network models it is not possible to observe how coefficients are obtained within the hidden layers. However, they do provide information related to the significance of the impact of independent variables on the dependent variable. This is done through variable importance analysis, as seen in table 7.

Table 7
Variable importance analysis

Variable	Importance	Normalized importance *(percentages)*
Innovation	0.133	55.9
Software use	0.132	55.3
ICT availability and use	0.142	59.7
Human resources capacity	0.146	61.5
Investment per employee	0.128	53.7
Exports per employee	0.238	100.0
Experience	0.08	33.8

Source: Prepared by the authors.
Note: SPSS 23 software was used.

The importance of an independent variable is a measure of how much the network's model-predicted value changes for different values of the independent variable. Normalized importance is simply the importance values divided by the largest importance values and expressed as percentages (IBM, 2011).

The data in the table above show that for the simulated artificial neural network model, the key variable for understanding productivity is the volume of exports per employee. The educational qualifications of the workforce and the availability and use of ICT in organizations, respectively, rank second and third in order of importance as determinants of productivity. Innovation (be it in products or processes) is the fourth most important factor and also helps to explain productivity in Mexican companies with more than ten employees. However, it is the largest firms, with exports that account for more than 20% of total income, that are the most innovative. When this group of firms (which represents less than 4% of the total sample) is excluded from the analysis, exports and innovation fall to fourth and fifth position, respectively, while human resource capacities and the availability and use of ICTs move up to first and second position, respectively, in the order of importance, with investment per employee in third position.

V. Conclusions

The theoretical frame of reference of most of the research on the impact of ICT on productivity is neoclassical growth theory, in which technological change plays a central role in explaining productivity growth. However, as we have seen from the studies discussed in the present analysis, this theory is incapable of explaining why there are such discrepancies in productivity among companies with similar levels of ICT adoption.

The existence of differentiated initial conditions, in particular those involving the capacities of organizations, has been largely overlooked in the literature. Our research shows that including these differences in the analysis significantly improves the understanding of variation in productivity. This is particularly true in the case of Mexico, where the issue has not been examined extensively.

This paper identifies four important factors that explain productivity. The first is the availability of ICT in companies. Coupled with this is a set of capacities that determine how well technology is incorporated into production and business processes. We call this factor "organizational capacities", which include employees' education level, the training they receive and the existence of a specialized ICT department. The third factor involves the use and exploitation of technology, associated with the level of innovation (in products or processes), and the fourth is capital intensity per worker.

Organizations' exposure to competition and their market experience increase their capacity to absorb knowledge and raise productivity, as shown by the importance of exports and company experience as key production variables. The combination of these factors makes it possible to understand differences in labour productivity. At firm level, the analysis by artificial neural networks shows that the combination of exports, human resources and ICT use seems to adequately explain a significant aspect of productivity behaviour in organizations with an income per worker of less than 10 million pesos. In firms with higher labour productivity, other factors appear to explain productivity behaviour.

This study has shown that it is not only technology, but also factors such as education and organizational maturity that make production processes more dynamic and lay the foundations for high productivity. This points to a need for complementarity in public policy in three areas:

(i) Encouraging appropriate development of ICT infrastructure, particularly in economic sectors or activities considered priority, either because they occupy a strategic position in the value chain or because of their high impact in terms of production linkages and employment generation. This policy should be geared towards developing sufficient and suitable ICT infrastructure (particularly the Internet and software, which are indispensable for the operation of other types of services, such as cloud services) for key sectors.

(ii) As this study has established, ensuring the availability of infrastructure is the first essential step towards improving labour productivity. However, this alone does not suffice. Government policies to enhance infrastructure must be accompanied by policies on capacity-building in the use of technological tools. One way of promoting and transmitting the importance of training to facilitate the effective use of technology could be the establishment of public-private partnerships. Such partnerships could, for example, allow for training costs to be covered in part by public funds with the remainder borne by the company, or for some form of tax exemption for firms that regularly provide technological training for their employees.

(iii) In addition to developing specific policies on ICT training for current employees in companies, there is a need for a long-term policy on capacity-building. For this to be achieved, the best strategy appears to be that proposed in early studies on endogenous growth theory, namely, greater investment in education as a prerequisite for long-term economic growth. It would appear that this is already part of the debate in Mexican public policy, but it is far from being reflected in a formal policy aimed at increasing investment in education.

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The impact of public debt on economic growth: an empirical study of Mexico (1994–2016)

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Abstract

Following on from recent literature on the same subject, this paper analyses the impact of public debt on economic growth in Mexico between 1994 and 2016, against a global macroeconomic backdrop of sharp rises in public sector debt indicators, owing to expansionary fiscal strategies adopted after the 2007–2008 crisis. The main objectives of this study are to determine whether the relationship between these two variables has followed a non-linear path in the form of an inverted "U", and to find the threshold beyond which increases in debt generate marginal decreases in growth. Using a dynamic model, a non-linear inverted U-shaped relationship is demonstrated, and the threshold in the debt-to-GDP ratio is found to be 27%.

Keywords

Economic conditions, economic growth, econometric models, gross domestic product, macroeconomics, Mexico, public debt

JEL classification

E62; H63; O54

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I. Introduction

Compared to the rest of the twentieth century, from the late 1970s to the early 1990s economic and social conditions were dismal in Mexico and almost all the other Latin American countries. In some countries of the region, the key factor that drove them into this painful period was the establishment of dictatorships, while in others it was the debt crisis.

In Mexico, for instance, between 1982 and 1986 production was stagnant, while on average no less than 6% of gross domestic product (GDP) was transferred to external creditors (van Wijnbergen, 1991a). Faced with imminent economic collapse, the restraint measures implemented under the Brady Plan[1] helped Mexico move forward, investors' confidence was restored and capital flight was avoided. This generated greater macroeconomic stability and the right conditions for a return to the economic growth that Mexico had seen over the 30–40 years prior to the crisis.

Debt restructuring contributed to the return to growth in the second half of 1989. However, the 1994 debt crisis hit Mexico particularly hard, mainly because a significant portion of government payable bonds were denominated in dollars, in addition to the mismanagement of public finances and the unstable global economic environment. Once again on the verge of declaring a moratorium, this time it was the United States that created a rescue plan to prevent a Mexican default.

Despite the complicated economic situation and the difficulties caused by the sudden and forced opening of trade, Mexico was able to rein in its debt problems, as reflected in its levels of public debt, which were contained below the threshold of 18%[2] of GDP for the rest of the 1990s and almost the entire first decade of the twenty-first century. During this period, under the New Consensus Macroeconomics (NCM) model that governed economic policy around the world, fiscal policy was limited to being a mere automatic stabilizer, with no active role in countries' economies.

However, the global financial crisis of 2007–2008 caused an imbalance in the public finances of the vast majority of countries, both developed and developing, around the world.[3] This was mainly a result of the expansionary strategies adopted by governments to boost their economies through public spending and investment, which had generated large fiscal deficits.[4] Consequently, debt-to-GDP ratios rose rapidly, hitting levels not seen since the post-war period, when the welfare state model prevailed.

Mexico was not immune to this global trend, and was also forced to abandon its previously stable debt levels, in order to overcome the ravages of the crisis. From 1994 to 2008 the country's debt-to-GDP ratio averaged 16.83%, and its debt was even reduced by an average of 2.74% a year, bringing it down from 22.02% in 1995 to 14.74% in 2008. However, from 2009 to 2016, the debt-to-GDP ratio ballooned by 14.12% per year, leaving the average for the period at 31.58%. It jumped from 14.74% in 2008 to 25.52% in 2009, and in 2016 it reached 37.49%. Figure 1 shows the evolution of the debt-to-GDP ratio in Mexico.

This pattern, which was seen in Mexico and many other parts of the world, together with over-optimism about fiscal expansion owing to a revival in Keynesian ideas, generated concern among some academics over the impact that high debt ratios have, or could have, on economic growth.

[1] The Brady Plan consisted of restructuring Latin American developing countries' debt held by commercial banks. Through the extension of terms, grace periods and greater ease of payment, the aim was to reduce the balance owed and generate a higher level of productive investment that would translate into growth and, subsequently, greater capacity to pay. For a detailed analysis of this plan and the benefits it brought to the Mexican economy, see van Wijnbergen (1991a and 1991b).

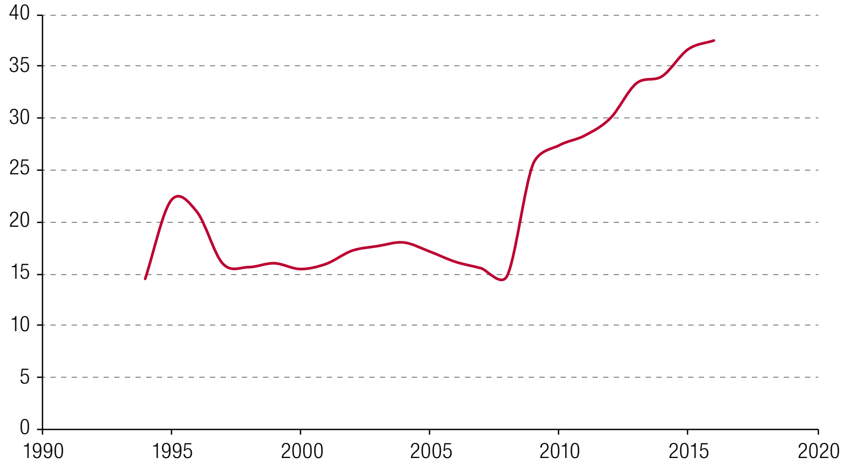
[2] For the purposes of this study, the debt-to-GDP ratio is calculated on the basis of the net public sector debt figures of the Bank of Mexico, deflated by the GDP deflator, with 2008 as the base year. GDP data for Mexico can be consulted at [online] https://www.inegi.org.mx/sistemas/bie/.

[3] For example, in Iceland, Ireland, Spain, the United Kingdom and the United States, the average debt-to-GDP ratio increased by about 75% between 2007 and 2009 (Reinhart and Rogoff, 2010).

[4] In the eurozone, the fiscal deficit increased rapidly from 0.7% of GDP in 2007 to 6% of GDP in 2010 (Checherita-Westphal and Rother, 2012).

Figure 1

Mexico: public debt as a proportion of GDP, 1994–2016



Source: Prepared by the authors, on the basis of data from the National Institute of Statistics and Geography (INEGI).

Existing literature suggests that debt has a non-linear and inverted U-shaped relation with growth: public debt initially has a positive impact on the economy, since it can boost aggregate demand through consumption, as well as financing activities and productive investments with private resources that would otherwise not be able to be carried out. Nevertheless, there is a point beyond which debt has a negative effect on marginal growth, since speculation arises over governments' ability to pay and capital begins to migrate, seeking projects elsewhere, thus reducing investment and stalling growth in any economy.

It is for this reason that, in the current context, a study of the relationship between public debt and growth in Mexico is of great importance. The aim of this document is to examine the impact that debt has had on the growth in the country, to verify whether a U-shaped curve exists and, if it does, to use econometric tools to determine the threshold in the ratio beyond which debt has a negative marginal impact on the economy.

It is true that, compared to other countries,[5] Mexico's debt figures do not put the economy at risk or herald an imminent crisis. Nevertheless, if nothing is done and the debt-to-GDP ratio is allowed to continue to grow at its current rate for several more years, it will only be a matter of time before we witness serious instability and recessions, with a weakened State that has little capacity to intervene.

Although several studies have attempted to understand and explain this relationship, the average range for the inflection point in the inverted U can be said to be between 30% and 50% of debt to GDP. These figures suggest that now is an opportune moment to address the issue in Mexico, since, as can be seen in figure 1, the country's debt-to-GDP ratio was just under 38% in 2016. In addition, as indicated by Rojas (2017), the financial services company Standard & Poor's assumes a high probability that Mexico's public debt will increase, in view of the economic policy packages it has adopted in recent years.

The rest of this document is structured as follows: section II examines the literature and the academic and political discussions of recent years on this controversial topic. Section III describes and justifies the data and variables used in the econometric model, and the methodology used. Section IV presents the results of the model and offers some policy suggestions to address the current situation. Lastly, the conclusions are set out in section V.

[5] According to San Isidoro (2017), Japan topped the list of the most indebted countries in terms of debt-to-GDP ratio, with 237%, followed by Greece with 181%. The United States was in sixteenth position with 105%, while China ranked one hundred and sixth with a ratio of 42%.

II. Literature review

1. The relationship between public debt and growth

Literature on the impact of public debt on economic growth is scarce and the bulk of the research work dates from the 2010s, perhaps due to the substantial increase in fiscal deficits around the world after the 2007–2008 crisis. Of those papers that were published prior to 2010, the most notable are Pattillo, Poirson and Ricci (2002) and van Wijnbergen (1991a).

The dramatic increase in fiscal deficits after the 2007-2008 crisis was a result of a paradigm shift in the developed world, which was later repeated in many developing countries. After the Second World War, the Keynesian model and the welfare state gathered noticeable momentum, and the public sector played an important role in countries' economic activity. At that time, public spending was therefore an essential tool for sustaining growth, owing to its effects on aggregate demand. This model was accompanied by very strong economic growth in several countries around the world, and the post-war period is even remembered in Western Europe as the "glorious thirties".

Some economies that had previously lagged behind the major economic powers, namely the United States and the United Kingdom, began to gain ground on them after the Second World War. Therefore, in an effort to retake the helm of the world economy, the major economic powers decided to implement a new neoliberal economic model, which was then adopted by a number of other countries. This decision is still being questioned to this day by some of those countries, as growth rates slumped after the model was implemented. The outcomes of this change included an opening up to trade, a withdrawal of the State from economic activity and the adoption of NCM.

The NCM model revolutionized economic policy, marking a move away from the Keynesian model of effective aggregate demand to one of inflation targets and flexible exchange rates in which the short-term interest rate was an essential monetary policy instrument (Arestis, 2009). Conversely, fiscal policy was discredited and dismissed as inefficient, with its role limited to that of a mere stabilizer of the economy. In other words, NCM assume a direct relationship between aggregate demand and interest rates.

However, in recent years, despite low interest rates in some robust economies that follow the NCM model, the developed world has not been able to recover from ongoing crises or return to the growth rates of past decades. Several countries are therefore looking once again to fiscal policy to drive aggregate demand and, consequently, economic growth.

This is the paradigm shift that has led to an increase in States' fiscal deficits and debt levels in recent years. This in turn has provoked an in-depth discussion on the effects of debt on economic growth, a discussion that seems far from over.

In theoretical literature, there is a diversity of positions regarding this phenomenon: some assume a negative relationship between debt and per capita economic growth, while several other endogenous growth models show that debt has a positive impact on growth, provided that the resources obtained from third parties are used to finance productive public capital, which is primarily the case in developing countries.

The dominant theory today is that debt has a negative impact on growth. ECLAC (2018) identifies three transmission channels that justify the conclusion that the current economic model and NCM have discredited the use of fiscal policy and the power of fiscal deficits to boost growth.

The first transmission channel, and perhaps the one most often invoked, is the concept of Ricardian equivalence, which assumes that a rise in public spending financed by debt will sooner or later force the government to raise taxes to pay it down. It is thought that this will lead economic agents to save the extra income generated by the increase in public spending since they will have to pay more taxes in future. As a result, a fiscal deficit does not lead to greater aggregate demand.

The second transmission channel is higher inflation and reduced purchasing power driven by increased public spending, because it stimulates consumption but not productivity. Accordingly, overall aggregate demand would fall. In other words, the transfer of resources from the private to the public sector acts as a tax, since the transfer takes the form of a price increase, decreasing the purchasing power of economic agents.

Lastly, the third transmission mechanism is "crowding out", which assumes that indebtedness hurts private investment, due to the resulting movements in the capital market. Interest rates rise, due to competition for resources among the public, private and external sectors. Higher interest rates discourage investment and cause the exchange rate to appreciate, with a combined impact on aggregate demand that almost always outweighs the economic incentive generated through the fiscal deficit. This rationale is advocated by those who consider that a crisis can be postponed, but not averted.

According to Arestis (2009), the main consequence of NCM is a narrow interpretation of fiscal policy as an instrument that should only be concerned with balancing government expenditure and taxation, downgrading its importance as an active instrument of economic policy. For this reason, the defenders of this model consider the public deficit strategy to be entirely inefficient.

In contrast, there are advocates of the opposite position, which is to say that there is a positive relationship between the public deficit and economic growth. Among them is Krugman (2009), who argues that an increase in government spending automatically raises future debt, but not by an equal amount, because higher spending raises GDP, it leads to higher revenue, which offsets a significant fraction of the initial outlay. Krugman (2009) suggests that the actual cost of fiscal stimulus is approximately 60%, since the other 40% is offset by growth in aggregate demand.

Furthermore, in the same study, Krugman (2009) argues that today, in a world dominated by expectations, the main determinant of private investment is the state of the economy. This means that anything that improves the state of the national economy, including fiscal stimulus, leads to more investment and hence raises the economy's future potential. It is for this reason that deficit spending does not lead to crowding out, but rather to crowding in. He therefore concludes that the worst thing that could be done for future generations is not to run sufficiently large deficits now.

Lastly, Krugman (2009) formulates this proposal within a developed economy immersed in a liquidity trap, where low interest rates result in monetary policy that is unable to encourage private investment. He therefore concludes that, upon emerging from the liquidity trap through this strategy, the normal rules of economic prudence will reassert themselves. That is to say, the fiscal deficit must be used at certain times to boost aggregate demand, but it should not become an established doctrine since it can generate serious problems for economies.

The concept of crowding in, which was first described by Aschauer (1989a and 1989b), assumes that public spending has a significant positive impact on private investment by increasing productivity, but only if public funds are earmarked for public investment and capital expenditure, meaning spending on areas such as research, roads, transport, infrastructure and energy projects. Hatano (2010) provides empirical evidence that supports this position.

With regard to the relationship between public debt and economic growth, the current consensus is that both the concepts of crowding in and crowding out have some impact, thus the relationship can be illustrated by a Laffer curve or, in other words, it follows an inverted U-shaped trend. In countries with low levels of indebtedness, the resources generate a marginal positive impact on the economy due to their impact on aggregate demand, until they pass the threshold beyond which their effects produce a negative marginal trend, mainly owing to expectations regarding debt sustainability and capital market problems.

In this case, if debt resources are allocated to capital expenditure instead of social spending, this non-linear relationship is not modified, but they can alter the slope of the curves and displace the point of inflection in the curves, making the debt more productive and allowing it to stimulate economic growth.

Among the first empirical references to this Laffer curve or inverted U-curve between public debt and economic growth were made by Pattillo, Poirson and Ricci (2002), who undertook a study of 93 developing countries over the period 1969–1998 and found that the point at which the overall contribution of debt to growth appears to become negative is between 160% and 170% of exports, and between 35% and 40% of GDP. They therefore concluded that the main determinant of this inflection point and of growth differences across countries is total factor productivity rather than factor accumulation; hence, the inflection point could change over time or among different countries, depending on how resources obtained through borrowing are allocated.

Although it is a very complete study, both in terms of data (number of countries and years) and in methodological tools, its publication did not have much impact on the academic or political spheres, perhaps due to the predominant feeling of economic calm and stability in the early 2000s.

However, after the global crisis, the ground-breaking article by Reinhart and Rogoff (2010) used descriptive statistics to show that countries with a debt-to-GDP ratio above 90% recorded slower growth than countries with lower ratios. Even among advanced economies, in the period 1946–2009, a debt-to-GDP ratio of 90% was correlated with a 0.1% reduction in growth.

Although this work was very similar to that of Pattillo, Poirson and Ricci (2002), and even had fewer methodological requirements, it had an overwhelming impact on society. According to Krugman (2013), the Reinhart and Rogoff paper may have had the more immediate influence on public debate than any previous paper in the history of economics. This was because it was published in the midst of the debate over whether Keynesian expansion or neoclassical fiscal consolidation was the best government response to the financial crisis. The conclusions of Reinhart and Rogoff led to the adoption of numerous consolidation policies around the world (Domínguez, 2013).

While those conclusions were still influencing the economic policy strategies of many countries, Herndon, Ash and Pollin (2013) identified methodological flaws in the work of Reinhart and Rogoff (2010). Correcting for errors and omissions, they show that the debt-to-GDP ratio threshold was above 120%, much higher than the figure of 90% cited by Reinhart and Rogoff.

This new evidence bolstered the Keynesian view that spending financed with debt remained the most effective instrument available to combat the mass unemployment caused by recessions and severe economic crises. Therefore, Herndon, Ash and Pollin (2013) invited the leaders of the United States and Europe to reconsider the austerity policies they had implemented in the light of Reinhart and Rogoff's findings.[6]

A decisive point made by Herndon, Ash and Pollin (2013) is that econometrics can be used to study the inflection point beyond which the marginal contributions of debt to growth are negative. In this regard, they find that the threshold is debt-to-GDP ratios between 0% and 30%.

In addition to Reinhart and Rogoff (2010) and Herndon, Ash and Pollin (2013), which are considered seminal works in the study of the effects of debt on growth, other authors also took an interest in the subject and made significant progress in expanding on the causal relationship between these two variables. For example, Cecchetti, Mohanty and Zampolli (2011) find an inverted U-shaped relationship for their sample of 18 advanced economies belonging to the Organization for Economic Cooperation and Development (OECD). The threshold they identify is a debt-to-GDP ratio of 84%.

Cecchetti, Mohanty and Zampolli (2011) are convinced that debt is a crucial part of the economic system, since, without it, economies cannot grow, and macroeconomic volatility would also be greater than desirable. Also, if it were not for debt, countries would be poor and would surely remain so for a long time. However, when debt reaches high levels it becomes very dangerous because it generates systemic risk, raises real volatility and increases financial fragility in the country, reducing average growth and increasing the likelihood of a default. Although debt is beneficial for growth, governments' ability to

[6] For further details of the discussion raised by Reinhart and Rogoff (2010) and Herndon, Ash and Pollin (2013), see Domínguez (2013).

borrow is not unlimited. When private investors consider debt levels to be high and there is uncertainty over governments' fiscal capacity to repay it and to maintain macroeconomic stability, growth may plummet and governments' capacity to intervene will become very limited.

Meanwhile, in their study of 12 eurozone countries over 40 years, Checherita-Westphal and Rother (2012) find a non-linear relationship between debt and growth and a threshold of between 90% and 100% beyond which debt has a negative impact on the economy.

Égert (2015) makes one of the most recent and important contributions to this discussion, noting that finding a negative non-linear relationship between the public debt-to-GDP ratio and economic growth is extremely difficult and is sensitive to data coverage, meaning that the correlation is not as obvious as it may seem. However, using formal econometric testing, he finds that in the cases in which an inverted U-shape can be detected in the relationship between growth and debt, negative marginal correlation occurs at levels between 20 %to 60% of GDP. According to Égert, recent empirical evidence suggests that the reason for this is that the multiplier on public investment may be large for countries with low public debt ratios. His results also suggest that the threshold may be found at such levels because high-return public investment opportunities may exist at low levels of public infrastructure and debt.

Based on this information, it can be concluded that public capital expenditure does have a positive effect on economic growth with a multiplier greater than social spending, in accordance with the Golden Rule of contemporary economic theory, but that this ability it is not infinite. Therefore, provided that capital spending represents a larger proportion of total spending than social spending, the non-linear relationship will not change. Nonetheless, the positive slope of the inverted U-curve can change, and the inflection point can shift, allowing countries to have higher levels of productive indebtedness and, therefore, greater opportunities for growth. The calculation of the multipliers of social spending and capital spending in Mexico will be left for future research, to further this discussion.

The aforementioned literature make it clear that the debate on the scope of fiscal policy in today's economy is far from over: public debt and the Keynesian multiplier have appeared as considerations in new fiscal policy, as opposed to the rules of NCM established a few years ago.

Lastly, it should be borne in mind that the study of the effects of debt on growth support the impassioned debate over fiscal expansion versus fiscal consolidation, which has become more heated as a result of higher public spending policies adopted after the financial crisis of 2007–2008.

In this regard, Roeger and Veld (2013) seek to adopt a more neutral stance and analyse both the advantages and the disadvantages of each of these strategies. For example, they set out the arguments that when countries have been hit by external adverse shocks —as is currently the case, following the global financial crash— fiscal consolidation and austerity worsens the demand shortfall in the economy, while non-consolidation can have the same or even worse consequences for countries with high debt levels, as a result of the potential costs of higher debt premiums and risk of sovereign default.

Despite the intense discussions and the array of results and conclusions, it is an inescapable fact that the fiscal strategies adopted by governments to stimulate economic activity today will have a cost of potentially lower growth in the future. If this were not the case, as Domínguez (2013) asks, why not use expansionary fiscal policies indefinitely?

2. Public debt and economic growth in Mexico

With the notable exception of Pattillo, Poirson and Ricci (who used a panel of 93 developing economies), both empirical studies and the macroeconomic debate on the relationship between debt and economic growth have focused almost exclusively on developed countries, meaning that the literature fails to provide up-to-date analysis of the situation in developing economies, such as those in Latin America.

This is reflected in the case of Mexico by the fact that literature on this subject is very scarce: only Sánchez-Juárez and García-Almada (2016) address this discussion. In their study, they determine that the growing debt of Mexico's subnational governments has promoted an increase in public investment, and with it, the economic growth of the states. However, although they find a positive correlation, they stress that attention must be paid to the trajectory of states' debt levels in order to avoid the tipping point beyond which growth would be negatively affected.

This again substantiates the economic precept of incurring debt exclusively for public investment or capital expenditure, given that the multiplier effect they have on growth is greater than that of social spending. However, Sánchez-Juárez and García-Almada (2016) also suggest a non-linear trend and assume that debt can have negative effects on the functioning of economies.

The reason given by Sánchez-Juárez and García-Almada (2016) for studying this relationship at the level of the Mexican states is that the volume of national debt has not yet reached a level that gives cause for concern or that threatens macroeconomic stability and investors' expectations. Therefore, they do not consider national debt to represent a problem that requires analysis.

Unlike Sánchez-Juárez and García-Almada (2016), based on the empirical results of the aforementioned documents, in this study the view is taken that Mexico's current debt levels and its debt trends of recent years make the subject worthy of examination. Such a study will provide information to help clarify a relationship between variables that remains very diffuse. This study is also important given the latent potential in Mexico's economy, where interest rates are much higher than the rate of economic growth, increasing the possibility of an explosive increase in the debt-to-GDP ratio, with severe economic repercussions.

These conditions exist in a context —following the global financial crisis— in which fiscal policy has been given the role of stabilizing the economy. However, in Mexico, as in much of Latin America, the trend in fiscal policy has been procyclical, which has deepened cycles instead of softening them. But in times of crisis, faced with the lack of automatic stabilizers, governments have fallen into a debt trap to finance unproductive spending, with the aim of boosting aggregate demand in the short term, resulting in a persistent public deficit.

Moreover, according to ECLAC (2018), there is a tendency in the region, and also in Mexico, to increase public spending, but with a notable preference for social spending and a constant reduction in levels of capital expenditure. For example, according to data from Durán (2018) and based on the Public Finance Studies Centre of the Chamber of Deputies, since 2006 the trend in Mexico has been to increase current spending and reduce private investment. Indeed, the latter declined from 3.7% of GDP in 2015 to 2.6% in 2017.

According to Albarrán (2017), a report by the Federal Superior Audit Office (ASF) of Mexico shows that physical investment shrank from 20.3% of the federal government's budgeted spending in 2010 to 15.9% in 2016, meaning that on average such investment declined by 1.1% a year in real terms over the period. In addition, between 2000 and 2016, public spending has grown twice as fast as the economy (4.4% versus 2.2%). If only the period following the financial crisis is taken, this figure becomes more critical: average annual economic growth of 2.05% versus average annual growth in net debt (deflated by the GDP deflator) of 13.81%. In addition, the ASF report states that education spending is below the average for the OECD countries, and that health spending is below the level recommended by the Pan American Health Organization.

We can therefore see that public spending does not contribute greatly to economic growth in Mexico, because historically capital spending has been very low, and it remains so, even declining in some periods of the twenty-first century. In addition, Albarrán (2017) asserts that public debt resources have been used to finance public pensions, federal contributions to regional and local budgets, and financial costs, expenditures that are far from being productive.

Moreover, Mexican public spending shows procyclical behaviour: it increases when the economy is expanding, but does not decrease proportionally when the economy is in recession. As a result, persistent budget deficits have been accumulated, along with growing public debt. This is why, like Mexico, other countries of the region have suffered problems of over-indebtedness in recent years, which they have attempted to solve with fiscal responsibility laws.

III. Description of the model

The aim of this document is to analyse the impact of public debt on economic growth in Mexico, and specifically to determine whether the relationship between these two variables forms an inverted "U". If such a non-linear relationship is found, the aim is also to identify the inflection point in the curve. The study period is 1994–2016, due to the availability and homogeneity of the data that the National Institute of Statistics and Geography (INEGI) has for that interval.

The hypothesis, based on the theoretical and empirical evidence outlined above, is that there is a Laffer curve effect between debt and growth. In addition, the inflection point of the curve is between 20% and 60% of the debt-to-GDP ratio, as calculated by Égert (2015).

Through a basic statistical exercise, it was determined that the coefficient of correlation between the variables of per capita production and the debt-to-GDP ratio was 0.63, so the two show a moderate linear association in their historical trends.

To justify a quadratic model, we must demonstrate the potential non-linear relationship between the two variables. To this end, in figure 2 the horizontal scale shows the debt-to-GDP ratios and the vertical scale shows growth rates in per capita GDP. There is a clear non-linear relationship that supports the inverted U-curve hypothesis, although with an imperfect shape, due to a very steep slope in the positive part with debt ratios lower than approximately 20%, and a gentler slope in the negative part once the debt ratio passes 20%–25%.

Figure 2

Mexico: relationship between public debt and economic growth

Source: Prepared by the authors, on the basis of data from the National Institute of Statistics and Geography (INEGI).
Note: The atypical observation corresponds to 2009, when Mexico was severely affected by the global crisis.

These results suggest that a quadratic model with econometric tools be used in order to gain insight into elasticity and the inflection point beyond which debt negatively affects marginal growth (according to figure 2, around 20%–25%); as well as checking the statistical significance of these results. The goal of this model is to match the results of the empirical evidence with the mechanistic theories of causality, and thus corroborate the resulting conclusions (Maziarz, 2017).

To achieve the objective set out in this document, a simple function was applied, in which per capita GDP is affected by debt. In order to develop the model and set the control variables, a traditional production function approach was used, according to which per capita GDP is a function of physical and human capital and labour input. To quantify this function, we followed the steps set out by Égert (2015) to establish the following proxy variables for each of the independent variables: debt-to-GDP ratio for the debt variable; investment-to-GDP ratio for physical capital; average years of schooling for human capital; and population growth for labour input. The population growth data was obtained from the National Population Council (CONAPO), while the rest of the information was based on INEGI data.

First, an individual analysis was performed to detect the presence of autocorrelation in each of the variables using the identification process from the recursive method of Bartlett (1946). In all of them, both dependent and independent, including control variables, the null hypothesis of no autocorrelation was rejected. However, when obtaining the first difference of each of them and the second difference in the case of average years of schooling, the problem was corrected, and stationary variables were obtained.

A decision was therefore made to implement a dynamic model, in which a delayed endogenous variable is added as part of the explanatory variables. Sánchez-Juárez and García-Almada (2016) assert that this kind of model is appropriate when attempting to explain a variable based largely on past behaviour, which is very helpful in a context in which history plays an important role.

In addition, for the final design of the model, the methodology proposed by Pattillo, Poirson and Ricci (2002) was used as a reference, and natural logarithms were applied to all the variables, except the debt ratio and squared debt ratio, since they would present exact co-linearity problems.

The proposed model was as follows:

$$l\_GDPcap_t = \beta_1\, Debt\_GDP\_1_t + \beta_2\, sq\_Debt\_DGP\_1_t + \beta_3\, l\_DemGrowth\_1_t + \beta_4\, l\_Inv\_GDP\_1_t + \beta_5\, l\_Esc\_2_t + \beta_6\, l\_GDPcap\_1_t + \varepsilon_t$$

Where l_GDPcap_t is the natural logarithm of per capita GDP in period t, $Debt\_GDP\_1_t$ is the first difference of the debt-to-GDP ratio in period t, $sq\_Debt\_GDP\_1_t$ is the first difference of the square debt-to-GDP ratio in period t, $l\_DemGrowth\_1_t$ is the first difference of the natural logarithm of demographic growth in period t, $l\_Inv\_GDP\_1_t$ is the first difference of the natural logarithm of the investment-to-GDP ratio in period t, $l\_Esc\_2_t$ is the second difference of the natural logarithm of average schooling in period t and $l\_GDPcap\_1_t$ is the first difference of the natural logarithm of per capita GDP in period t.

The results obtained from the econometric analysis are presented in the following section.

IV. Results

The model proposed in the previous section was implemented. The statistics to evaluate the validity of the model as a whole were favourable, as well as the corresponding evidence of heteroscedasticity, residual normality and autocorrelation. Table 1 shows the results obtained from the coefficients and their statistical significance.

Table 1
Results of the regression model
Dependent Variable: l_GDPcap

	Coefficient	Standard Deviation	t Statistic	p Value
Debt_GDP_1	1.89473	0.745717	2.5408	0.02261**
sq_Debt_GDP_1	-3.49558	1.47711	-2.3665	0.03184 **
l_DemGrowth_1	-0.107548	0.0765673	-1.4046	0.1805
l_Inv_GDP_1	-0.0734902	0.091145	-0.8063	0.43267
l_Esc_2	-0.181212	0.175181	-1.0344	0.31733
l_GDPcap_1	0.963512	0.0532298	18.101	<0.00001***
		F(6, 15) = 1 213 218		
		Prob > F = 0.0000		
		R^2 = 0.99		
Ho: Absence of heteroscedasticity			Prob > chi	0.5625
Ho: Error is normally distributed			Prob > chi	0.2453
Ho: Absence of autocorrelation			P-value	0.3377

Source: Prepared by the authors.

First, the negative sign of the variable debt-to-GDP ratio squared ($sq\_Debt\_GDP\_1$) confirms the quadratic or non-linear relationship, as well as the existence of an upper limit in the inverted U-shaped curve, between public debt accumulation and economic growth. In addition, both this variable and the debt-to-GDP ratio as a linear relationship $Debt\_GDP\_1$ are statistically significant. Except for the statistical validity of the first difference of the dependent variable (l_GDPcap_1), which shows the correlation of economic growth with its past, none of the other control variables show a p-value below 0.05. Fortunately, it is not in our interest to use the elasticity coefficients of these parameters.

According to the data, it can be said that initially, when the accumulation of national debt is low and the curve is following an upward path, a 10% increase in debt as a proportion of GDP allows per capita production to increase, by an average of 0.19 percentage points. However, once the threshold beyond which the curve begins a downward path is passed, a 10% increase in the debt-to-GDP ratio causes a reduction in GDP of 0.35 percentage points on average.

Having confirmed the existence of the non-linear relationship, the main interest of this document is in determining the threshold beyond which debt ceases to have positive effects on growth and begins to generate marginal decreases in GDP. Another goal is to obtain some idea of the level of debt that could be considered to cause negative economic growth.

It was found that $\frac{\partial Debt\_GDP}{\partial GDPcap} = 0.2707$. This means that, according to the data used in the proposed model, in Mexico the maximum debt-to-GDP ratio beyond which marginal impacts become negative is just over 27%. This does not mean that the country stops growing, but that the accumulation of more debt will cause the economy to grow more slowly. Finally, according to the estimates made, the debt ratio of Mexico would have to reach around 55% for the economy to stagnate, that is, for the growth rate to be less than 0%.

However, to confirm this result, a decision was made to implement another model with the same characteristics, the only difference being that the variable of schooling was eliminated— annual constant growth had been assumed for this variable due to a lack of official information. This model is also statistically significant as a whole, and does not present any problems of heteroscedasticity, autocorrelation or non-normality in the distribution of residuals.

As shown in table 2, the negative sign of the variable $sq\_Debt\_GDP\_1$ reconfirms the existence of the inverted U-shaped curve. In addition, both this variable and $Debt\_GDP\_1$ are statistically significant. In this new model, unlike the previous one, the rest of the control variables pass the tests of statistical validity, although the negative sign of investment and demographic growth do not reflect the expected effects on growth based on economic literature. The lagged variable of per capita GDP remains significant and with the expected sign.

Table 2
Results of the second regression model
Dependent Variable: l_GDPcap

	Coefficient	Standard Deviation	t Statistic	p Value
Debt_GDP_1	2.2804	0.719039	3.1715	0.00558***
sq_Debt_GDP_1	-4.5183	1.47314	-3.0671	0.00698***
l_DemGrowth_1	-0.212412	0.0667334	-3.183	0.00544***
l_Inv_GDP_1	-0.149109	0.0679229	-2.1953	0.04232**
l_GDPcap_1	0.87819	0.0291621	30.1141	<0.00001***
		F(5, 17) = 1 268 095		
		Prob > F = 0.0000		
		R^2 = 0.99		
Ho: Absence of heteroscedasticity			Prob > chi	0.3494
Ho: Error is normally distributed			Prob > chi	0.3571
Ho: Absence of autocorrelation			P-value	0.0929

Source: Prepared by the authors

Elasticity before and after the inflection point is very similar to that in the previous model: in the rising part, with a 10% increase in the debt ratio, the per capita GDP increases by an average of 0.23 percentage points, and in the descending part, with the same increase in the debt-to-GDP ratio, per capita product is reduced by 0.45 percentage points.

In this case, the threshold was found to be just over 25%, only 2 percentage points below the level from the previous model. In addition, the level of debt that must be reached to negatively impact the rate of GDP growth is 50%, also slightly lower than in the previous model. This confirms that the handling of the schooling data did not have a major impact on the results of the model. It is important to note that the levels detected in this document are within the range proposed by Égert (2015), despite being closer to the lower limit than the average.

One of the main causes of this low threshold is considered to be inefficient use of public resources and, therefore, the low productivity of the deficit. In previous paragraphs, data have been presented that reflect the sustained increase in social spending and reduction in capital expenditure in recent years, resulting in a low threshold.

The authorities responsible for planning and implementing Mexico's economic policy should take these figures into account. Although the country's debt is not yet at the worrying levels that endanger national sovereignty previously seen in the late 1980s and mid-1990s, it is important to take appropriate and timely measures to ensure that point is not reached.

It is true that we are facing a very complex macroeconomic environment, with more threats than opportunities, and greater concern over nations' stability than with their growth and development. This is why it is crucial for governments to be involved in economic activity and to provide an incentive through aggregate demand.

However, using debt to support increases in spending and public investment is a questionable strategy that must be analysed in depth, because it can lead a country into a worse situation. This does not mean that debt itself is bad. Rather, as stated in this paper, debt is a powerful instrument to grow and finance productive projects, but a large accumulation of debt can lead to pessimistic sovereign risk expectations and can impact private investment, potentially undoing any progress and even wrecking a modern economy.

Moreover, although it will not change the non-linear relationship, especially in developing countries, resources obtained through a deficit that are channelled into public investment and capital expenditures may shift the threshold in the relationship between debt and growth to the right. This is because the expectations and attraction of private investment generate a crowding-in effect. In fact, public spending on public investment and capital expenditures can be a bridge to a more competitive future and greater economic growth.

Now is the time to introduce new models that allow States to remain actively involved in the economy and that stimulate economic growth, but with strategies that allow earnings to be obtained and that are sustainable in the medium to long term, while not undermining the sovereignty of nations.

For instance, we can look for more efficient tax collection mechanisms that better distribute income and wealth, thereby encouraging expansion in aggregate demand through its main variables: consumption, private investment and public spending.

V. Conclusions

Despite the difficulty of finding a relationship in the form of an inverted U that represents the effects of public debt on economic growth as mentioned by Égert (2015), this paper was able to demonstrate the existence of this phenomenon in Mexico in the period from 1994 to 2016. The inflection point of the curve was also detected at a debt-to-GDP ratio of 27%. Therefore, beyond this approximate limit, marginal contributions to growth become negative. Moreover, if the debt-to-GDP ratio surpasses a threshold of 55%, there is an expectation of growth rates of close to 0% or even negative growth.

The 27% threshold is within the range provided by Égert (2015), despite being very close to the lower limit. Nonetheless it is outside the range proposed by Pattillo, Poirson and Ricci (2002). This raises the question of why Mexico's threshold seems to be below the results found by other authors in other countries.

The most logical answer to this question seems to be that each country has its own limit according to its characteristics, such as private investors' perception of what that limit might be. For example, the probability of sovereign default is much higher in Mexico than in the United States, so its limit will be much lower. Another reason could be the misuse of resources in non-productive activities that do not generate growth, so that debt accumulation reaches a point of divergence faster than in countries where they are properly invested. In the case of Mexico, Sánchez-Juárez and García-Almada (2016) found that federal debt is predominantly used to finance social spending, rather than public investment projects, which would have a direct impact on economic growth by attracting private investment. Such investment can move the threshold in the relationship between debt and growth to the right, increasing the Mexican economy's capacity for indebtedness, and therefore also for growth.

Future research papers should focus on discussing the causes of this limit in Mexico, which seems very low compared to the results for other countries and regions of the world. In addition, calculation of the multipliers for social spending and capital spending in Mexico will be left for future research, to further this discussion and determine what impact can be derived from use of the public deficit in productive activities in Mexico.

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The importance of the BRICS group in the specialization of production and export competitiveness of North-East Brazil

Jevuks Matheus de Araújo, Lúcia Nunes de Barros Vitorio, Sergiany da Silva Lima and Danilo Raimundo de Arruda

Summary

This article seeks to identify and analyse the pattern of specialization in the export structure of North-East Brazil in 2003–2014, following the expansion of international trade with the BRICS countries (Brazil, Russian Federation, India, China and South Africa). The Aliceweb and Trademap databases are used to calculate the relevant indicators, namely the specialization coefficient, revealed comparative advantage, contribution to the trade balance, and degree of intraindustry trade. Trade with the BRICS countries led to exports being reorganized by specialization groups, thereby confirming a historical trend of comparative advantage in exports in the following product categories: food, tobacco and beverages; paper and pulp; chemicals; plastics and rubber; textiles; footwear and leather. Trade with the BRICS countries did not promote diversification or increase the technology content of the North-East's export structure.

Keywords

Foreign trade, regional development, exports, production specialization, competitiveness, measurement, trade policy, economic relations, China, India, Russia, South Africa, trade statistics, Brazil

JEL classification

F10, F14, F15

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I. Introduction

In the first decade of the twenty-first century, the BRICS[1] countries joined forces to strengthen their foreign trade partnerships. Their participation in international trade had expanded considerably in the late twentieth century, with their share of the world market doubling between the 1990s and the early 2000 decade (Mathur and Dasgupta, 2013). This has influenced the international trade of North-East Brazil in the twenty-first century. Exports from North-East Brazil to the other BRICS[2] countries grew by 4% between 2003 and 2009 to account for 15.45% of its total exports in the latter year; they then expanded further to 18.96% share in 2014. In total, exports to India grew by 80.96% and those to the Russian Federation by 73.45%. Nonetheless, it was exports to China that had the largest trade impact, growing by 1,719.28% in the same period. In contrast, exports from North-East Brazil to South Africa accounted for just 1%.[3]

Given the growth of exports from the North-East to the BRICS countries, identifying the products with the largest share in this trade is fundamental for formulating sector-level economic policies. Understanding this trade would make it possible to strengthen the comparative advantages of products with market potential in the BRICS countries, particularly China owing to its economic weight in the bloc. For Hidalgo and Da Mata (2005):

> Knowledge of the products that have a comparative advantage in international trade is extremely important, both when formulating growth strategies and for the economic well-being of a given region or country. Identifying such products makes it possible to establish robust strategies for the economy's international participation in an increasingly globalized and competitive world (Hidalgo and Da Mata, 2005, p. 967).

In late 2014, the BRICS countries accounted for 22% of global gross domestic product (GDP). Most of the bloc's GDP was produced by China (61%), with smaller shares contributed by Brazil (14%), India (12%), the Russian Federation (11%) and South Africa (2%). China is also the bloc's leading exporter, accounting for 68% of the total, while Brazil is ranked fourth, with 6%, ahead of only South Africa, which has a 3% share. The Russian Federation and India are in second and third place, generating 14% and 9% of the bloc's exports, respectively. On average, BRICS exports grew by 251.2% between 2004 and 2014. Although Brazil and South Africa exported the least during the reporting period, their exports still more than doubled, increasing by 132.8% and 125%, respectively. India's exports grew by 319.2%, while China's increased by 294.9% and those of the Russian Federation expanded by 171%. In 2014, China absorbed 81.1% of Brazilian exports to the BRICS group, with the remainder distributed among the other countries as follows: India 9.3%, the Russian Federation 6.1% and South Africa 3.6%.

The economic and political scenario of the 1990s raised the status of the BRICS countries, and China became the world's second largest economy and its largest exporter in 2010. Brazil became the sixth largest economy in 2011, followed by India, which maintained high annual growth rates and established itself in ninth place in the global GDP ranking. The Russian Federation managed to recover as a result of economic stability, to become the world's eleventh largest economy; and South Africa rebuilt its national dignity by ending apartheid and consolidating democracy and the economy (Reis, 2012).

[1] The BRICS are a country grouping consisting of Brazil, the Russian Federation, India, China and South Africa. The bloc is seen as a group of economies with rapid economic growth prospects.

[2] Although the term "BRICS" is used in this article, the analysis actually refers to the North-Eastern region of Brazil and the other countries of the bloc except Brazil, namely the Russian Federation, India, China and South Africa.

[3] This description was based on data from the Ministry of Development, Industry and Foreign Trade.

Against this backdrop, increased participation in international commerce has boosted trade between the BRICS countries and led to a major restructuring of their export sectors over the past 19 years, with the share of commodities diminishing and that of higher value added products expanding (Kocourek, 2015).

The aim of this research is to analyse the impact of the BRICS countries on the product specialization and competitiveness of exports from the Brazilian North-East. The competitiveness of commodities produced in the North-East is classified by trade activity groups and the degree to which foreign trade takes place within rather than between industries.

The article is divided into five sections, including this introduction. Section II reviews the literature on the relations between international trade and the North-Eastern region, and section III describes the methodology used and the indices calculated. Section IV analyses and discusses the results, and the fifth and final section presents the main conclusions.

II. International trade and North-East Brazil

The economic development process in Brazil has been (and remains) characterized by socioeconomic inequalities; and regional disparity is a recurrent theme in Brazilian economic literature. Many authors[4] have attempted to elucidate the historical, social, economic, cultural and institutional factors that underlie the persistence and deepening of regional inequalities in Brazil, in the context of the twenty-first century, especially as regards the international engagement of the country's different regions and, in particular, the North-East.[5]

Although it was one of the most dynamic areas of national territory during the golden age of sugarcane, growth in the North-East has been lacklustre in recent decades; and, despite making progress in its socioeconomic indicators, it has lagged well behind the other regions of the country, particularly the South-East and the South.[6] This makes it important to analyse the how the BRICS countries have influenced the economy of the North-East and their role in the reorganization of its production and export competitiveness.

Guimarães Neto (1997) notes that, during Brazil's colonization period, the economy of the North-East was foreign-trade-oriented, based mainly on sugarcane monoculture. When this declined, it was replaced by other crops including cotton, tobacco and cocoa. This export-oriented period lasted until the mid-nineteenth century. Then, from the end of the nineteenth century until the first half of the twentieth, with the crisis of the North-East export sector and emergence of manufacturing industry in the South-East of the country (especially in São Paulo), the North-East strove to engage with this market to sell its surpluses, becoming the chief supplier of cotton to the nascent textile industry in São Paulo. In the 1930s, however, the latter's non-durable consumer goods industry made advances that caused the North-East to lose the market not only outside but also within the region. The situation worsened in the 1950s, when it was invaded by heavy industry from the South-East.

Guimarães Neto (1997) also notes that dissatisfaction expressed by social and political movements spawned fiscal and financial studies and incentives, such that, from 1975 onward, the North-East was able to mitigate regional disparity by increasing its industrial activity and promoting its decentralization

[4] Almeida and Araújo (2004), Diniz (2009), Furtado (1997), Guimarães Neto (1997) and Gomes and Vergolino (1995).

[5] Hidalgo (2000), Feistel and Hidalgo (2007 and 2011), Hidalgo and Da Mata (2005) and Carvalho, De Melo Caldas and Lima (2013).

[6] To illustrate this disparity in gross domestic product (GDP), the South-Eastern region accounted for 55.2% of national GDP in 2012, followed by the South with 16.2%, the North-East with 13.6%, the Centre-West with 9.8% and the North with 5.3%. In the same year, 76.6% of national GDP was concentrated in just eight states (São Paulo, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, Paraná, Santa Catarina, the Federal District and Bahia) which, with the sole exception of Bahia, belong to the South and South-Eastern regions (see [online] http://www.valor.com.br/brasil).

across the country. Nonetheless, the capital employed came from the consolidated industry of the South-East and was allocated to activities and regions selected by it, specifically the most dynamic ones; and it occupied spaces in the activities of the South-East. The result was that modernized areas were created in the midst of zones of stagnation.[7]

To illustrate the inequality of the North-East, Gomes and Vergolino (1995) used economic criteria to divide the region into the following four subregions according to their dynamics and activities:

(i) Metropolitan region: where the large industrial complexes are located and on which the greatest fiscal incentives, especially federal ones, were targeted. The region encompasses Fortaleza (State of Ceará), Recife (State of Pernambuco) and Salvador (State of Bahia), where production is based mainly on the textile, metal-mechanical, chemical, paper and pulp, and food product sectors;

(ii) Forest area *(Zona da Mata)*: characterized by significant agricultural and manufacturing activity;

(iii) Irrigation hubs: where the main irrigation areas of the North-East are concentrated;

(iv) Semi-arid region: composed of the *agreste* region (an area of transition between the semi-arid *sertão* and the *mata* zone) and the *sertão* (a large area with a semi-arid climate); it has low-productivity subsistence agriculture, linked to extensive cattle raising.

Lima (1998) notes that, in the late 1980s, Brazil eased control over imports, thereby altering the course of economic policy following several decades of import-substitution industrialization. This trade liberalization process benefited the South and South-East more than the North-East, both because of the proximity of these regions to the Southern Common Market (MERCOSUR), and because of the tariff hierarchy that protected the durable and capital goods that are characteristic of the South-South-East axis. Analysing the period from 1990 to 2005, Feistel and Hidalgo (2011) note that exports from the North-East grew by less than those of Brazil as a whole (by 198% compared to 276%), while imports posted equivalent growth.

In order to identify the most appropriate strategy for the international engagement of the North-Eastern region, Hidalgo (2000) used indices of revealed comparative advantages and coverage coefficients to identify the products that are the region's strengths in international trade, along with the sources on which these advantages are based and the role of natural resources, in a period spanning 1975 to 1995. The results showed that the region has comparative advantages in certain manufactured products, such as petrochemicals, non-metallic minerals, basic metals and cellulose; and that its regional specialization is based heavily on natural resources.

Feistel and Hidalgo (2007) analysed the evolution of the North-Eastern region's specialization model between 1990 and 2004, with a view to determining whether international trade makes it possible to exploit comparative advantages. The methodology used involved collecting data on the income generated in each sector of production and on its natural resource requirements. The endowment triangle method is used to calculate each sector's direct and indirect input requirements, with outputs classified by factor intensity. The authors applied input-output analysis to the factor composition of the region's foreign trade and found that, although there are products in the region that make intensive use of both natural resources and capital, the most abundant factor is labour. During the period under

[7] More than 60 years ago, the Working Group for the Development of the North-East (GTDN), led by Celso Furtado, launched discussion on the Brazilian regional issue by identifying industrialization and technology as the pillar of the Plan of Action (1959) for state intervention in the North-Eastern region. The structural problems identified in the GTDN diagnosis, which placed the economy of the North-East far below Brazil's economic and social development (the latter already being seen as peripheral), were the following: (i) regional income inequality; (ii) low rate of growth of GDP and GDP per capita; (iii) transfer of resources for private sector investment from the North-East to other regions of the country, in search of better investment opportunities; (iv) development based exclusively on the commodity export sector, for example: sugar, cotton, cocoa, tobacco, leather, oilseeds and some minerals; (v) regressive tax system; and, (vi) semi-arid region characterized by an extensive livestock economy and low-yield agriculture which, in periods of drought, has a disproportionate impact on the weakest part of the North-Eastern economic system, namely subsistence agriculture (GTDN, 1959).

review, the share of capital-intensive exports increased by over 300%, while that of labour-intensive exports flatlined. The authors then suggested that a failure to exploit comparative advantages may account for the slow growth of the region's exports.

To determine which products from the North-Eastern region and the State of Pernambuco had a comparative advantage in the international market between 1996 and 2002, Hidalgo and Da Mata (2005) used revealed comparative advantage, an indicator of contribution to-the trade balance and an index of the degree of intraindustry trade. The results revealed comparative advantages for the North-East in the categories of food, tobacco and beverages; chemicals; plastics and rubber; paper and pulp; textiles; and metals; and advantages for Pernambuco in the food, tobacco and beverages; chemicals; plastics and rubber; and textile groups.

In the aforementioned study, the index measuring the degree to which trade occurs within, rather than between, industries showed that, in the North-Eastern region, intraindustry trade is significant in inorganic chemicals but less so in footwear and sugar. In Pernambuco, sugar displays a low level of intraindustry trade, while the opposite is true for plastics, rubber, articles of stone, plaster and cement. In that state, the products that make a positive contribution to the trade balance are food, tobacco and beverages; plastics and rubber; footwear and leather; textiles; non-metallic minerals; and others. In the North-Eastern region, positive contributors pertain to the following categories: food, tobacco and beverages; chemicals; plastics and rubber; footwear and leather; wood and charcoal; paper and pulp; non-metallic minerals; basic metals; and others.

Feistel and Hidalgo (2011) studied the nature of, and changes in, the structure of trade between the North-Eastern region and China, along with the products that displayed comparative advantages in 1992–2009. The authors applied indices of product concentration, revealed comparative advantage, revealed symmetric comparative advantage, and intraindustry trade. This enabled them to verify a growing share for the food and beverage category, followed by the mineral and non-metallic mineral groups, which are subject to high levels of volatility. The machinery and equipment, basic metals and chemicals categories became less competitive during the period analysed. In contrast, the pulp and paper category was the only sector to show a clear comparative advantage and was the mainstay of the North-East's trade with China, accounting for over half of its exports in the latter year. The North-East's trade with China proved to be between industries, or interindustry.

To analyse trading relations between the North-Eastern region and MERCOSUR, Carvalho, De Melo Caldas and Lima (2013) used the specialization coefficient, revealed comparative advantages, the trade complementarity index,[8] the trade effectiveness index,[9] and the hypothesis of achieved potential (data for 2010).[10] The results revealed concentration, in both the export and the import structure, with intraindustry characteristics. They also identified revealed comparative advantages in 26 of the 96 items analysed, and trade potential for 30 industrial sectors, 18 of which are considered underexploited. No sector was found to be trade-effective.

Marques and others (2017) analysed the competitiveness of Brazilian cashew exports in 2000–2011, relative to that of the world's leading cashew producers. The states of Ceará, Piauí and Rio Grande do Norte, which are located in Brazil's North-Eastern region, are the main producers of cashew nuts in the country. The methodology used included the revealed-comparative-advantage index, the performance indicator[11] and the constant-market-share model.[12] All of the calculated indicators identified the loss

[8] This index analyses the potential for trade between the exporting region and the trade partner in question. Values above 1 indicate the existence of trade potential, while values below 1 suggest that such potential does not exist.

[9] This index evaluates the effectiveness of trade between two regions. A value below 1 indicates that trade potential is not being fully exploited.

[10] This index measures the quantity of exports needed for the trade effectiveness index to have a value of 1.

[11] This indicator shows whether a country's exports to the world decreased or increased in a given period.

[12] This model captures the effect of the variation in exports as a function of changes in the economy's export structure by destination.

of competitiveness of Brazilian cashew, together with a relative loss of market share. While the volume of Brazil's exports increased, cashew exports from Viet Nam and Côte d'Ivoire increased significantly, thereby taking market share from competitor countries.

Hidalgo and Sales (2014) analyse the effects of trade on the distribution of income, finding that wages in the North and North-East are lower than in other parts of Brazil. The North and North-Eastern regions tend to be poorly integrated into domestic and international trade, so further regional analysis is needed to promote greater integration, since trade favours higher skills and better wages.

According to data from the Brazilian Institute of Geography and Statistics (IBGE), in 2009 roughly 70% of formal workers in the North-East earned no more than twice the minimum wage. The same source also reports a per capita GDP situation similar to that prevailing in the 1950s, when the per capita income of the North-East was just one third of that of the South-East (35% in 2009).

In recent decades, the North-East, which is socioeconomically fragile, has been targeted by a set of policies related to a variety of projects. These include the refineries in Suape (Pernambuco) (now operating); the trans-North-East railway; the São Francisco River transposition; the petrochemical industry in Pernambuco; port investments in Pernambuco, Bahia and Ceará; the expansion agribusinesses and the issue of food security, investments and wind energy in Bahia; prospects for wind energy and irrigated fruit farming in the semi-arid North-East; pharmaceutical investments in Pernambuco and investments in the automobile industry in Bahia and Pernambuco.

Analysing data for 1996–2004, Carvalho and Alves (2006) highlight the concentration of exports from the North-East to the Russian Federation, in which the states of Alagoas and Pernambuco are the leading exporters of commodities to that country. In this connection, half of the North-East's exports were concentrated in Bahia. Exports of North-Eastern products to China, one of Brazil's main BRICS trading partners, increased from 2% in 2000 to approximately 12% in 2010.[13]

This shows the need to consider the importance of the BRICS countries in the reorganization of production in the North-East and in the region's external competitiveness. Although it displays relative indicators of external engagement, mainly in terms of exports of natural products to those countries (the fastest growing trade partners in the last decade), the challenges and opportunities posed for the North-Eastern region are enormous, especially in terms of setting up a competitive and diversified industrial complex.

III. Methodology

The level of commodity specialization in the Brazilian North-East, is measured by calculating the specialization coefficient (SC); and the competitiveness of the region's exports to the BRICS is analysed using indicators of revealed comparative advantage (RCA) and contribution to the trade balance (CTB). The analyses focus on the period 2003 to 2014, and the degree of intraindustry trade is measured for the latter year. This period is justified by the economic rise of the BRICS in the first decade of the twenty-first century. It should be noted that 2003 also marks the start of a growth cycle in the Brazilian economy that was strongly associated with the expansion of exports.

1. Specialization coefficient (SC)

By mathematical construction, the product i specialization coefficient (SC_i) represents the share of exports of that good in a region j (X_{ij}) in total exports from the same region $\left(\sum_i^n x_{ij}\right)$. According to Carvalho, De Melo Caldas and Lima (2013) this coefficient can be measured through equation 1.

[13] See [online] http://aliceweb.desenvolvimento.gov.br.

$$SC_{ij} = \frac{x_{ij}}{\sum_{i}^{n} x_{ij}} \quad (1)$$

A high value for SC indicates that the region's exports are concentrated or specialized in terms of products, whereas a low value signals the absence of export specialization, in other words a wide diversity of products in the regional export basket. The SC index is also used to measure the region's specialization by export destination, by estimating the share of exports of product i from region j (x_{ij}) in the region's total exports (x_j) to a specific destination (Feistel and Hidalgo, 2011).

2. Revealed comparative advantage (RCA)

The revealed comparative advantage index was originally developed by Balassa (1965). Only import values were included in its composition, on the grounds that imports are affected by the protectionist policies implemented by the trade partners in question. The RCA indicator measures the share of exports of product i from region j in the region's total agricultural exports (X_{ij}/X_j) divided by the export share of product i relative to the total agricultural output of the rest of the world (X_{ijz}/X_z).

However, the revealed comparative advantage index for commodity i of the North-Eastern region j (RCA_{ij}) is used to capture the comparative advantage of exports from the North-East to the BRICS countries, as expressed in equation 2.

$$RCA_{ij} = \frac{x_{ij}/x_{iz}}{x_j/x_z} \quad (2)$$

Thus, X_{ij}/X_j is the export share of the commodity i in the total agricultural exports of the Brazilian North-East; while X_{ijz}/X_z is the share of the same commodity i in total agricultural exports from the rest of the world.

When $RCA_{ij}>1$ product i is said to have a revealed comparative advantage in the region. In the opposite case, $RCA_{ij}<1$ means that product i reveals a comparative disadvantage in the reference region j.

3. Index of contribution to the trade balance (CTB)

The index of contribution to the trade balance is also an indicator of revealed comparative advantage. This indicator was developed by Lafay (1990) to demonstrate the comparative advantage of commodity i in relation to the trade balance of economy j, as expressed in equation 3.

$$CTB_{ij} = \frac{100}{(X+M)/2}\left[(X_i - M_i) - (X-M)\frac{(X_i+M_i)}{(X+M)}\right] \quad (3)$$

The variables X_i and M_i represent exports and imports of good i, respectively. Therefore, the difference between the product i trade balance ($X_i - M_i$) and the trade balance weighted by the share of commodity i in foreign trade $\left((X-M)\frac{(X_i+M_i)}{(X+M)}\right)$ determines the sign of the respective CTB_{ij}.

The interpretation is analogous to that of the RCA indicator: when $CTB_{ij}>0$ product i is said to have a revealed comparative advantage; and, conversely, when $CTB_{ij}<0$, it is said to have a comparative disadvantage. This index makes it possible to identify the products with the greatest advantage in the composition of the region's trade balance.

4. Intraindustry trade index

The Grubel-Lloyd (GL) index of intraindustry trade is used to measure the extent to which an economy's foreign trade takes place within industries. Its mathematical construction is suggested as a measure of the trade pattern (Grubel and Lloyd, 1975).

$$GL = 1 - \frac{\sum_i \left| X_i - M_i \right|}{\sum_i \left(X_i + M_i \right)} \quad (4)$$

The GL index varies from 0 to 1 ($0 \leq GL \leq 1$). Variables X_i and M_i represent exports and imports of good i, respectively. When GL=0, trade is said to be *inter*industry, in other words determined by the abundant factor as described in the Heckscher-Ohlin model. Conversely, where GL=1, trade is understood to be intraindustry, or characterized by the exchange of products within the same sector using similar technologies and economies of scale (Caldarelli and Miranda, 2009). In practice, the midpoint of the range of values is used as a rule of thumb for interpreting the results of the GL, as suggested by Hidalgo (1993). Thus, when $0,5 < GL \leq 1$ trade is intraindustry and when $0 \leq GL \leq 0,5$ trade is interindustry.

5. Presentation of variables and data sources

The methodology used in this research has the specific purpose of measuring the specialization coefficient (*SC*), competitiveness (*RCA* and *CTB*) and the pattern of commodity trade in the Brazilian North-East. By mathematical construction all indicators are determined exclusively by foreign trade variables, as follows:

(i) The specialization ratio (*SC*) is composed of the variable representing exports of domestic commodities to the BRICS countries;

(ii) The revealed comparative advantage (*RCA*) index consists of the variables representing commodity exports and total exports from the North-Eastern region to the BRICS countries, relative to commodity exports and total exports from the rest of the world;

(iii) The index measuring contribution to the trade balance (*CTB*) is composed of the variables representing commodity and total exports and imports from (to) the Brazilian North-East to (from) the BRICS countries;

(iv) The sector level Grubel-Lloyd intraindustry trade index (*GL*) is also measured by the variables representing exports and imports of the region's commodities to and from the BRICS countries.

The level of data aggregation is conditioned by availability constraints in the databases consulted, namely Aliceweb (Government of Brazil, n/d) and Trademap (ITC, n/d). Aliceweb collects monthly data from the Ministry of Development, Industry and Foreign Trade and makes it possible to consult data on the exports and imports of Brazil, and its states and regions, of national origin and destined for other countries, economic blocs, agreements or partnerships around the world.[14] Trademap gathers information from the World Trade Organization (WTO), with annual data on the destination and origin of products for countries, blocs, agreements and alliances. The data are classified through the Harmonized System and coincide with those available in Aliceweb2 (Government of Brazil, n/d).

[14] The variables in the Aliceweb database are organized according to the Brazilian Nomenclature of Markets (NBM) and the MERCOSUR Common Nomenclature (NCM), as noted by Thorstensen and others (1994, pp. 50–51), cited in Feistel and Hidalgo (2011).

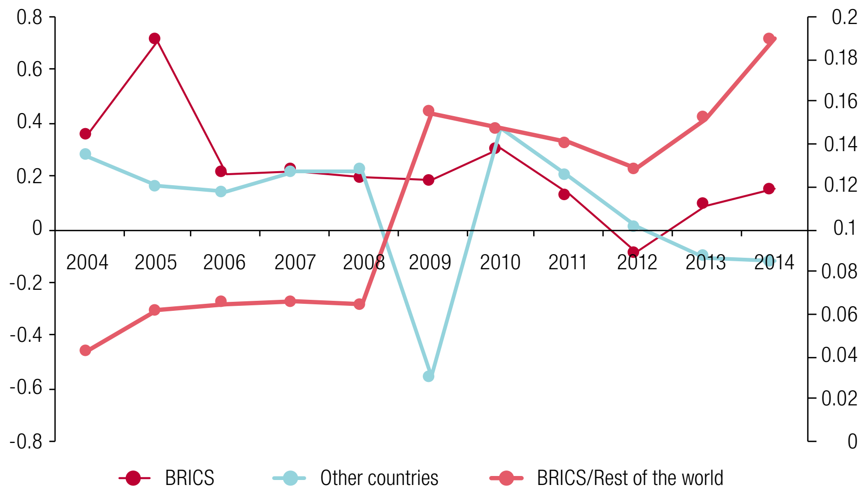
IV. Analysis of the results

The results of this research are reported in five subsections. The first analyses the evolution of foreign trade between the North-Eastern region of Brazil and the BRICS countries. The second identifies regional products traded with the BRICS countries by analysing the export specialization coefficients. The third and fourth subsections assess the competitiveness of exports from the North-East to the BRICS countries, compared to the rest of the world, by analysing the exported products' revealed comparative advantage and contribution to the trade balance. The last subsection discusses the degree to which exports are intraindustry. In general, China emerges as the main importer of products from the Brazilian North-East, followed by the Russian Federation. The region clearly specializes in low value-added agricultural products that are highly competitive externally. The profile of North-Eastern exports to the BRICS countries also shows interindustry characteristics, with production reflecting the advantage based on relative factor endowments.

1. Trend of exports from the Brazilian North-East to the BRICS countries

In 2003, exports from North-East Brazil to the BRICS countries represented just 4% of the region's exports to the rest of the world. In 2009, this share had grown to reached 15.45%, and by the end of 2014 it stood at 18.96%. Data show that the region's exports to the rest of the world shrank by roughly 50% in value terms in 2009, as the uptrend in export volume that had lasted since 2003 went into reverse. This was one of the consequences of the 2007 sub-prime mortgage crisis, which triggered a financial crisis in the United States in 2008.[15] Nonetheless, this did not affect trade between the Brazilian North-East and the BRICS countries, which has been expanding since early 2003. Unlike exports to the rest of the world, influenced by sales to the United States, exports to the BRICS countries grew by roughly 18% in 2009 alone (see figure 1).

Figure 1
Share and rate of growth of exports from North-East Brazil to the BRICS[a] countries, relative to its exports to the rest of the world, 2003–2014
(Percentages)



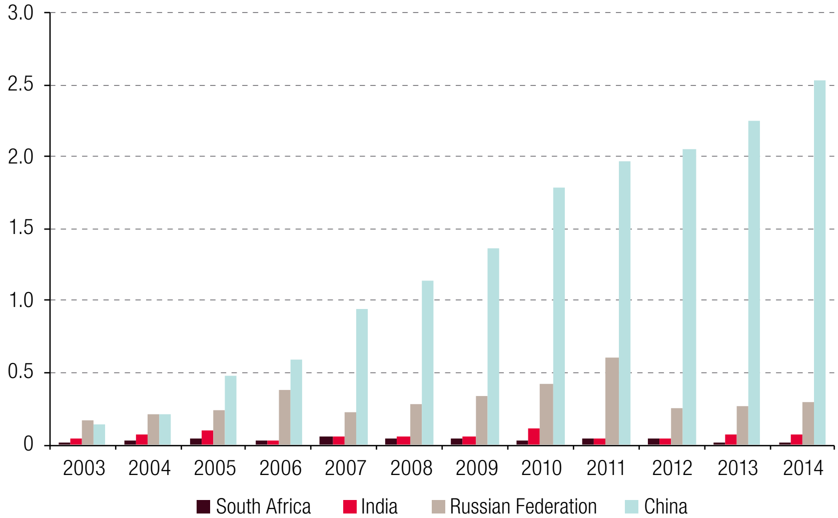
Source: Prepared by the authors, on the basis of data from the Government of Brazil, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.

[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.

[15] The subprime mortgage crisis of 2007 led to what became known as the United States financial crisis in 2008, which is seen as reflecting a profound crisis of confidence resulting from a chain of what were originally real estate loans made to insolvent borrowers. By causing economic agents to opt for liquidity and pay off their credits, this is driving banks and other financial firms into bankruptcy, even though they themselves are solvent (Bresser-Pereira, 2009, p. 133).

Since 2004, China has been the main destination for exports from North-East Brazil to the other BRICS countries, followed by the Russian Federation, India and South Africa (see figure 2). The value of Chinese imports of products from North-East Brazil has been increasing steadily, and in 2014 it was more than 17 times the value traded in 2003. In contrast, the Russian Federation reduced its imports from the Brazilian North-East in 2007, and this situation persisted until 2012. Thereafter exports to the Russian Federation grew by 73.45% between 2013 and 2014. Even though the value of exports fell by 40.59% in 2007 and by 57.02% in 2012, foreign trade actually grew. Trade with the Russian Federation appears to be affected by natural constraints inherent to the production capacity of the North-Eastern region: in 2007 and 2009, exports of food, tobacco and beverages to that country came almost exclusively from the state of Alagoas (Government of Brazil, n/d).[16]

Figure 2
Trend of exports from North-East Brazil to the BRICS countries,[a] 2003–2014
(Billions of dollars F.O.B.)



Source: Prepared by the authors, on the basis of data from Brazil Government, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.

[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.

2. Specialization coefficient

According to the classification of products exported to the BRICS countries as measured by the specialization coefficient (SC), North-East Brazil displays specialization in low value added agricultural sectors (see table 1). A review of the two main destinations of exports from the North-East to the BRICS countries (China and the Russian Federation) shows that the most highly specialized foreign trade is concentrated in the food, tobacco and beverages category. Nearly all exports from the North-East to the Russian Federation belong to this group. Exports of food, tobacco and beverages to China have also risen to the top of the list of Chinese imports from North-East Brazil, especially since the 2008 financial crisis in the United States. That year also saw the strongest growth in the volume of exports from the North-East to the BRICS countries, driven mainly by Chinese imports. The chemicals specialization of the North-East's exports to India and South Africa reveals a trade channel involving a more complex and higher value-added product. After 2008, the profile of exports to India has become more diversified, favouring specialization in products in the basic metals, minerals and non-metallic minerals category. In the same period, exports to South Africa, which were mainly in the food, tobacco and beverages category, have been diversifying

[16] Nearly of the Russian Federation's imports from the Brazilian North-East are in the food, tobacco and beverages category.

towards products in the minerals, footwear and leather categories. However, the overall volume of exports from the North-East to these two BRICS countries is minimal. Consequently, it can be argued that the impact of the BRICS countries on the export production profile of Brazil's North-Eastern region is very weak relative to the stimulus of investments in sectors with higher technological content and value-added.

Table 1
Specialization coefficient of exports from North-East Brazil to the BRICS countries[a]

NBM/NCM sections[b]	2003	Rank	2008	Rank	2011	Rank	2013	Rank	2014	Rank
China										
Food, tobacco and beverages	0.1218	2	0.2711	2	0.3800	1	0.3542	1	0.3678	1
Paper and cellulose	0.3296	1	0.3203	1	0.2845	2	0.2690	2	0.3382	2
Basic metals	0.0603	8	0.0457	4	0.0908	4	0.2620	3	0.1161	3
Chemicals	0.1148	3	0.0381	5	0.0177	7	0.0158	7	0.0687	4
Textiles	0.0722	7	0.0264	7	0.1418	3	0.0342	4	0.0577	5
Shoes and leather	0.0220	9	0.0272	6	0.0247	6	0.0247	5	0.0247	6
Minerals	0.0859	5	0.2625	3	0.0464	5	0.0137	8	0.0149	7
Plastics and rubber	0.1108	4	0.0065	8	0.0114	8	0.0069	9	0.0099	8
Russian Federation										
Food, tobacco and beverages	0.9901	1	0.9510	1	0.9818	1	0.9616	1	0.8930	1
Chemicals	0.0002	4	0.0026	5	0.0003	6	0.0203	2	0.0788	2
Shoes and leather	0.0087	2	0.0172	2	0.0129	2	0.0127	3	0.0105	3
Plastics and rubber	0.0000	12	0.0086	4	0.0022	3	0.0003	5	0.0061	4
Textiles	0.0008	3	0.0014	7	0.0010	5	0.0049	4	0.0056	5
India										
Chemicals	0.7256	1	0.5743	1	0.2706	2	0.2446	1	0.3551	1
Minerals	0.0008	8	0.0008	9	0.1140	4	0.0237	9	0.1982	2
Shoes and leather	0.0074	6	0.0021	8	0.0270	7	0.1082	4	0.1081	3
Transport equipment	0.0000	-	0.0001	11	0.0003	10	0.0899	5	0.0725	4
Non-metallic minerals	0.0108	5	0.0511	4	0.2883	1	0.1254	3	0.0575	5
Basic metals	0.0000	-	0.0000	-	0.0001	-	0.2299	2	0.0492	6
Food, tobacco and beverages	0.1739	2	0.2749	2	0.2105	3	0.0594	7	0.0491	7
Textiles	0.0316	4	0.0133	6	0.0287	6	0.0204	10	0.0373	8
Plastics and rubber	0.0468	3	0.0539	3	0.0557	5	0.0272	8	0.0352	9
South Africa										
Minerals	0.0129	8	0.0130	8	0.0000	13	0.0026	10	0.2774	1
Shoes and leather	0.2092	2	0.0521	3	0.0799	4	0.2733	1	0.2077	2
Food, tobacco and beverages	0.1121	3	0.6654	1	0.3321	1	0.2718	2	0.1400	3
Plastics and rubber	0.0594	5	0.0416	5	0.1518	3	0.1678	3	0.1381	4
Chemicals	0.4706	1	0.1298	2	0.3192	2	0.1611	4	0.1185	5
Machines and equipment	0.0054	10	0.0267	6	0.0355	6	0.0616	5	0.0411	6
Basic metals	0.0109	9	0.0446	4	0.0147	7	0.0205	6	0.0366	7
Textiles	0.0268	7	0.0178	7	0.0618	5	0.0129	8	0.0239	8

Source: Prepared by the authors, on the basis of data from Brazil Government, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.
Note: - not available.
[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.
[b] Brazilian merchandise nomenclature / MERCOSUR Common Nomenclature.

3. Revealed comparative advantage

When combined with the specialization coefficient of the previous section, the indicator of revealed comparative advantage (RCA) demonstrates the external competitiveness of the products exported from the Brazilian North-East (see table 2). It is therefore unsurprising that the most competitive products are the same as those in which the region specializes. The North-Eastern region displays a level of competitiveness well above the world average for the following product categories: food, tobacco and beverages; paper and pulp; and footwear and leather. All of those exports are the result of trade with the BRICS countries. The competitiveness of the food, tobacco and beverages group stems mainly from exports to the Russian Federation, which is the second largest destination for exports from North-East Brazil. In trade with China, which is the main destination of exports from the North-East, the food, tobacco and beverage group has become relatively more competitive, especially since the 2008 crisis. However, it is in paper and pulp that the North-East is most competitive in trade with China, as also reported by Feistel and Hidalgo (2011) for that country. The product categories which are most competitive in exports from the North-East to India and South Africa are chemicals; plastics and rubber; and footwear and leather. Although South Africa is one of the destinations receiving the lowest volume of exports from Brazil's North-East, the advantage of footwear and leather products exported to that market is at least ten times greater than that of the rest of the world. In general, the effect of the BRICS countries on the foreign trade of the North-East changes the regional production matrix very little.

Table 2

Revealed comparative advantage of exports from North-East Brazil to the BRICS countries[a] by product category

NBM/NCM sections[b]	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
China												
Paper and cellulose	47.68	43.58	34.89	36.69	19.33	44.11	41.44	38.09	33.25	31.43	30.02	36.35
Food, tobacco and beverages	2.59	2.76	8.04	9.22	7.48	9.99	7.52	5.99	12.31	11.07	11.97	12.42
Basic metals	1.22	0.81	0.27	0.91	3.76	0.72	3.90	2.42	1.64	1.52	4.93	2.11
Chemicals	2.71	3.29	1.28	1.39	2.14	0.79	1.03	1.01	0.35	1.32	0.36	1.47
Minerals	2.96	9.07	8.56	9.29	10.67	10.29	0.97	13.10	2.43	4.05	0.81	0.91
Shoes and leather	0.35	0.82	0.83	1.02	0.82	0.72	0.64	0.57	0.57	0.48	0.55	0.55
Textiles	0.43	0.34	0.60	0.33	0.30	0.21	0.21	0.32	1.12	1.19	0.28	0.47
Plastics and rubber	3.87	1.60	1.86	1.36	0.18	0.22	1.79	0.17	0.32	0.28	0.18	0.26
Non-metallic minerals	2.44	0.88	0.01	0.02	0.35	0.03	0.99	0.55	0.04	0.27	0.29	0.01
Russian Federation												
Food, tobacco and beverages	49.19	72.4	61.48	57.7	40.9	53.0	32.0	51.5	44.8	29.3	31.2	23.5
Chemicals	0.00	0.07	0.05	1.66	0.16	0.06	0.04	0.01	0.00	0.60	0.44	1.84
Shoes and leather	4.43	3.21	4.13	3.35	13.7	23.9	13.1	17.8	14.3	19.0	8.65	8.06
Textiles	0.17	0.33	0.74	0.81	1.31	1.48	0.73	1.15	3.03	5.62	3.40	3.32
India												
Shoes and leather	0.20	0.21	0.06	0.86	0.21	0.09	0.28	0.22	1.51	4.78	5.29	4.75
Paper and cellulose	0.00	0.00	0.00	0.08	0.44	1.45	0.78	0.79	0.00	0.01	0.01	4.05
Chemicals	7.04	5.28	5.16	6.89	8.47	5.48	4.46	5.90	2.98	2.26	2.33	3.34
Plastics and rubber	1.57	1.15	2.17	3.01	1.49	2.19	9.33	0.60	2.09	1.95	0.99	1.37
Minerals	0.01	0.52	0.56	0.01	0.01	0.00	0.03	0.03	0.54	1.45	0.11	0.96
Basic metals	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.08	0.00	0.47	5.06	0.95
Transport equipment	0.00	0.02	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.05	1.39	0.89
Food, tobacco and beverages	1.48	2.49	2.92	0.61	0.35	2.65	3.50	3.55	2.13	0.44	0.47	0.40
Non-metallic minerals	0.05	0.05	0.04	0.13	0.22	0.31	0.30	0.28	1.45	0.99	0.74	0.35
South Africa												
Shoes and leather	29.3	27.62	13.0	10.2	10.1	15.0	23.1	17.4	15.1	17.4	35.9	24.8
Plastics and rubber	2.78	6.30	3.56	5.22	2.46	2.40	2.58	7.80	7.75	3.53	7.59	5.24
Minerals	0.09	0.12	0.77	0.70	0.36	0.07	0.00	0.03	0.00	0.00	0.01	1.73
Chemicals	7.12	6.00	4.07	5.23	2.79	1.93	1.09	4.75	5.57	0.78	2.67	1.68
Textiles	1.04	0.79	0.61	1.66	0.56	2.00	0.58	1.08	5.07	1.15	0.95	1.56
Food, tobacco and beverages	1.08	2.21	4.01	3.73	8.43	8.46	6.77	3.23	3.85	7.67	2.70	1.18
Paper and cellulose	2.20	0.00	0.72	0.00	0.00	0.06	0.00	0.65	0.00	0.00	0.75	0.03

Source: Prepared by the authors, on the basis of data from Brazil Government, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.

[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.

[b] Brazilian merchandise nomenclature / MERCOSUR Common Nomenclature.

4. Contribution to the trade balance (CTB)

The comparative advantage measured by the contribution to the trade balance (CTB) indicator presented in this research ranks the categories of products exported from the Brazilian North-East to the BRICS countries by their contribution to the region's trade balance (see table 3). The relative advantages indicated for the food, tobacco and beverages category are common to all BRICS countries, with a trade balance that exceeds the region's theoretical trade balance. Nonetheless, the greatest trade advantages can be seen in the two main destinations of exports from North-East Brazil, namely China and the Russian Federation. The second and third groups of products with the greatest trade advantage in exports to China are, respectively, paper and pulp (the most specialized product in the North-East's trade with that country until 2008) and basic metals. The main products imported by the Russian Federation pertain to the food, tobacco and beverages group, so it is not surprising that this group made the largest contribution to the North-East's trade balance with that country. There are four other products with a comparative advantage in the trade balance, albeit with a much lower relative value, namely: chemicals, non-metallic materials, basic metals and plastics, and rubber. In foreign trade with India and South Africa, the product categories that make the largest contribution to the region's trade balance are more diversified, although the overall share of exports to these countries is very small. Even so, the following categories have an advantage in comparison with the trade balance: minerals, chemicals, machinery and equipment, Basic metals and textiles, to mention only the most important commodities.

Table 3
Contribution to the trade balance made by exports from North-East Brazil to the BRICS countries,[a] 2014

NBM/NCM sections[b]	China	Russian Federation	India	South Africa
Food, tobacco and beverages	7.95	39.20	1.45	4.38
Minerals	0.14	-3.70	20.34	18.79
Chemicals	0.56	4.53	10.91	17.97
Plastics and rubber	0.18	1.24	2.33	4.84
Shoes and leather	0.27	0.20	1.09	5.59
Wood and charcoal	0.00	0.00	0.01	0.10
Paper and cellulose	6.82	0.04	0.26	2.04
Textiles	0.27	0.10	8.17	0.61
Non-metallic minerals	-0.61	2.47	2.59	4.65
Basic metals	1.29	2.35	1.67	13.95
Machines and equipment	-5.54	0.10	5.16	8.84
Transport equipment	0.14	0.10	2.26	0.78
Optics and instruments	0.06	0.01	0.53	0.02
Others	0.09	0.00	0.05	0.02

Source: Prepared by the authors, on the basis of data from Brazil Government, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.

[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.

[b] Brazilian merchandise nomenclature / MERCOSUR Common Nomenclature.

5. Degree of intraindustry trade

Based on the indicator of the degree of intraindustry trade (GL) in the main products exported from the Brazilian North-East to the two most important BRICS export destinations, it is easy to see that trade between industries (interindustry trade) is the predominant characteristic (see table 4). The two main products exported to China, according to the specialization coefficients presented in section IV.2, belong to the paper and pulp and food, tobacco and beverages categories. The GL index for these two groups in regional exports to China is much lower than the parameter of intraindustry activity, which is above 0.5. The only product groups that showed an intraindustry trade pattern were those of low-concentration Chinese imports originating in the Brazilian North-East: minerals, chemicals, footwear and leather and basic metals. Trade with the Russian Federation is predominantly interindustry in all products exported. In foreign trade with India, a large proportion of the exported products are intraindustry. However, India and South Africa are the BRICS countries that import the least from Brazil's North-Eastern region. It can thus be said that exports from the North-East are basically explained by relative factor endowments, as per the Heckscher-Ohlin model (Ohlin, 1967). This result is also consistent with the analysis made by Feistel and Hidalgo (2011).

Table 4
Degree of intraindustry trade in exports from North-East Brazil to the BRICS countries,[a] 2014

NBM/NCM sections[b]	China	Russian Federation	India	South Africa
Food, Tobacco and Beverages	0.11	0.00	0.60	0.34
Minerals	0.92	0.00	0.02	0.63
Chemicals	0.80	0.32	0.56	0.17
Plastics and rubber	0.30	0.17	0.27	0.53
Shoes and leather	0.75	0.00	0.22	0.00
Wood and charcoal	0.04	0.00	0.00	0.00
Paper and cellulose	0.05	0.00	0.72	0.01
Textiles	0.60	0.00	0.08	0.05
Non-metallic minerals	0.00	0.00	0.39	0.04
Basic metals	0.57	0.01	0.53	0.09
Machines and equipment	0.00	0.03	0.06	0.20
Transport equipment	0.05	0.00	0.57	0.50
Optics and instruments	0.00	0.00	0.00	0.64
Others	0.01	0.14	0.48	0.32

Source: Prepared by the authors, on the basis of data from Brazil Government, "Aliceweb2", n/d [online] http://comexstat.mdic.gov.br/pt/home.
[a] Country bloc formed by Brazil, the Russian Federation, India, China and South Africa. In this case, the analysis refers to the North-Eastern region of Brazil and the other BRICS countries excluding Brazil.
[b] Brazilian merchandise nomenclature / MERCOSUR Common Nomenclature.

V. Conclusions

In view of the economic importance of foreign trade for the development of North-East Brazil and the importance of the BRICS countries for Brazil's foreign trade, this article has analysed the influence of these countries on the productive restructuring of the North-East by specialization groups. It also reviewed the relative competitiveness of commodities produced in the North-East and the type of trade activity measured by the degree of intraindustry trade. According to the classification by specialization group, there has been little restructuring of North-Eastern exports, and this has only a minimal effect on the relative importance of the categories of products exported to the BRICS countries. On average, exports to the BRICS countries display revealed comparative advantages, especially in the case of product categories with a higher trade concentration or specialization coefficient. Nonetheless, the intraindustry trade result makes clear that these competitive advantages in trade with the BRICS countries arise mainly from relative factor endowments.

These countries have not caused major changes in the production and foreign trade matrix of the North-Eastern region, nor have they influenced high value added production sectors or those invested in technology-intensive products. On the contrary, the Brazilian North-East's foreign trade with the BRICS countries exploits a historical feature of the regional economy, through its near-exclusive focus on the commodities in the food and mineral sectors, produced with comparative advantage in

North-East Brazil. The results clearly show that the expansion of trade between the Brazilian North-East and the BRICS countries preserves one of the key features of the regional economy, namely specialization in producing and exporting food products.

China is the country in this group that imported the most products from the North-East, concentrated in the food, tobacco and beverages, and paper and pulp categories, in which North-East Brazil has a comparative advantage. The Russian Federation represents the second largest market for the region's exports, absorbing products from the food, tobacco and beverages sector almost exclusively. While the other countries have a more diversified trade in products from the Brazilian North-East, the overall volume of exports to India and South Africa is negligible. Trade with India is stimulating demand in the chemicals sector; and the recent focus on the minerals, footwear and leather groups followed the intensification of trade in 2008. Exports from the North-East to South Africa are more varied and encompass minerals; footwear and leather; food, tobacco and beverages; plastics and rubber; and chemicals. All these products had a specialization ratio of more than 0.10 in 2014.

The indicator of contribution to the trade balance showed that trade between the BRICS and the North-East of Brazil contributed positively to the region's balance of trade. It was found that the North-Eastern region has a revealed comparative advantage in trade with the BRICS countries for various product groups. Nonetheless, policies are needed not only to maintain these advantages, but also to enable the products in question to gain greater traction in the markets of India, South Africa and the Russian Federation. Exports to these economies have grown far more slowly than trade with China. The formulation of trade policies to exploit comparative advantages in plastics and rubber for India, footwear and leather for the Russian Federation, and textiles for South Africa and the Russian Federation, is seen as essential.

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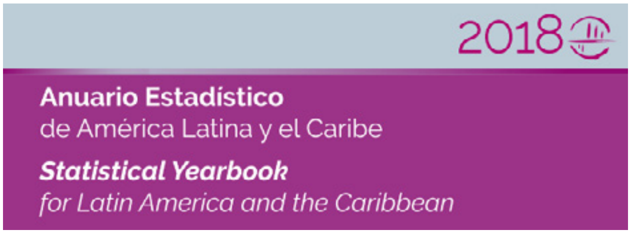

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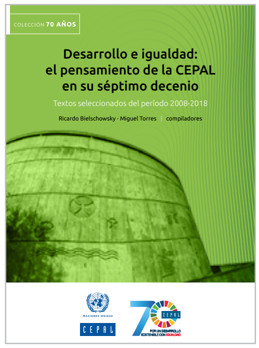

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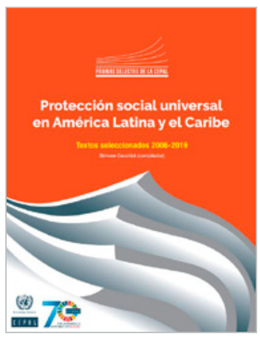

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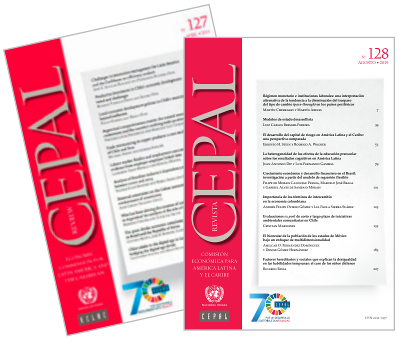

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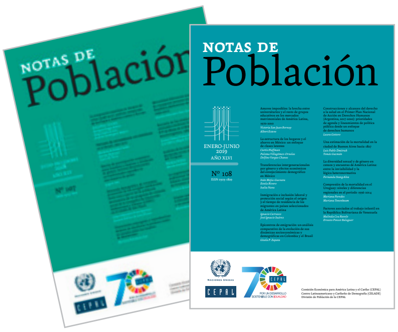

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