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How sophisticated is Brazilian agribusiness? An exploratory analysis based on productivity and complexity

Rafael Stefani[1]
Rodrigo Daniel Feix[2]
Joana Colussi[3]

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Abstract

The significant growth of Brazilian agribusiness has contributed to spreading a collective perception that Brazil produces with high levels of efficiency and has a competitive advantage in a wide range of sophisticated products. But is this image an accurate representation of Brazilian agribusiness in an international context? To answer this question and to analyze the sources of agricultural productivity differences between countries, we adopted the economic complexity approach. The results indicated that, despite all the scale, the complexity of Brazilian agribusiness products is at an intermediate stage, far from the countries with the highest value added per worker in agriculture. In addition, as suggested by theory, we found a positive association between labor productivity in agriculture and the agribusiness complexity up to the year 2012, when the signal reverses—possibly owing to the greater importance of south-south agricultural flows and the protectionist movements in the post international crisis period. In conclusion, even though Brazilian *agro* can be qualified as *pop*, it does not seem appropriate to define it as *high tech*, especially if the reference is to the labor productivity and product complexity of leading countries. The construction of complexity in agribusiness goes beyond the boundaries of traditional agricultural development policies. Industrial policies aimed at building complexity need to be comprehensive enough to identify key products and the fundamental capabilities for their successful market performance. This applies to products and industrial sectors as well as to agribusiness.

Keywords: Economic complexity; Agricultural productivity; technical progress; Economic development

Quão sofisticado é o agronegócio brasileiro? Uma análise exploratória baseada em produtividade e complexidade

Resumo

O crescimento significativo do agronegócio brasileiro nos últimos tempos contribuiu para disseminar uma percepção coletiva de que o Brasil produz com altos níveis de eficiência e possui vantagem competitiva em uma ampla gama de produtos sofisticados. Mas essa imagem representa com precisão o agronegócio brasileiro no contexto internacional? Para responder a essa pergunta e analisar as fontes das diferenças de produtividade agrícola entre países, adotamos a abordagem da complexidade econômica. Os resultados indicaram que, apesar de toda a escala, a complexidade dos produtos do agronegócio brasileiro está em um estágio intermediário, distante dos países com maior valor agregado por trabalhador na agricultura. Além disso, conforme sugerido pela teoria, encontramos uma associação positiva entre a produtividade do trabalho na agricultura e a complexidade do agronegócio até o ano de 2012, quando o sinal se inverte — possivelmente devido à maior importância dos fluxos agrícolas sul-sul e aos movimentos protecionistas no período pós-crise internacional. Em conclusão, embora o agro brasileiro possa ser classificado como popular, não parece apropriado defini-lo como de alta tecnologia, especialmente se a referência for a produtividade do trabalho e a complexidade dos produtos dos países líderes. A construção da complexidade no agronegócio vai além dos limites das políticas tradicionais de desenvolvimento agrícola. Políticas industriais voltadas para a construção da complexidade precisam ser abrangentes o suficiente para identificar produtos-chave e as capacidades fundamentais para seu desempenho bem-sucedido no mercado. Isso se aplica tanto a produtos e setores industriais quanto ao agronegócio.

Palavras-chave: *Complexidade econômica; Produtividade agrícola; Progresso técnico; Desenvolvimento econômico.*

[1] Doutorado em Economia (UFRGS). Professor do Instituto Federal do Rio Grande do Sul (IFRS). rafstefani@gmail.com

[2] Doutorado em Economia (UFRGS). Analista-pesquisador da Secretaria de Planejamento, Governança e Gestão do Estado do Rio Grande do Sul (SPGG-RS). rdfeix@gmail.com

[3] Doutorado em Administração (UFRGS). joanacolussi@gmail.com

1 Introduction

Brazil is known as one of the world's largest producers of food, feed, fibers, tobacco, and renewable fuels. Between May 2023 and April 2024, Brazilian agribusiness exports reached $168.36 billion, accounting for 49.3% of the country's total exports during this period (BRASIL, MINISTÉRIO DA AGRICULTURA E PECUÁRIA, 2024). In 2023, the agriculture, forestry, and fishing sectors contributed 6.24% to Brazil's GDP, reflecting an increase from previous years. Notably, the agricultural sector experienced a significant growth of 15.1% between 2022 and 2023, substantially influencing the nation's GDP performance (IBGE, 2024).

This performance contributed to rekindling the debate about the limits and possibilities of economic development from the agricultural route. In Brazil, as in many countries, economists and policy makers in general believe that agriculture is a traditional, low-tech sector that crowds out the development of other economic sectors and the country as a whole (CHADDAD, 2015). In recent years, the fact that the main driver of Brazilian agriculture growth was productivity (FUGLIE *et al*., 2012; GASQUES *et al*., 2014) contributed to generate a new collective perception in Brazilian society (i.e. that local agribusiness is *high-tech*), operates close to international levels of efficiency and has a competitive advantage in a wide range of sophisticated products.

In addition to answering the research question mentioned above, we seek to evaluate whether it is possible to associate the differences in the levels and growth of agricultural productivity of countries with the sophistication of traded products. To fulfill this second objective, we embrace the economic complexity approach. This analytical proposal is quite new since the economic literature traditionally associates the growth of productivity and welfare in agriculture with the availability of natural resources, technology, and agricultural policy strategies (EVENSON; KISLEV, 1975; HAYAMI; RUTTAN, 1985; CRAIG *et al*., 1997; WIEBE *et al*., 2003; AVILA; EVENSON, 2010; FUGLIE *et al*., 2012).

But is this image an accurate representation of Brazilian agriculture in an international context? To answer the research question, we seek to evaluate whether it is possible to associate the differences in the levels and growth of agricultural productivity of countries with the sophistication of traded products. To fulfill this objective, we embrace the productivity and complexity approach. In short, we will put gains of scale and scope together and check their behavior over time.

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CRAIG *et al*., 1997; WIEBE *et al*., 2003; AVILA; EVENSON, 2010; FUGLIE *et al*., 2012), while we will consider also the complexity and variety of agriproducts, not only as the output of production but especially the market values.

Most of the studies that evaluated the aggregate productivity evolution of Brazilian agriculture were conducted under a temporal perspective, comparing Brazil with itself in different periods. In these analyses, international references of productivity excellence (leading countries) were rarely considered[1]. This study intends to contribute to fill this gap in the economic literature.

The study was conducted in four successive stages. First, we compare the evolutionary trajectory of labor productivity in agriculture for a selected set of countries. Second, to compare the diversity and sophistication of the productivity know-how required to produce the agribusiness products, we create and analyze an indicator of countries' complex exports. Third, we analyze the association between labor productivity in agriculture and the agribusiness indicator of complexity. Finally, we discuss possible ways to build complexity and boost agricultural productivity.

The rest of this paper is organized as follows. Section 2 reviews the literature about the sources of agricultural productivity and economic growth, considering some key aspects of Neo-Schumpeterian and economic complexity theories. Section 3 presents the methodological procedures, and section 4 describes and discuss the results. Section 5 deals with the policy implications of the study. The last section concludes.

2 Sources of agricultural growth productivity and complexity: theoretical background

The agricultural productivity lag between countries can be explained from different theoretical perspectives. In this session we present a brief discussion about the sources of productivity growth, according to Neo-Schumpeterian and economic complexity theories. Both emphasize the importance of differentiated knowledge for innovation and development, but they start from different theoretical traditions and methods of analysis that widen the range of interpretive insights.

2.1 Efficiency, innovation, and productivity growth

[1] An important exception is the study by Fuglie et al. (2012). However, the focus is still in productivity growth, not in the difference in agricultural productivity levels across countries.

The Neo-Schumpeterian authors reiterate the importance of technical progress as the main source of economic growth (NELSON; WINTER, 1982; FREEMAN, 1987; DOSI, 1991; LUNDVALL, 1992; NELSON, 1993). Competition through innovation is seen as the central factor and an active process for creating new competitive advantages, both reinforcing existing ones and obtaining monopolistic profits from them. If innovation is the driving forcefor firm's survival and growth, its performance depends on a set of specific factors encompassing industries, markets, individuals, institutions, knowledge, and related competitive elements (POSSAS *et al*., 1996).

In this context, empirical evidence has shown that innovation is rather a systemic process, and interactive learning is the main dynamic mechanism for knowledge accumulation, innovation, and growth of firms (NELSON, 1993). The innovation processes that take place at the firm level are generated and sustained by their relationships with other companies and organizations. Therefore, the concept of an innovation system extends the object of analysis to a broader way, with regard to conventional visions circumscribed to public and individual organizations (LUNDVALL, 1992).

If innovation is the result of a complex tangle of systemic relationships, its greater or lesser impact on development should be perceived through the profile of different economic activities and their outcomes in terms of new value, productivity increase or enhanced efficiency. Large markets are to be focused on productivity, while niche is mostly attached to new value, and highly competitive ones looks forward gains of efficiency. Traditionally, the Neo-Schumpeterian approach has shed light on industrial studies. But this is no different when the eye turns to agricultural activity.

Despite its specificities, agriculture can also be analyzed from an evolutionary perspective. Grain production in South America and United States, for example, can be referred to as a contemporary example of co-evolution between technology and institutions. Since the mid-1990s, a new technology package to produce grains has been developed, adapted, and adopted by a group of industrial and agricultural companies, multinational and local, that have boosted and obtained higher profits in developed and developing countries. The new economic advantages quickly attracted a large number of producers that expanded the production, reduced the average costs, raised the product quality, and put the previous business model in crisis (BISANG *et al*., 2013). This is a process of creative destruction, similar to that analyzed in the industrial world almost a century ago by Schumpeter (HUERGO, 2005; PÉREZ, 2012; DABAT, 2014).

Agriculture is known to have large variations in productivity between countries. Gollin *et al*. (2014) concluded that these differences are real and not an artifact of poor measurement. Several hypotheses have been tested in the *mainstream* literature to explain this situation[2]. A causal relationship that emerges from heterodox growth theories associates agriculture productivity with the firms' competitive strategies and capabilities. The country's economic benefits from the international insertion are greater when the profile of external specialization reflects simultaneously what in the evolutionary literature is called Keynesian and Schumpeterian efficiency (DOSI *et al*., 1990; CIMOLI *et al*., 2010), in contrast to a profile in which sectors only have static efficiency associated with lower production costs (Ricardian efficiency).

Keynesian efficiency refers to a kind of international insertion based on products with high income elasticity of demand. Specializing in these products favors the extension of the market, an increase in productive specialization and in the division of labor, the exploitation of economies of scale, and an increase in productivity. Schumpeterian efficiency refers to a type of specialization based on sectors in which innovation and technical change are the key element of external competitiveness. This type of efficiency corresponds to products characterized by high technological complexity, high levels of productivity, increasing yields, spill overs, and strong productive linkages. On the other hand, the Ricardian efficiency refers to a pattern of international specialization that reflects only static advantages derived from the factorial endowment.

Even in intrasectoral terms, as in the production of agribusiness products, it is possible to identify firms that sustain their competitive performance from different types of efficiency. Firms that operate in market segments where the main attribute of competitiveness is the production cost (*commodities*) would tend to seek process innovations, mainly focused on improving production efficiency. On the other hand, firms established in markets whose competitive advantages derives from product differentiation (premium food) would tend to invest in the production of novelties (product innovation and marketing) in search of temporary monopolies and higher profits.

These definitions of static and dynamic efficiency are closely related to an old theoretical debate about product neutrality in economic growth. For the evolutionary theory and for the

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[2] One hypothesis is that policies that distort farm size lead to a misallocation of farmland to farm operators (ADAMOPOULOS; RESTUCCIA, 2014). Another hypothesis tested is that farm operators in poor countries avoid using productivity-enhancing inputs, such as fertilizers and pesticides, because doing so increases their consumption risk (DONOVAN, 2016). A third hypothesis is that the agriculture sector in developing countries tends to employ the lowest-ability workers (LAGAKOS; WAUGH, 2013).

economic complexity perspective, production at equivalent or similar productivity of the world's leading countries involves not only making optimal use of resources, given the *best technology available on the market* (Ricardian efficiency), but mainly having a know-how or productive capability to fill the technological and market gaps advantageously, which results in higher profits and higher productivities per worker (Keynesian and Schumpeterian efficiency). Therefore, to be a leader in productivity, the country would need to climb the technological ladder toward productive sophistication. This is true in sectoral terms (e.g., agriculture and agribusiness) and for the economy as a whole.

Thus, even in the agribusiness sector, a particular country's predominance of firms (or products) whose competitiveness is based on cost or differentiation leadership strategy can affect the sectoral path of productivity and income growth at the national level. In the sequence, we describe the advances of complexity theory in the empirical evaluation of this relation.

2.2 The economic complexity approach

Economic complexity literature shows that countries that favor the development of a more diversified and complex productive structure are more likely to achieve higher levels of economic and social development than countries that display high levels of export concentration (HIDALGO *et al*., 2007; HIDALGO; HAUSMANN, 2009).

As described by Gala (2017), these conclusions are quite similar to the original structuralism. These economists already realized that economic development requires a structural change from lower productivity sectors to higher productivity sectors. Briefly, economic development was seen as a process of structural change geared toward the sophistication of the productive structure. In this route, the group of higher value-added activities contrasts with the lower value-added activities, usually predominant in poor or middle-income countries, which presents the typical structure of perfect competition: lower R&D expenditures, lower technological innovation, perfect information, absence of learning curves, and diminished possibilities of labor division (KATTEL; REINERT, 2010). The specialization in agricultural and extractive origin products are often referred to as typical examples of these activities.

On the other hand, the most technologically sophisticated products compete in markets with oligopoly structures and monopolistic competition. In these sectors high start-up costs and other barriers to entry, economies of scale, and differentiation by brands blocked the establishment of new players from emerging countries. Thus, the development trajectory is full of obstacles because the countries that are engaged in it must be able to set up companies in these already well-occupied sectors where the potential for economies of scale and profits is greater: that's where high productivity is (GALA, 2017).

The great contribution of theorists of economic complexity was the development of a method to assess the productive knowledge of a society indirectly, through the analysis of the products that it makes. The central argument is that each product uses a specific amount of knowledge in its manufacturing process. Some products are relatively easy to make, while others are difficult because they require more and specific knowledge and skills. Since each worker can absorb and use only a small amount of knowledge, the manufacture of the most complex products—the ones that demand the most knowledge—requires that knowledge be divided into *pieces* (person bites) and shared across networks (HIDALGO; HAUSMANN, 2009; HAUSMANN *et al*., 2013). Thus, it is considered that certain products can only be manufactured if the society has a wide range of specific knowledge and if it can bring together in productive networks the workers who have this knowledge. Therefore, the development of society depends on its ability to gather this knowledge and build ever-larger networks.

Given that it is impossible to directly observe the capabilities and knowledge held by countries, Hidalgo *et al*. (2007) resorted to trade data in order to build the network of relatedness between products, or *product space*. Product space is a visualization that depicts the connectedness between products based on the similarities of the know-how required to produce them. Products are linked by their proximity to each other (distance) measured by the probability of co-export of the two products[3]. The shape of the product space shows how diversification works in practice: countries move from things they know how to do, to things that are nearby or related, or what they call the *adjacent possible*. In other words, the structural change—and the related economic growth—is a path-dependent process that is conditioned by the current profile of the productive structure.

Hidalgo *et al*. (2007) showed that far from homogenous, the product space appears to have a core-periphery structure. Products at the periphery of the product space require a type of know-how that is less readily redeployed into many new industries. Most upscale products are located in a densely connected core, while lower income products occupy a less-connected

[3]A product's distance (from 0 to 1) looks to capture the extent of a location's existing capabilities to make the product measured by how closely related a product is to its current exports. A nearby product of a shorter distance requires related capabilities to those that exist, with greater likelihood of success. A country's distance from a given product, for example Product A, is calculated by summing the proximities to Product A from all products in which the country does not have Revealed Comparative Advantage and dividing that by the sum of the proximities to A from all products (HAUSMANN *et al*., 2013).

periphery (HIDALGO *et al.*, 2007)[4]. Countries located in dense parts of the product space with many products nearby find diversification easier than countries producing isolated items that are peripheral in the product space. This empirical finding lends to strong support in the hypothesis that production involves learning and that the process of growth and diversification does not follow a random path—rather, it is incremental and to some extent predictable. Moreover, a country's particular starting point in the product space provides important clues as to what products and industries it is in a good position to develop next—specifically, it is more likely to move to the products that are nearby[5] (HAUSMANN; CHAUVIN, 2015).

In a subsequent paper, Hidalgo and Hausmann (2009) interpreted trade data as a bipartite network in which countries are connected to the products they export and showed that is possible to quantify the complexity of a country's economy by characterizing the structure of this network. A country will be able to produce a product if it has all of the available capabilities. Hence the bipartite network connecting countries to products is a result of the tripartite network connecting countries to their available capabilities and products to the capabilities they require. Based on this interpretation, Hidalgo and Hausmann (2009) developed an indicator to measure the complexity of the productive structure of countries, formally known as the Economic Complexity Index (ECI). This indicator is calculated based on the diversity of exports a country produces and their ubiquity, or the number of countries able to produce them (and those countries' complexity).

The concept of complexity also emphasizes how the production process of a particular product is dependent on the interaction between different specific knowledge and how these interactions permit the innovation and production of more complex products. It is expected that countries with more capabilities will be able to make more products (higher diversification), while products that require more capabilities will be accessible to fewer countries (lower ubiquity). Thus, the theory provides that more complex countries will be more diversified and will make fewer ubiquitous products.

Hausmann et al. (2013) also showed how these bimodal complexity indexes correlate well with aggregate levels of per capita income. Moreover, they showed how economic complexity

[4] The core is formed by metal products, machinery, and chemicals; while the periphery is formed by the rest of the product classes.

[5] Brazil is a good example to illustrate the product space idea. Despite having undergone significant structural change in the twentieth century, Brazil is in a regressive specialization process, with increasing dependence on products from the product space periphery (agricultural and mineral commodities). These industries produce fewer complex products and have fewer connections toward the densely connected area of product space. According to the economic complexity approach, countries with this kind of specialization tend to face more problems in diversifying their production structure, although not impossible.

can be a good predictor of future growth: "the ability of the ECI to predict future economic growth suggests that countries tend to move towards an income level that is compatible with their overall level of embedded know-how" (HIDALGO *et al*., 2007, p. 27).

Among agribusiness products, product complexity and opportunities of diversification vary significantly. In this study we want to evaluate the complexity of agribusiness products in Brazil, compared to other countries, and evaluate if this indicator is relevant to explain the cross-country levels and growth differences of productivity in agriculture.

3 Material and methods

The methodological procedures adopted in this study are described below beginning with the presentation of some key concepts and analytical issues. Then, the data sources and the indicators methodology are indicated.

3.1 Key concepts and analytical issues

First, distinguishing the concept of *agriculture* from *agribusiness products* is important. The first concept is less comprehensive and refers exclusively to activities of primary production, that is, that which occurs on the agricultural production unit (farms). The products from agriculture corresponds to International Standard Industrial Classification (ISIC) tabulation category A (revision 4) and includes forestry, hunting, and fishing as well as cultivation of crops and livestock production.

The scope of the agribusiness concept is broader and includes products from the manufacturing industry that uses raw products from the agriculture sector as an input. Thus, agribusiness products range from the products of agriculture (raw materials and consumer-oriented products) to agro-industry products (intermediate and consumer-oriented products)[6].

A subliminal hypothesis of this study, related to the concepts of *agriculture* and *agribusiness* products, is that the predominant competitiveness strategy in agribusiness of a particular country (based on costs or product differentiation) and the capabilities required for a successful market performance from the agro-industrial firms are associated with cross-country differences of productivity and per capita income in agriculture. In other words, the specificities

[6] For statistical purposes, agribusiness is comprised of the products from The Atlas of Economic Complexity chapters 01 to 24 of HS-4 (see more in the next subsection).

of agro-industrial sectors, especially those related to product complexity, are assumed to be determinants of the levels and growth rates of value added per worker in agriculture. For this reason, economic complexity was calculated for all agribusiness products and related to productivity of agriculture.

3.2 Data sources and indicators methodology

Hidalgo and Hausmann (2009) have created the Product Complexity Index (PCI) which measures how complex a product is, i.e. how many capabilities it requires. The PCI is based on Harmonized Commodity Description and Coding Systems at four-digit code (HS-4) and is updated by The Atlas of Economic Complexity (THE GROWTH LAB AT HARVARD UNIVERSITY, 2018). The PCI ranking shows that most complex products—that only a few and complex countries can produce—include sophisticated machinery, electronics, and chemicals. On the other hand, the lower complex products include raw materials and simple agricultural products. In 2016 the PCI ranged from -3.22 (less complex product: HS5303 – jute and other textile-based fibers) to 3.51 (more complex product: HS7414 – endless bands of copper wire for machinery). Of the 1240 mapped products, 200 are agribusiness products (chapters 01-24 of HS). In general, as we would expect, agribusiness products occupy a peripheral position in the ranking of product complexity: only one product appears among the first 250, in the third position[7]. While the average complexity of manufactured products (chapters 28-99 of HS) is 0.2398, the average complexity of agribusiness products is negative (-0.8411).

In order to measure how much new products developed by a country improve its position in the product space and affect its future opportunities for diversification, Hausmann et al. (2013) created the indicator of *opportunity outlook gain*. The indicator is calculated as the change in the *complexity outlook* from developing a Revealed Comparative Advantage (RCA) in a new product. Opportunity outlook gain classifies the strategic value of a product based on the new paths to diversification in the more complex sectors that it opens up. This measure is important because a new product can be strategically valuable if it *opens doors* for future diversification by decreasing the distance to other strategic products (HAUSMANN; CHAUVIN, 2015).

The measure of productivity in agriculture adopted in our study is the agriculture value-added per worker that denotes the sector net output after adding up all outputs and subtracting intermediate inputs. It is an indicator of partial productivity as it uses only one type of input, i.e.,

[7]Among the top 500 products of product complexity ranking, only nine are from the agribusiness sector; and they represent <3% of the sector's global exports in 2014-2016.

labor, and does not capture the effect of other inputs employed in farm production, e.g., physical capital and land. Despite the limitations of this kind of indicator[8], it allows for ready comparison across sectors and countries, which fits the objectives of this study. The agricultural productivity time series data is sourced by the World Bank (2018) and is expressed in constant 2010 U.S. dollars.

The measure of agribusiness products complexity was calculated based on the PCI results of The Atlas of Economic Complexity (THE GROWTH LAB AT HARVARD UNIVERSITY, 2018). The PCI and country complexity rankings (ECI) are calculated from international trade data. The authors made this choice because it is the only data set available that has richly detailed cross-country information linking countries to the products that they produce in a standardized classification. The PCI is calculated based on how many other countries can make the product and on the economic complexity of those countries. In effect, the indicator captures the sophistication of know-how required to produce a product. Based on the PCI value, we developed the Agribusiness Complexity Index (AgrPCI), measured for all countries. The AgrPCI is the PCI average for agribusiness products, weighted by the value of each country's exports. Thus, countries with a high value of AgrPCI are specialized in relatively complex agribusiness products, while countries with low AgrPCI produce relatively simple agribusiness products.

Agribusiness exports data is provided by The Atlas of Economic Complexity. The source of raw trade data is the United Nations Comtrade. Because of limited, delayed, or inaccurate reporting of trade data to the UN Comtrade, The Atlas of Economic Complexity research team developed a method to clean the data to account for inconsistent reporting practices and thereby generating estimates of trade flows between countries. This data cleaning is known as the Bustos-Yildirim method in the literature. All statistics described from the results and discussion section (exports, productivity, and AgrPCI) were converted into three-year averages in order to smooth out eventual cyclical fluctuations.

4 Results and discussion

In this section, we analyze and qualify the phenomenon of productivity growth in Brazilian agriculture in comparison to the main exporters and productivity leading countries of

[8] The productivity estimate using the broadest aggregate of inputs is Total Factor Productivity (TFP). Simply stated, TFP is the ratio of an aggregate index of output to an aggregate index of inputs used in production. For details see the seminal work of Gardner (2002).

agribusiness (section 4.1). In addition, we analyze the relationship between agricultural productivity performance and agribusiness complexity in Brazil and selected countries (sections 4.2 and 4.3).

4.1 The evolution of Brazilian productivity in agriculture

In 2016, Brazil accounted for 5.3% of total global agribusiness exports, ranking behind only the United States, the Netherlands, and Germany. Between 2001 and 2016, Brazilian agribusiness exports grew at an average annual rate of 8.7% (value in constant 2010 US dollars), the highest rate among the world's top 10 exporting countries. In 2023, Brazilian agribusiness exports reached a record high of USD 166.55 billion, a 4.8% increase compared to 2022. This sector accounted for 49% of the country's total exports that year (COMEX, 2024).

The significant increase in Brazilian agricultural production and exportable surpluses in the twenty-first century is primarily explained by increased productivity (FUGLIE *et al.*, 2012; GASQUES *et al.*, 2014). In fact, Brazilian agriculture underwent a quick process of technical and structural changes. In recent decades, the trend toward a reduction in the use of labor has been consolidated, as well as an increase in farm machinery capital stock and consumption of raw materials such as fertilizers and crop protectants (CHADDAD, 2015). But how has Brazilian productivity evolved in relation to world-leading countries? Considering the performance on this variable, is it possible to affirm that Brazilian agriculture is in a process of catching up[9]?

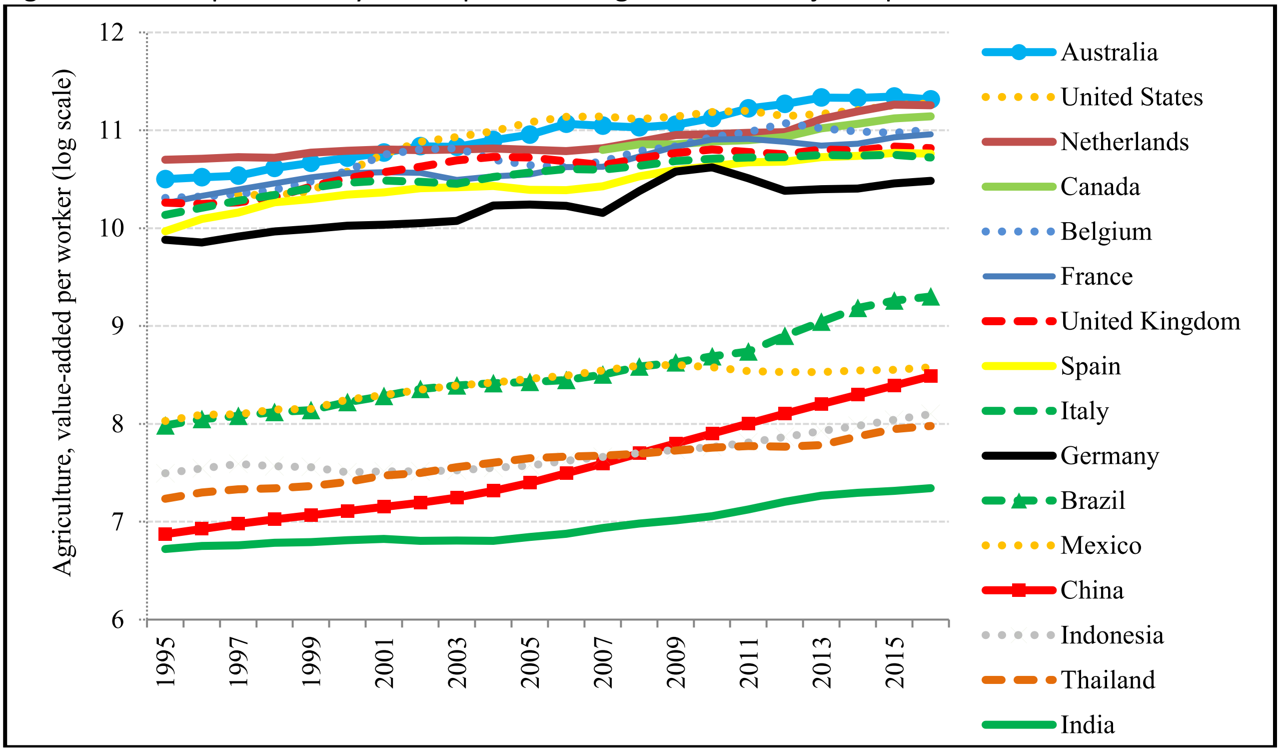
The evolution of added-value per worker in agriculture since the mid-1990s shows two groups of countries among the main world agribusiness exporters. In the first group with the highest productivity are Australia, United States, Netherlands, Canada, and other European Union countries. Brazil, Mexico, China, and other major exporters from Asia are part of the second group at a much lower level (Figure. 1).

Over time no country of the second group has been able to catch-up the leading countries. A hasty look at figure 1 might suggest the conclusion that Brazil is a victim of the *Red Queen Effect*. The idea is simple: however much a country improves its productivity, its competitors may be doing the same, at a similar pace. Thus, despite its productivity increase over time, in the end

[9] In general, *catch-up* relates to the ability of a single country to narrow the gap in productivity or per capita income vis-à-vis the world leader country (FAGERBERG; GODINHO, 2003), in line with the original proposal of Abramovitz (1986). We have adapted this concept to evaluate the performance of a particular economic sector: agriculture. The economic literature is abundant in controversies about the limits of productive specialization in natural resource intensive sectors. However, in this study the focus is more on the explanation of agricultural productivity performance and less on its development consequences.

the differences remain much the same or the gap just narrows marginally, not resulting in complete catching-up or forging-ahead processes.

Figure 1 - Labor productivity developments in agriculture – major exporters.



Source: World Bank (2018), own calculations.

Notes: (1) Countries that contribute at least 2% of world agribusiness exports in 2016 were selected; (2) values measured in constant 2010 US$ (averaged over 3-year period); (3) Argentina was excluded because of statistical inconsistency.

However, the *Red Queen Effect* hypothesis cannot be accepted for Brazil (Table 1). The South American country was the second that has advanced most in productivity since the beginning of the twenty-first century (7.0% per year), losing only to China (9.3% per year). Although it lacks much to reach the leading countries in productivity, this recent trajectory indicates that Brazil is in a process of catching-up. Taking the United States as a reference, in 2000 the value-added per worker in Brazilian agriculture was equivalent to 9% of that country and grew to 14% in 2016. Compared to the European Union, this difference ranged from 23% in 1995 to 43% in 2016. Brazil not only approached the leading countries, but also opened an advantage over other emerging countries with prominence in the international trade of agricultural products (except China). These results are consistent with those of Fuglie et al. (2012), which showed that Brazil and China have achieved remarkable productivity over the past decades. Other developing countries, especially those in sub-Saharan Africa and India, continue to lag far behind these kinds of productivity growth.

Table 1 - Value-added per worker in agriculture – annual growth rate and Brazilian catching-up indicator

Country/region	Annual growth rate (%)				Catching-up indicator (Brazil-selected countries ratio)			
	1995-2000	2001-2010	2011-2016	2001-2016	1995	2000	2010	2016
Australia	4,4	4,0	1,8	3,7	0,08	0,08	0,09	0,13
United States	-	4,9	1,5	3,5	-	0,09	0,08	0,14
Netherlands	-	1,7	5,8	3,1	0,07	0,08	0,10	0,14
Canada	-	-	5,0	-	-	-	0,11	0,16
Belgium	-	-	0,5	-	0,10	0,09	0,11	0,18
France	6,3	3,8	1,0	2,6	0,10	0,10	0,11	0,19
United Kingdom	5,1	2,6	0,8	1,7	0,10	0,10	0,12	0,22
Spain	7,8	3,0	1,8	2,7	0,14	0,12	0,14	0,23
Italy	6,8	2,5	0,0	1,6	0,12	0,11	0,13	0,24
Germany	2,9	6,7	-0,5	3,0	0,15	0,16	0,15	0,31
European Union	2,8	4,6	2,6	3,7	0,23	0,26	0,27	0,43
Brazil	**4,9**	**4,6**	**11,9**	**7,0**	**1,00**	**1,00**	**1,00**	**1,00**
Mexico	4,5	3,2	0,8	1,9	0,96	0,97	1,12	2,06
China	4,8	8,7	10,2	9,3	3,04	3,05	2,21	2,26
Indonesia	0,2	2,8	6,0	4,0	1,63	2,05	2,53	3,32
Thailand	3,5	3,2	4,2	3,4	2,12	2,26	2,55	3,75
India	1,8	2,6	4,4	3,5	3,53	4,09	5,13	7,08
Latin America & Caribbean	2,0	2,8	4,0	3,0	0,76	0,87	1,06	1,60
World	4,1	3,7	4,1	3,9	1,90	1,97	2,22	3,19
Sub-Saharan Africa	1,7	3,9	1,5	3,0	3,86	4,50	5,04	8,39

Source: World Bank (2018), own calculations.

Several studies have attempted to identify the sources of productivity growth in Brazilian agriculture. The main determinants cited were natural resource availability, external competition, changes in agricultural policy, the macroeconomic environment, entrepreneurship, value chain organization, and the cumulative effect of research and development spending on the emergence of new technologies adapted to tropical conditions. Regarding this last aspect, it is important to consider that although part of the comparative advantages of Brazilian agriculture is derived from the privileged availability of natural resources and the rapid modernization promoted since the 1970s, productivity growth observed in the last decades is also the result of the technological and organizational innovations distribution in the country. From the mid-1990s onward, a new technological package for grain production was established, combining agronomic innovations (no-till), biotechnology (transgenic seeds), chemical industry innovations (agricultural pesticides and fertilizers), and machinery innovations (adaptation to precision agriculture and no-till). Its development and absorption and absorption of this new package were not homogeneous but occurred quickly.

Public research in Brazil is internationally recognized for the innovations developed by the Brazilian Agricultural Research Corporation (EMBRAPA). In fact, a complex and diversified National Agricultural Research System was established in the country, where EMBRAPA played a key role, which was fundamental to boost the grain-meat complex and to the consequent transformation of Brazilian agriculture (SILVEIRA, 2014). Currently, EMBRAPA employs 42% of the country's agricultural researchers, predominantly focusing on crop research (mostly fruit, soybeans, and maize) in tropical areas (IFPRI, 2016). The agency applies a decentralized model of research, split between national commodity, regional resource, and *thematic* centers that allow for a national and local focus. Initially, EMBRAPA was tasked with providing extension services for the distribution of technological packages, including new seeds, soil correction techniques, and improved production practices. The most notable achievement, however, has been the development of technologies allowing agricultural expansion to the acidic soils of the Midwest region, a phenomenon known as the Brazil's Cerrado agricultural miracle (RADA; VALDES, 2012; RADA, 2013).

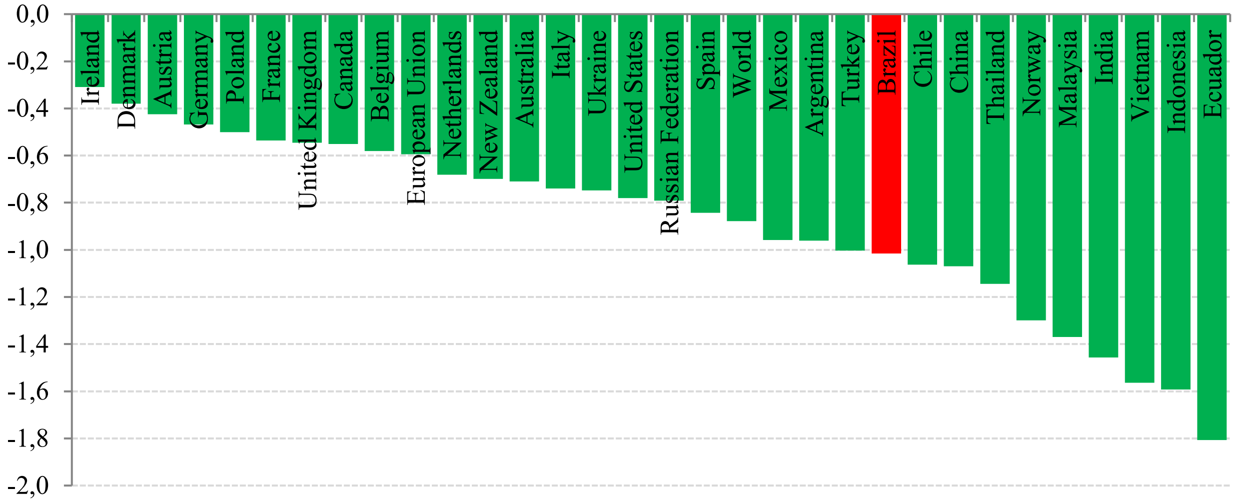
A less-considered hypothesis to explain productivity growth is the structural change that is expressed in the sophistication of Brazilian agribusiness products. This topic will be discussed in the following sections.

4.2 The complexity of agribusiness products: Brazil in focus

The calculation of the complexity indicator for agribusiness products showed that in 2016, among the main exporting countries, Ireland was at the top of the ranking, followed by Denmark, Austria, and Germany. In addition to being located in a region of high per capita income, which favors the demand for more sophisticated products (*high-end food*) (MUHAMMAD *et al*., 2011), these countries have in common the productive specialization in industries such as animal protein and other food preparations (preserved meat, sausages, whey, butter, etc.). Fourth in the ranking of exporters, Brazil ranks 21st in terms of agribusiness product complexity, considering the top 30 exporters worldwide (Figure 2).

Evaluation of the AgrPCI indicator since the mid-1990s reveals different growth patterns among major agribusiness exporting countries. From 1997 to 2012 Brazil presented the third largest absolute growth in AgrPCI, behind Russia and Vietnam. Other countries that stood out in the sequence were Thailand, Mexico, and India. Among other export leaders, the AgrPCI recorded a significant drop in the European Union and a remarkable increase in China and United States (Figure 3). These performances occurred in a period of high growth of food trade, rising food prices, and stability of the complexity of globally traded products.

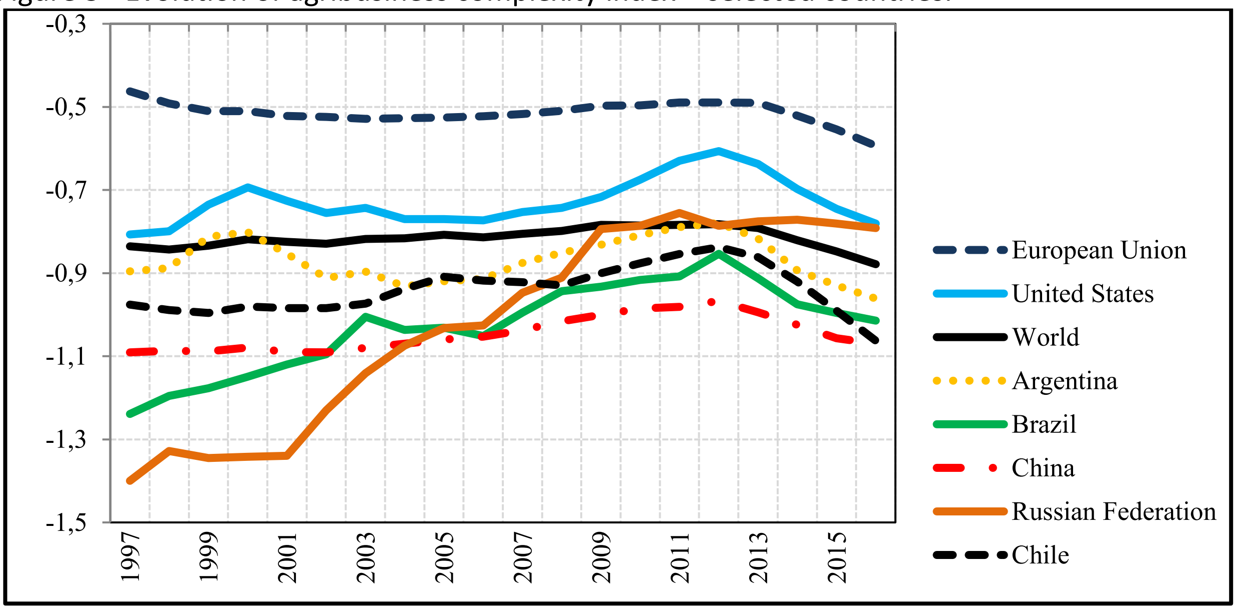
Figure 2 - Agribusiness Complexity Index of major exporting countries – 2016



Source: The Growth Lab at Harvard University (2018), own calculations.

The decomposition of AgrPCI reveals that the increase in the complexity of the Brazilian agribusiness products is explained by the agri-food manufactured products export performance, especially coffee, soybean meal and oil, fruit juice, poultry, and tobacco.

Figure 3 - Evolution of agribusiness complexity index – selected countries.



Source: The Growth Lab at Harvard University (2018), own calculations.

After 2012 Brazilian performance deteriorated significantly. Among the 30 largest exporters, the country recorded the sixth major fall in AgrPCI, being ahead only of Chile, Argentina, Denmark, United States, and Canada. That was the turning point of a favorable conjuncture, shaped by high prices of agricultural commodities. After 2012 the growth of agribusiness exports has been sustained mainly by the demand of low- and middle-income developing countries such as China. This situation contributes to a supply focus on low technological sophistication products in order to meet a typical consumer profile with sufficient income to satisfy the basic needs of food but does not allow access to higher priced food preparations. It is exactly the opposite of consumer trends observed in high-income countries that could sophisticate their consumption habits, including in the basket, for example, processed functional foods that require high levels of investment in R&D and tacit knowledge to be produced.

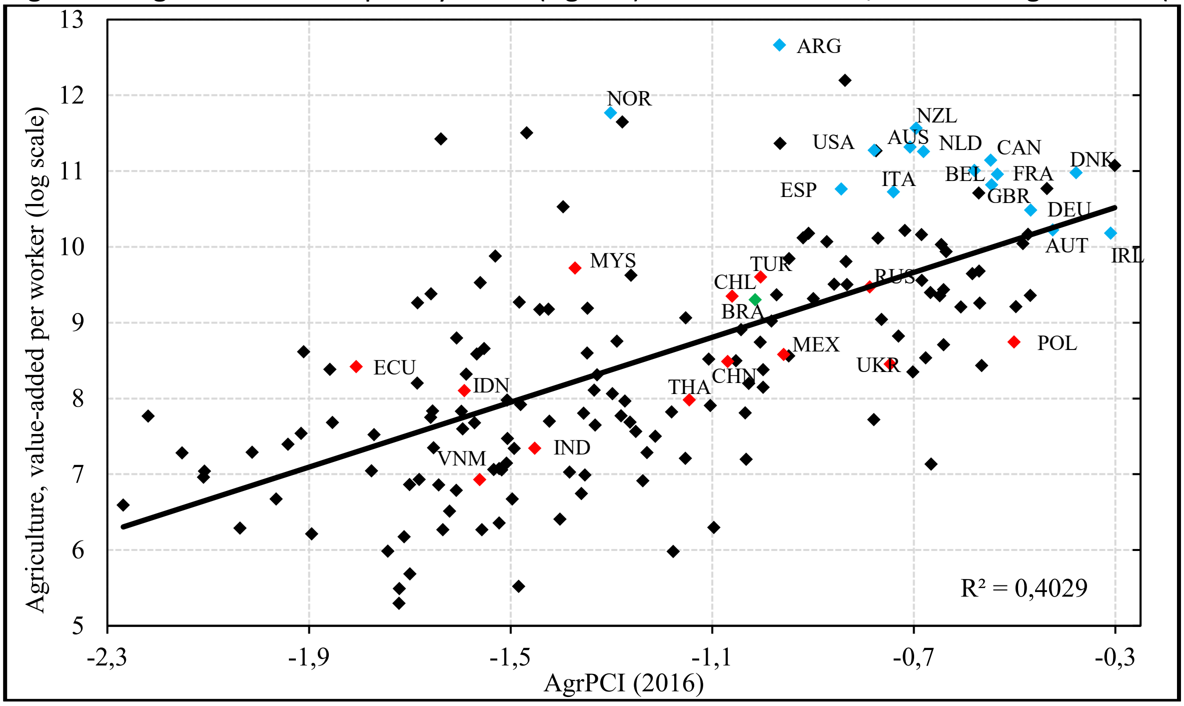
At least part of the reduction in the complexity of agricultural products exported by Brazil after 2012 can be attributed to the change in the composition of world trade. Soybean was the product that most contributed to reducing the world complexity of agribusiness products. Given the high share of South American countries and the United States in world supply of this product, the fall in the complexity of these countries was a natural consequence. During this period, besides soybeans, other commodities that contributed to reduce Brazil's AgrPCI were sugarcane and corn. There is evidence to suggest that until 2012 the international conjuncture favored competition strategies via product differentiation in agribusiness. After the international economic crisis, export growth was increasingly based on Ricardian efficiency, as a result of the growing importance of commercial flows to the south.

4.3 Productivity in agriculture and agribusiness products complexity

Results of the AgrPCI indicator are consistent with the theory of economic complexity, adapted to study a specific sector. A positive correlation is evident between the complexity of agribusiness products (AgrPCI) and agriculture value-added per worker of countries. In general, considering the largest world exporters of agribusiness products in 2016, the leading countries in productivity (the blue point in Figure 4) are specialized in more complex products.

On the other hand, large agricultural exporters that are not in the group of leading countries in productivity are specialized in products with substantially lower complexity (the red points in Figure 4). Brazil is in an intermediate position, above the regression line, which indicates that its productivity is higher than the average for countries of similar AgrPCI. This last remark is also true for all leading countries in productivity that are large exporters, except Ireland. This suggests that other factors, besides the complexity (e.g., productive efficiency, lower transaction costs, proximity to high-income consumer markets, institutional conditions), contribute to inflating their average productivity in agriculture.

Figure 4 - Agribusiness Complexity Index (AgrPCI) and value-added/worker in agriculture (2016)



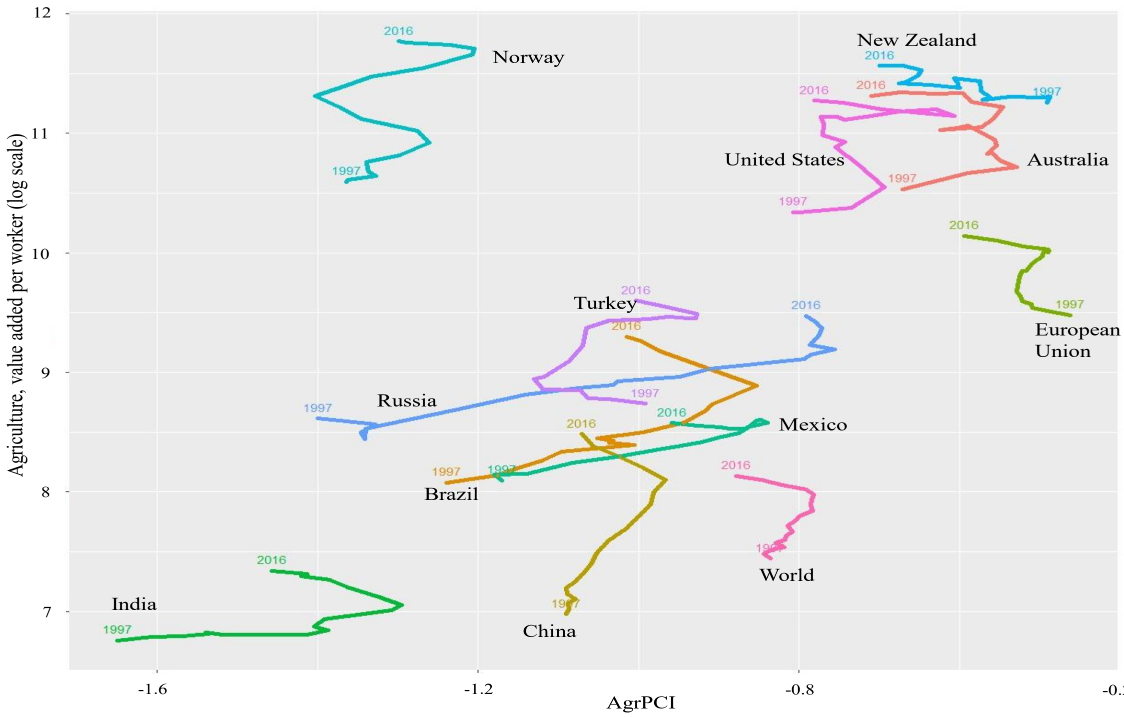
Sources: World Bank (2018) and The Growth Lab at Harvard University (2018), own calculations.

The comparative analysis of Brazil's exports with countries that lead the ranking of value-added per worker in agriculture reveals significant differences in terms of the diversification and composition of the export basket. While the United States and Netherlands have broadly diversified agri-food exports and industrialized final consumption products, Brazil continues to specialize in the supply of agricultural raw materials whose main attribute of competitiveness is the low cost of production. Among the leading countries in productivity, New Zealand, Australia, and Ireland are the most specialized; however, this occurs in agribusiness products that are more complex, such as milk, malt, meats, cheeses, butter, wines, and fruits. In the Netherlands, diversification is the rule and ranges from traditional flowers to a myriad of food preparations. In the United States, the main export product is the same as Brazil (soybeans), but the export basket is much more diverse.

In Brazil, on the other hand, the trend has been to intensify the supply of an increasingly narrow set of products that dominate sales. By 2016, 11 products accounted for more than 80% of Brazilian sales. In the Netherlands and United States, the 11 main agribusiness products sold accounted for <30% and 50% of the total, respectively (THE GROWTH LAB AT HARVARD UNIVERSITY, 2018). Thus, results suggest that the know-how available in these countries favors the diversification of agribusiness production. In addition, the share of less ubiquitous products is relatively higher, which is compatible with a high added-value per worker.

Paradoxically, from 2012 when the complexity of its products declined, the value added per worker more grew in some developing countries, such as Brazil, India and China. In this period the concentration of Brazilian exports (especially soybeans and corn) increased to developing countries, mainly China (South-South trade). The same phenomenon was registered in other countries and may have contributed to a movement of increase in the value added per worker (productivity) and reduction of complexity (Figure 5).

Figure 5 - Changes in agricultural productivity and complexity of agribusiness products – selected countries.



Sources: World Bank (2018) and The Growth Lab at Harvard University (2018), own calculations.

Given the supposed predictive power of the complexity indicators for economic growth, that is not good news. The complexity theory suggests that less complexity today tends to translate into lower productivity growth in the future, which can mean lower income for farmers. However, in the period analyzed, the possible association is between the levels of agricultural productivity and product complexity. The empirical verification of the causal relationship between the growth rates of these indicators is more problematic.

If the relationship between agribusiness product complexity and productivity in agriculture is correct, the recent trend in Brazilian exports may jeopardize continuity of the catching-up process. In the case of grains, the production organization model and the available technological package have evolved to favor gains in scale and increased the capital-labor ratio, which also contributes to growth in per capita income in agriculture, not only by increasing production but also by reducing the number of workers. Another hypothesis, associated with the concept of product space, is that the agribusiness products that Brazil exports also have lost complexity because the country's manufacturing industry is in crisis (premature deindustrialization) with a loss of technological sophistication. If this is true, even if the external scenario changed and the more complex agricultural products returned to gaining participation in the international trade, Brazil would have difficulties in raising its market share.

5 Building complexity in agribusiness: policy implications

In the previous sections we evaluated, from theoretical and empirical points of view, the linear association between the complexity of agribusiness products and labor productivity in agriculture, with emphasis on Brazil and other exporting countries. Considering this relationship, how do we build complexity in agribusiness? This issue refers to the accumulation and exploitation of the capabilities needed to increase and diversify the production of products with greater complexity.

Analysis of the productive specialization of the countries is important to evaluate the possible trajectories for the productive sophistication of the whole economy. For the complexity of agribusiness, this can be done by analyzing the products in which the country has comparative advantages and their respective connectivity in the product space, whether between agribusiness products or not. The conclusions of Hidalgo and Hausmann (2009) suggested that changes in a country's productive structure can be understood as a combination of two processes. The first is one where countries find new products derived from at present unexplored combinations of capabilities they already have. The second is the process by which countries accumulate new capabilities and combine them with other previously available capabilities to develop yet more products.

Considering these processes, the Atlas of Economic Complexity has developed indicators to assess the country's opportunities for diversification and to improve complexity based on what is currently exported (frontier products). According to Hausmann and Chauvin (2015), these “frontier products” should satisfy the following criteria: (i) they are more complex than what the country already exports (high PCI); (ii) they are feasible given the country’s productive knowledge (short distance); and (iii) they open up paths to future diversification (high opportunity gain). However, a trade-off often exists between these three desired properties. For most countries the products that have the highest PCI are also farthest away in terms of distance. Similarly, the products that deliver the highest opportunity gain also tend to lie at greater distances (HAUSMANN; CHAUVIN, 2015).

The definition of public policies to build complexity in agribusiness must address these characteristics. In Brazil, for example, several agribusiness products exist with RCA < 1, with AgrPCI higher than average, and with feasible products given the country's current position in the product space (meat, linseed, bovine sheep and goat fats; stearic acid; dairy products; solid vegetable oil and fat residues). The same products, in addition to grain sorghum and palm oil, appear as products with high opportunity gains. For the purposes of industrial policy guidance, given the particularities of agriculture, we recommend that this type of information be considered in the light of the available natural resources and the local edaphoclimatic conditions. In addition, to avoid continuity of the process of loss of complexity in Brazilian agribusiness, the well-established and complex products (RCA > 1 and AgrPCI higher than average) can also be encouraged. This is the case of some dairy products, meats, coffee, fruit juice, and farm equipment. By strengthening these supply chains, it is possible to increase the complexity of exports and to create value-added differentials that translate into higher productivity per worker.

The economic analysis of the productive knowledge available in countries also should be supplemented by the assessment of demand constraints in order to identify the markets in which the country can be an effective competitive seller. These analyses should consider the level of competition in each market, trade restrictions and agricultural policies (tariff barriers, nontariff barriers, and subsidies), transport costs, and the demand growth rates (Keynesian efficiency).

Regarding the growth of demand, taking into consideration the composition and destinations of foreign sales is also essential. China's high share in Brazilian sales, accentuated in the last decade, has contributed to the concentration of exports in low-tech products. Not surprisingly, soybeans have been prominent in Brazilian crops, occupying almost half of Brazil's agricultural area today. As Brazil becomes able to diversify its markets into high-income countries, it will be stimulated to produce more complex foods with greater value-adding potential. On the other hand, the incentive of Schumpeterian efficiency in agriculture connects directly with the concept of the techno-economic paradigm, especially in the context of transition to a bioeconomy and the renewed potential of natural-resource-based networks to serve as a platform for development strategies (PÉREZ, 2012).

In addition, product complexity can also be used in conjunction with sector linkage indicators as an instrument for policy making. Specialization in low complex products that are not nearby to high complex products or that do not generate opportunities to approach the denser area of the product space tends to lead to a kind of lock-in, limiting the growth possibilities of productivity and income. On the other hand, with sufficient investment even large distances in the product space can be overcome. Thus, economic resources available for industrial policies can be used more accurately and result in a greater impact on development when their effects on the consolidation of productive chains in the territory are considered. Development of a new capability that is critical to the development of agribusiness or industrial products may be sufficient to remove obstacles to the production of a range of products, with forward and backward linkages and impacts on production chains, resulting in a virtuous circle of economic growth.

Finally, the construction of complexity in agribusiness goes beyond the boundaries of traditional agricultural development policies. Evaluations conducted exclusively from sectoral perspectives may prove inappropriate for the definition of research and development resources allocation as the sophistication of the productive structure depends on the establishment of complex knowledge networks that are not guided by this logic of classification. Therefore, industrial policies aimed at building complexity need to be comprehensive enough to identify key products and the fundamental capabilities for their successful market performance. Pinning down these key products and finding binding constraints are obviously difficult. But they are likely more cost effective than a one-size-fits-all approach to industrial policy. This applies to products and industrial sectors as well as to agribusiness.

6 Limitations and future research

Some limitations and methodological weaknesses can be identified in the study. The complexity indicator relies on international trade data. According to Hausmann et al. (2013) it offers great advantages, but it does have limitations. The main one is that the countries' export basket is not always representative of their productive structure. This tends to be especially true for closed countries, where trade accounts for a small portion of domestic production. To the extent that some agribusiness products are typically exported and others are focused exclusively on the domestic market (and this occurs in Brazil), AgrPCI may not accurately reflect the complexity of agribusiness. However, trade data remains as the richly detailed, cross-country available source of information linking countries to the products they produce in a standardized classification.

Another important methodological limitation is the inability to do product-level analysis. Given that the analysis is restricted to the product baskets (HS-4 chapters), we did not see the real product complexity, e.g., Barilla pasta or Haagen Daz ice cream. What we see are just pasta and ice cream and the difference in complexity between these product groups. Obviously, expressive differences exist in the capabilities required to make products within each product chapter, and this is not adequately collected by the indicators.

In addition, per capita income differentials in agriculture may be derived from factors other than complexity. In Brazil and other developing countries, the precarious logistics infrastructure decreases the prices paid to producers and raises production costs. Finally, the average income in agriculture is also affected by the countries' agricultural and tax policies, but the analysis of these variables is beyond the scope of this article and can be performed in future work.

7 Conclusions

In this paper we seek to analyze the recent performance of Brazilian agricultural productivity and to understand its gap evolution in relation to the leading countries. The analysis leads us to conclude that Brazilian agriculture is not as technologically sophisticated, as it is popularly widespread and that this situation is associated with the local production knowledge and structures.

Therefore, even though agro is pop, it is not appropriate to define it as high-tech, especially if the reference of analysis is the world's leading countries in productivity and complexity. This recognition may constitute an important step toward the definition of a research and policy agenda oriented to innovation and the construction of complexity in Brazilian agribusiness. This still needs to be built, but the article offers several insights in this direction.

The application of economic complexity perspective to explain the cross-country agricultural productivity differentials constitutes the main methodological novelty of the article. There is no record in the literature of another attempt undertaken in this sense. This possibly is because of the fact that the authors aligned with this perspective concluded that the route to economic development is incompatible with agribusiness specialization and focused their attention on the manufacturing industry and on its segments aligned with the current techno-economic paradigm. The results also offer new evidence that even in agribusiness productivity growth is not product-neutral: specialization in products that are at the bottom of complexity ranking means less possibilities of raising productivity and average income in agriculture.

In theoretical terms, we identified several points of contact between the economic complexity approach and neo-Schumpeterian and structuralist theories, especially in an environment marked by increasingly frequent technological and economic changes. The results allow us to conclude that Brazilian exports continue to be dominated by low complexity products, which may limit future long-term growth in agricultural productivity. While the United States and European countries have specialized in offering products that demand differentiated knowledge, accessible to limited large-scale enterprises, Brazil has a leading role in commodity production, such as soybeans, corn, and chicken meat. Since 2012 the country has respecialized in the supply of less complex agribusiness products.

This movement is worrying for the continuity of the catching-up process in this sector. A long path must be taken to make this process successful in the long run. We understand that product space is an important tool in the strategic definition of policies aimed at structural change in developing countries like Brazil. In the agribusiness sector these policies may be partly geared toward transition from low to high complexity products that are close to the first ones in know-how. In this academic route, the economic complexity perspective suggests that local specialization in related activities induce innovation and interactive learning. In other words, new activities inside a region are not random events but immersed in territorial capabilities; hence, regional diversification can be understood as an emergent branching process in which those new activities are a recombination of related local activities (BOSCHMA, 2017). Thus, the higher the diversity across sectors, the higher the quantity of technologically related sectors and the more learning opportunities for the sectors in the region. It is about the economic relevance of bringing together different but complementary pieces of knowledge (ASHEIM et al., 2011).

In Brazilian agribusiness the policy makers understand that the scientific and technological systems are important to determine where countries are and where they can go. Agricultural R&D expenditures in Brazil are below the values invested in emerging countries and high productivity. In this way, additional and strategically oriented investments become important to break the technological standard and (most importantly) to expand the export activities by moving into products that are related to their present portfolio, creating a wide range of related technology and developing localized *capabilities* that are regional intangible assets with a high degree of tacit knowledge that are difficult to replicate in other places.

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