HOW SOPHISTICATED IS BRAZILIAN AGRIBUSINESS? AN EXPLORATORY ANALYSIS BASED ON ECONOMIC COMPLEXITY APPROACH

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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 agriculture in an international context? To answer this question and analyze the sources of agricultural productivity differences between countries we adopted the economic complexity approach. The results indicated that the Brazilian agribusiness complexity is at an intermediate stage, lower than the countries with the highest income per capita in agriculture. In addition, through a cross-country analysis we found a positive correlation between labor productivity in agriculture and the agribusiness complexity up to the year 2012, when the signal reverses, possibly due 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 the labor productivity and product complexity of leading countries.

Keywords: Brazilian agribusiness, technical progress, economic complexity.

Resumo: O expressivo crescimento do agronegócio brasileiro contribuiu para difundir uma percepção coletiva de que o Brasil produz com níveis elevados de eficiência e possui vantagem competitiva na oferta de um amplo conjunto de produtos sofisticados. Nesse trabalho questionamos até que ponto essa imagem é uma representação adequada da agricultura brasileira, considerando o contexto internacional? Para responder essa questão e analisar as fontes de diferença de produtividade na agricultura adotou-se a abordagem da complexidade econômica para analisar os produtos do agronegócio. Os resultados indicam que a complexidade dos produtos do agronegócio do Brasil está em um estágio intermediário, menor do que os países de elevada renda per capita que são grandes exportadores nesse setor. Além disso, evidenciou-se uma correlação positiva entre a renda per capita dos países e a complexidade das exportações do agronegócio. Essa relação foi interrompida em 2012, quando se intensificaram os fluxos comerciais Sul-Sul e aumentou o protecionismo internacional. Conclusivamente, o artigo sugere que embora o agronegócio brasileiro possa ser qualificado como pop, não parece ser adequado defini-lo como *high-tech*, especialmente

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se a referência for a produtividade média e a complexidade dos produtos ofertados pelos principais países líderes do setor.

Palavras chave: agronegócio brasileiro, progresso técnico, complexidade econômica.

JEL: Q0, Q16, Q55

Área temática: Dinâmicas industriais setoriais e dos sistemas de produção

Introduction

Brazil is known as one of the world's largest producers of food, feed, fibers, tobacco and renewable fuels. From 2000 to 2016 Brazil was the second country that contributed the most to the expansion of world agricultural exports, behind only the United States (UNITED NATIONS COMMODITY TRADE STATISTICS DATABASE, 2018). In the same period, agriculture was the fastest-growing economic activity in Brazil (3.3% annual growth rate averaged), according to the Brazilian Institute of Geography and Statistics (IBGE, 2018).

This performance contributed to rekindling the debate about the limits and possibilities of economic development from the agricultural route. The fact that the main driver of Brazilian agriculture growth was the productivity (GASQUES; BACHI; BASTOS, 2018) also reinforced a collective perception in Brazilian society 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[1].

But is this image an accurate representation of Brazilian agriculture in an international context? 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 analyzes, international references of productivity excellence (leading countries) were rarely considered, making it difficult to identify if Brazilian agriculture is in a process of catching-up. This study also intends to contribute to fill this gap in the economic literature.

In addition to answering the research question mentioned above, we sought to evaluate whether it is possible to associate the differences of average productivity in agriculture and the sophistication of the products that they export. To fulfill this second objective, we embrace the economic complexity approach.

The study was conducted in three successive stages. First, we analyze the cross-country data of labor productivity in agriculture, a sector productivity proxy. Second, to compare the diversity and sophistication of the productive know-how required to produce the agribusiness products, we created and analyzed an indicator of countries complexity exports. Third, we analyze the association between labor productivity in agriculture and the agribusiness indicator of complexity.

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 present the methodological procedures and section 4 describes and discuss the results. Finally, the last section concludes.

2. Sources of agricultural growth productivity and innovation: a literature review

The level and growth of agricultural productivity are critical both to the wellbeing of the population of the least developed countries and to the structural transformation of their economies. They are major determinants of poverty and of the income gap that separates them from other developing countries and developed countries, and play an essential role in the processes of rural

[1] Since June 2016, TV Globo, the largest television station in Brazil, began to broadcast an advertisement called Agro: Brazil's wealth-industry. The programs produced by the station and displayed in prime time highlights the efficiency of Brazilian agribusiness, in addition to its leading position in the world context. The idea of "Agro is tech, agro is pop, agro is everything" had great national repercussion, causing the station to win many awards.

structural transformation and development and in strengthening the rural non-farm economy (UNCTAD, 2015).

The 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 which widens the range of interpretive insights.

2.1 Efficiency, innovation and productivity growth

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

Considering these aspects, it is plausible to suppose that each country has its own economic subsystem in which institutions interact and mutually influence the achievement of technical change (FREEMAN, 1987, NELSON, 1993, LUNDVALL, 1992). Innovative activity, therefore, has a broad and complex meaning, which interacts with products and processes, R&D of companies and public agencies, as well as learning processes, incentive mechanisms and the availability of skilled labor.

This systemic and dynamic view of technical progress contrasts with the neoclassical perspective, whereby the allocation of resources in the innovative activity is governed by supply and demand forces in a linear way. In order to preserve the equilibrium premise, the neoclassical theory developed concepts like demand-pull, where the market is the main source of new ideas and drive R&D activities, and technology-push that emphasizes the opportunities determined by scientific and technological advances and consider the market as a kind of receptacle of R&D output.

But empirical evidence has shown that, far from being linear, innovation is a systemic process and interactive learning is the main dynamic mechanism for knowledge accumulation, innovation, and growth of firms. 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 innovation system extends the object of analysis, to a broader way, with regard to conventional visions circumscribed to public and individual organizations. The innovation systems approach incorporates the behaviors and motivations of agents, their relations, the current incentives and the connections with the environment, given that innovation is a phenomenon systemically conceived and presents a multifaceted complexity (BRESCHI; MALERBA, 1997; BISANG; ANLLÓ; CAMPI, 2015). From this evolutionary perspective, the innovative capacity of a country or region is seen as a result of the relationships between economic, political and social actors, and reflects its own cultural and institutional conditions.

The strategic role assigned to the manufacturing industry for technical progress and economic development has determined that studies conducted from the neoschumpeterian perspective focus mainly on this sector. Despite its specificities, agriculture can also be analyzed from an evolutionary perspective. The grain production in South America and United States can be referred as an 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, which have boosted and obtained higher profits in developed and developing countries. The new economic advantages quickly attracted a large number of producers who expanded the production, reduced the average costs, raised the product quality and put the previous business model in crisis (BISANG, ANLLÓ, CAMPI, 2013). This is a process of creative destruction, similar to that analyzed in the industrial world almost a century ago by Schumpeter (HUERGO, 2005; PEREZ, 2012; DABAT, 2014).

The agriculture is known to have large variations in productivity between countries. Gollin, Lagakos and Waugh (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, not yet tested in the literature, is the one that associates agriculture productivity with the firms' competitive strategies and capabilities. The country 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, 1988, DOSI; PAVITT; SOETE, 1990; CIMOLI; PORCILE; ROVIRA, 2010), in contrast to a profile in which sectors only have static efficiency associated to lower production costs (Ricardian efficiency). The 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 intra-sectoral 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 which operates in markets 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 (potato chips vs. computer chips debate). For evolutionary theory and the economic complexity perspective, produce at equivalent or similar productivity of 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, towards 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, the predominance in a particular country of firms whose competitiveness is based on cost or differentiation leadership strategy can affect the sectoral growth path of productivity and income at the national level. In the sequence, we describe the advances of complexity theory in the empirical evaluation of this relation.

2.2 Economic complexity: a new approach to understand the productivity growth

[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 farms operators in poor countries avoid using productivity-enhancing inputs, such as fertilizers and pesticides, because doing so increases their consumption risk (DONOVAN, 2013). A third hypothesis is that the agriculture sector in developing countries tends to employ the lowest-ability workers (LAGAKOS; WAUGH, 2013).

The economic complexity approach is a project developed in partnership by the Center for International Development at Harvard Kennedy School and the Massachusetts Institute of Technology Media Lab. This analytical approach encompasses recent theoretical and empirical developments led by the researchers Cesar Hidalgo and Ricardo Hausmann. This paper draws on the theoretical definitions and analysis tools consolidated in The Atlas of Economic Complexity (HIDALGO et al., 2014) and in three seminal articles on the theme: "The product space conditions the development of nations" (HIDALGO et al., 2007); "The structure of the product space and the evolution of comparative advantage" (HAUSMANN; KLINGER, 2007) and "The building blocks of economic complexity" (HIDALGO; HAUSMANN, 2009).

As described by Gala (2017), the economic complexity adopts a similar approach to that of the original structuralism economists and Latin Americans economists from the ECLAC tradition. These economists 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 towards the sophistication of the productive structure.

In this route, the group of higher value-added activities contrasts with the activities of lower value-added, usually predominant in poor or middle-income countries, which present 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 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 there are high start-up costs and others barriers to entry, economies of scale and differentiation by brands, which blocked the establishment of new players from emerging countries. Examples of this are the production of airplanes (Boeing, Airbus, Bombardier and Embraer), cars (Toyota, Hyundai, GM, Ford, Fiat) and processed foods (Nestlé, General Mills, Danone and Unilever). 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).

In line with the conclusions of early economic development theorists, the economic complexity theory provides new evidences to understand the origins of the wealth of nations. The empirical results of The Atlas of Economic Complexity have contributed to unsettle the thesis of the orthodox economists who, based on the theory of the general equilibrium, profess that the economic development is sector neutral. There is a complete disconnection between this economic theory and the reality unveiled by the atlas of economic complexity data (HAUSSMANN; HIDALGO et al., 2014).

Hausmann and Hidalgo (2009, 2014) defined economic complexity as a measure of the knowledge in a society as expressed in the products it makes. They argue that each product uses a specific amount of knowledge in its manufacturing process. Some products are relatively easy to manufacture, requiring little knowledge and skills, while others are difficult to manufacture 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; HIDALGO et al., 2012). 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. Thus, 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'. The likelihood that a country develops a particular product depends on its proximity in the product space to the products that the country is already able to export. Therefore, the 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, based on the probability of co-export both of the two products. The shape of the product space show 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 which 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 periphery (HIDALGO et al., 2007)[3].

Brazil is a good example to illustrate the product space idea. Figure 1 illustrates the world product space based on exports from Brazil. In this representation, the diameter of the circles varies according to the value of Brazilian exports and only the sectors with revealed comparative advantage greater than two are colored[4]. Despite having undergone significant structural change in the twentieth century, Brazil is in a regressive specialization process, with increasing dependence of products from the product space periphery (agricultural and mineral commodities). These industries offer less complex products and have fewer connections toward the densely connected area of product space. According to economic complexity approach, countries with this kind of specialization tend to face more problems to diversifying their production structure, although not impossible.

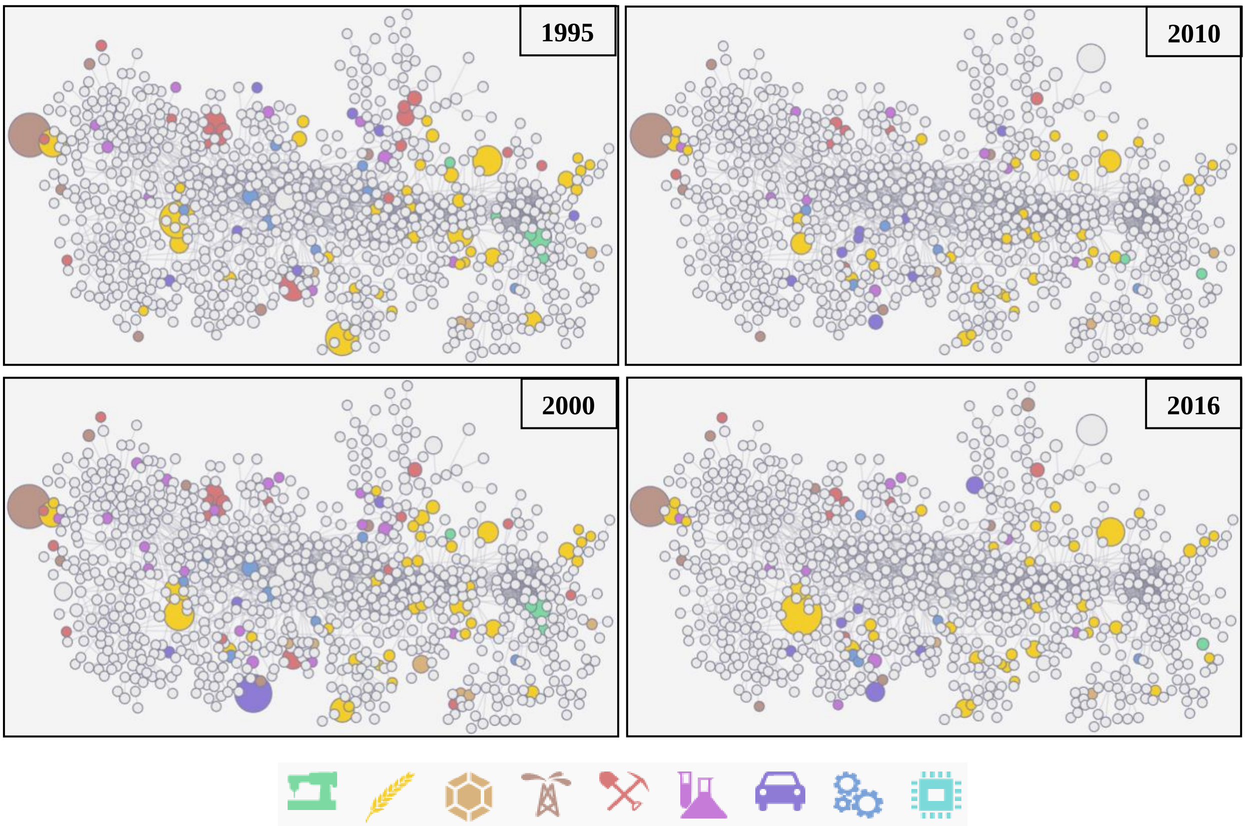

Figure 1: The Brazilian exports in the product space - 1995, 2000, 2010 and 2016
Source: The Atlas of Economic Complexity (2018)

[3] The core is formed by metal products, machinery and chemicals while the periphery is formed by the rest of the product classes.
[4] Products are classified in nine sectors according to Harmonized Commodity Description and Coding Systems at four-digit code (HS-4): agriculture or agribusiness (chapters 01-24 of HS), textiles, stone, minerals, metals, chemicals, vehicles, machinery and electronics.

In a subsequent paper, 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 emphasis 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 the production of more complex products and, therefore, advance in the configuration of a more complex and dynamic entire economy. 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 both more diversified and would make less ubiquitous products.

Hausmann and Hidalgo (2009, 2014) also showed how these bimodal complexity indexes correlate well with aggregate levels of per capita Gross Domestic Product (GDP). Moreover, they showed how economic complexity can be a good predictor of future growth: "a simple measure of current complexity and connectedness to new complex products, in relation to current income levels and expected natural resource exports, holds greater accuracy in predicting future growth than any other single economic indicator" (THE ATLAS OF ECONOMIC COMPLEXITY, 2018).

In addition, Haussman and Hidalgo (2009) have created the Product Complexity Index (PCI). The PCI is based on Harmonized Commodity Description and Coding Systems at four-digit code (HS-4) and is updated annually by The Atlas of Economic Complexity. As expected, the 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 product complexity index ranged from -3.22 (less complex product: HS5303 - jute and other textile bast fibers) to 3.51 (more complex product: HS7414 - endless bands of copper wire for machinery). Of the 1,240 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[5]. 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).

Among the agribusiness products, the complexity and opportunities of diversification and, consequently, of value-added per worker 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. It begins 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

It is important to distinguish the concept of "agriculture" from the "agribusiness products". The first concept is less comprehensive and refers exclusively to activities of primary production, that is, that occur on the agricultural production unit (farms). The products from agriculture corresponds to the 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.

[5]Among the top 500 products of product complexity ranking, only nine are from agribusiness sector, and represents less than 3% of the sector's global exports in the period 2014-2016.

The scope of the agribusiness concept is broader and includes the products from manufacturing industry that uses raw products from 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). For statistical purposes, agribusiness comprehend the products from chapters 01 to 24 of HS-4.

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 from the agro-industrial firms to a successful market performance are associated with cross-country differences of productivity and per capita income. In other words, it is assumed that the specificities of agro-industrial sectors, especially those related to the product complexity, are determinants of the levels and rates of income growth 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

The measure of productivity in agriculture adopted in our study is the agriculture value-added per worker which denotes the sector net output after adding up all outputs and subtracting intermediate inputs. It is an indicator of partial productivity, since it uses only one type of input, i.e. labor, and does not capture the effect of other inputs employed in farm production, like physical capital and land. Despite the limitations of this kind of indicator[6], 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 (2018). PCI and country complexity rankings (ECI) are calculated from international trade data. The authors made this choice because it is the only dataset available that has a rich detailed cross-country information linking countries to the products that they produce in a standardized classification[7]. PCI is calculated based on how many other countries can produce the product and 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. AgrPCI is the PCI average for the agribusiness products, weighted by the value of each country's exports. Agribusiness exports data is provided by The Atlas of Economic Complexity[8].

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

[6] The productivity estimate using the broadest aggregate of inputs is Total Factor Productivity (TFP), which gauges the productivity of all productive inputs when used jointly. In the case of agriculture, this typically takes account of land, labor, physical capital and material inputs (especially fertilizers) employed in farm production, and compare them with the total quantity of agricultural output.

[7] According to Haussman et al. (2014), it offers great advantages, but it does have limitations. First, it includes data on exports, not production. Countries may be able to make things that they do not export. Second, because the data is collected by customs offices, it includes only goods and not services. Finally, the data does not include information on non-tradable activities. These are an important part of the economic eco-system that allows products and services to be made.

[8] The source of raw trade data is the United Nations Comtrade. Due to limited, delayed, or inaccurate reporting of trade data to UN Comtrade, The Atlas of Economic Complexity research team developed a method to clean the data to account for inconsistent reporting practices and thereby generate estimates of trade flows between countries. This data cleaning is known as the Bustos-Yildirim Method in the literature.

4.1 The evolution of Brazilian productivity in agriculture

Brazil is in a prominent position in the ranking of exporting countries of agribusiness products. Brazil accounted for 5.1% of total world agribusiness exports in 2016, second only to the United States, the world's largest agricultural producer, the Netherlands and Germany, which hold Europe's main ports. Between 2000 and 2016 Brazilian agribusiness exports grew at an average rate of 10.6% per year. In absolute terms, the increase in Brazilian exports was the second largest of the period, only surpassed by the United States.

The significant increase in Brazilian agricultural production and exportable surpluses in the 21st century is explained by the intensive use of inputs and mainly by productivity gains (GASQUES et al., 2016). In fact, the Brazilian agriculture underwent a quick process of technical and structural change. In recent decades, the trend towards a reduction in the use of labor and land has been consolidated, as well as an increase in the use of capital (modernization). Productivity growth rates of these factors show that labor and land have been the main sources of agricultural output growth. These rates have increased over the period 2000-2014 with labor productivity increasing by 5.32% annually (GASQUES et al., 2016). But how has the 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 answer to these questions can be obtained by the analysis of the added-value per worker in agriculture, a proxy variable of labor productivity. The evolution of this variable since the beginning of the 1990s shows two groups of countries among the main world agribusiness exporters. While New Zealand, United States, Netherlands, Canada and other countries of the European Union registered the highest average productivities, Brazil, China and other major exporters from Asia are at a much lower level (Figure 2).

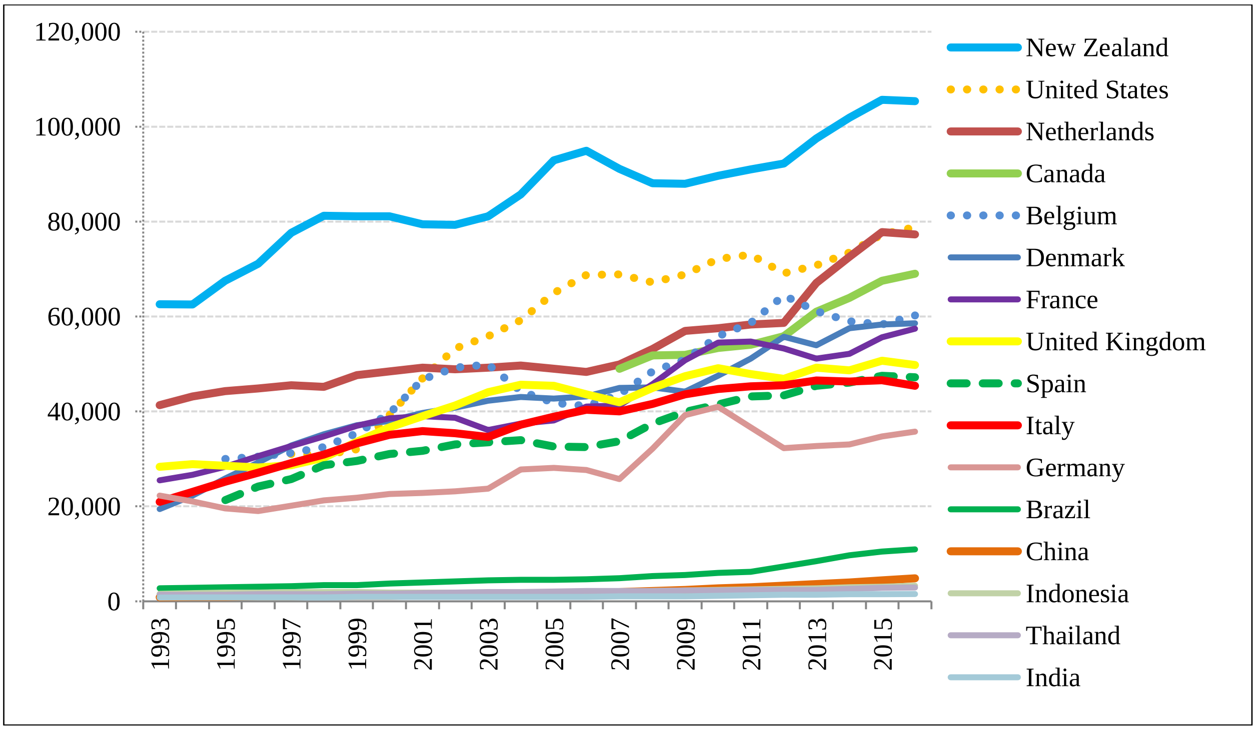

Figure 2: Value added per worker (constant 2010 US$) in agriculture - major exporters and leading countries

Source: WORLD BANK (2018)

[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: the agriculture. The economic literature is fruitful 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.

Since the mid-1990s no country of the second group has been able to catch-up the leading countries. Given the difference in productivity between the countries of the two groups, a hasty look at Figure 2 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 the differences remain pretty much the same.

But a closer look at the data led us to discard this hypothesis (Table 1). Brazil was the second country that has advanced most in productivity since the beginning of the 21st century (194.3%), losing only to China (297.3%). 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. This percentage fell to 8% in 2010 and rose to 14% in 2016. Brazil not only approached the leading countries, but also opened up advantage over other emerging countries with prominence in the international trade of agricultural products (except China). These results are consistent with those of Fuglie's (2012) study which showed that among more than 100 countries analyzed, Brazil, the United States and China had the highest rates of productivity growth from 2009 to 2012.

Country/region	**Δ %**				**Catching up indicator (Brazil-selected countries ratio)**			
	1993-2000	**2001-2010**	**2011-2016**	**2000-2016**	**1993**	**2000**	**2010**	**2016**
New Zealand	29.7	12.9	15.8	29.9	0.04	0.05	0.07	0.10
Australia	24.7	42.2	9.5	81.8	0.08	0.08	0.09	0.13
United States	-	53.6	7.9	100.6	-	0.09	0.08	0.14
Netherlands	17.3	16.9	32.4	59.3	0.07	0.08	0.10	0.14
Canada	-	-	27.7	-	-	-	0.11	0.16
Belgium	-	19.5	2.6	52.2	-	0.09	0.11	0.18
Denmark	95.6	19.7	14.4	54.0	0.14	0.10	0.13	0.19
France	51.3	39.9	4.9	48.9	0.11	0.10	0.11	0.19
United Kingdom	29.3	26.1	4.1	36.1	0.10	0.10	0.12	0.22
Spain	-	30.8	9.4	52.2	-	0.12	0.14	0.23
Italy	67.2	24.7	0.1	29.6	0.13	0.11	0.13	0.24
Germany	1.4	79.6	-2.5	58.2	0.12	0.16	0.15	0.31
Brazil	**35.2**	**50.1**	**75.3**	**194.3**	**1.00**	**1.00**	**1.00**	**1.00**
Latin America & Caribbean	11.0	27.7	21.8	61.1	0.72	0.87	1.06	1.60
China	41.5	111.6	62.6	297.3	3.19	3.05	2.21	2.26
World	31.3	39.3	22.4	82.0	1.92	1.97	2.22	3.19
India	14.0	25.9	24.1	70.0	3.45	4.09	5.13	7.08
Sub-Saharan Africa	6.8	41.0	7.7	58.0	3.56	4.50	5.04	8.39

Table 1: Value-added per worker in agriculture of selected countries and regions (constant 2010 US$) – growth rate and catching up indicator
Source: calculated based on WORLD BANK data (2018)

Several studies have attempted to identify the sources of productivity growth in Brazilian agriculture. The main determinants cited were external competition (increased productivity in the world), changes in agricultural policy and the macroeconomic environment, and the cumulative effect of research and development spending on the emergence of new technologies. Regarding this last aspect, it is important to consider that although part of the comparative advantages of Brazilian agriculture derives 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 spread in the country. From the mid-1990s onwards, a new technological package for grain production was established, combining agronomic innovations (no-tillage), biotechnology (transgenic seeds), chemical industry innovations (agricultural pesticides and fertilizers) and machinery innovations (adaptation to precision agriculture and no-tillage). Its development and absorption by Brazilian farmers 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 plays a key role, which was fundamental to boost the grain-meat complex and to the consequent transformation of Brazilian agriculture (SILVEIRA, 2014). Nowadays, Embrapa employs 42 percent 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 both 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 Cerrado biome (RADA & VALDAS, 2012).

A less considered hypothesis to explain the productivity growth is the structural change that is expressed in the sophistication of the 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 us animal protein and other food preparations (preserved meat, sausages, whey, butter, etc.). Fourth in the ranking of exporters, Brazil ranks 24st in terms of agribusiness product complexity, considering the top 30 exporters worldwide (Figure 3).

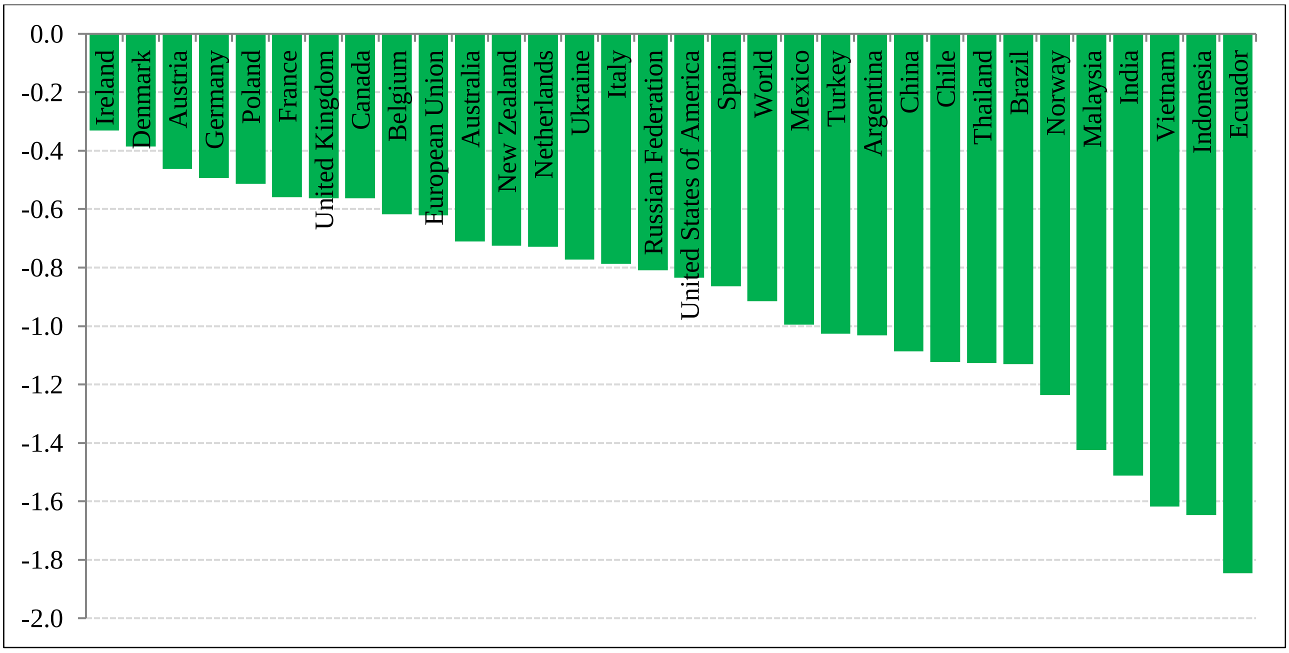

Figure 3: Agribusiness Complexity Index of major exporting countries in 2016
Source: Authors

The evaluation of AgrPCI indicator over time reveals that there were no significant position changes among the main agribusiness exporting countries since the mid-1990s. From 1995 to 2010 Brazil presented the fourth largest growth in AgrPCI, behind Russia, Vietnam and Thailand. The decomposition of AgrPCI reveals that the increase in the complexity of the Brazilian agribusiness products is explained by the contribution of a series of manufactured products, such as coffee, soybean meal and oil, fruit juice, poultry and tobacco. Other countries that stood out in the sequence were India, Mexico, Ecuador, Malaysia and Norway. Among the largest exporters, until 2010 the AgrPCI recorded a significant drop in European Union and a significant increase in China and United States (Figure 4). These performances occurred in a period of high growth of food trade, rising food prices and stability of the complexity of globally traded products.

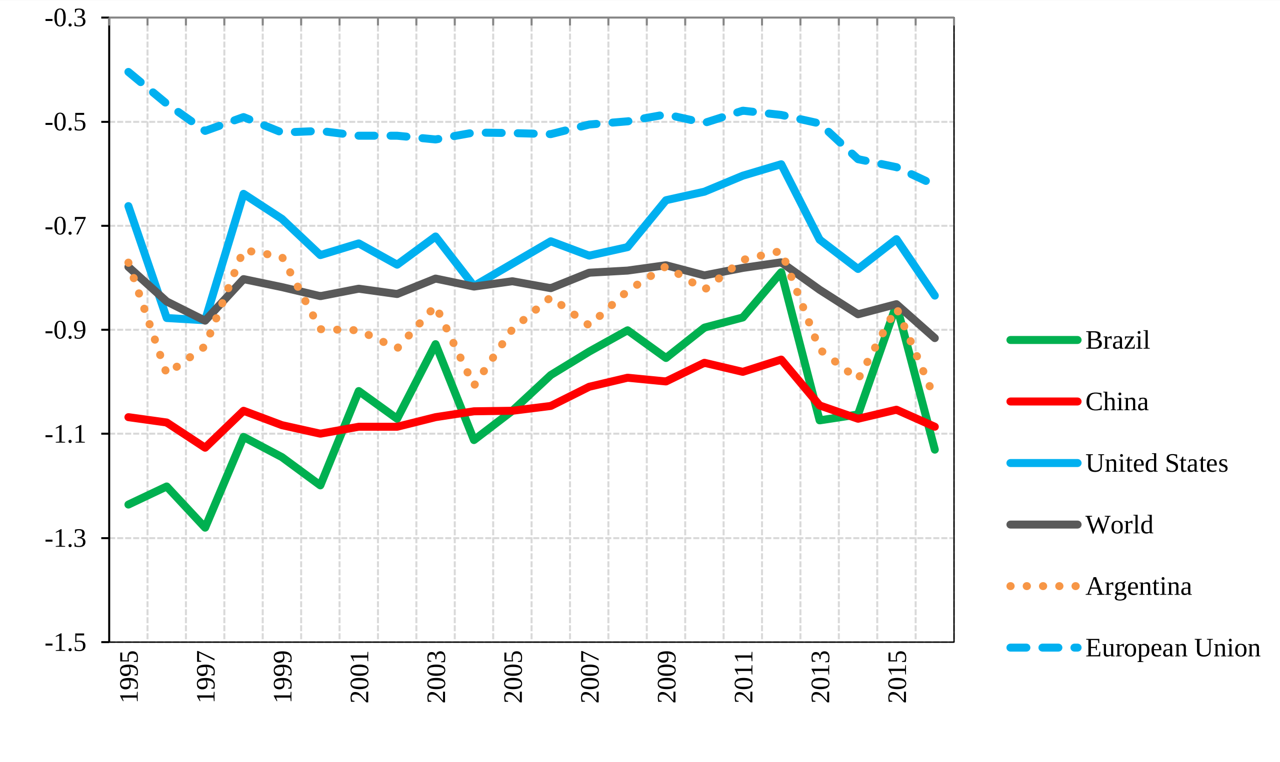

Figure 4: Evolution of agribusiness complexity index - selected countries
Source: Authors

After 2010 the Brazilian performance deteriorated significantly. Among the thirty largest exporters, the country recorded the second major fall in AgrPCI, being only ahead of Chile. This time was the culmination of a favorable conjuncture, shaped by the high prices of agricultural commodities[10]. Since 2010 the growth of agribusiness exports has been sustained mainly by the demand of low-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 the consumer trends observed in high-income countries which 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 can be attributed to the change in the composition of world trade. Soybean was the product that most contributed to reduce the world complexity of agribusiness products. Given the high share of the 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 poultry and corn. There are evidences to suggest that until 2010 the international conjuncture favored competition strategies via

[10] The increase in international food prices was one of the largest and most prolonged in recent history (International Monetary Fund, 2008) and is explained by a broad set of factors, ranging from average income and demographic growth in emerging countries to environmental restrictions for agricultural areas expansion and high levels of financial liquidity.

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 flows to developing countries (South trade).

4.3 Productivity in agriculture and complexity of agribusiness products

The results of AgrPCI indicator were consistent with the theory of economic complexity, adapted to study a specific sector. There is an evident positive correlation between the complexity of agribusiness products (AgrPCI) and agriculture value added per worker. In general, considering the largest world exporters of agricultural products in 2016, it is noted that leading countries in productivity (the blue point in Figure 5) are specialized in more complex products. On the other hand, large agricultural exporters that are not in the group of leading countries in productivity manufacture products with substantially lower complexity (the red points in Figure 5). 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 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., more complex productive structure, lower transaction costs, proximity to high-income consumer markets, institutional conditions) contribute to inflate their productivity in agriculture.

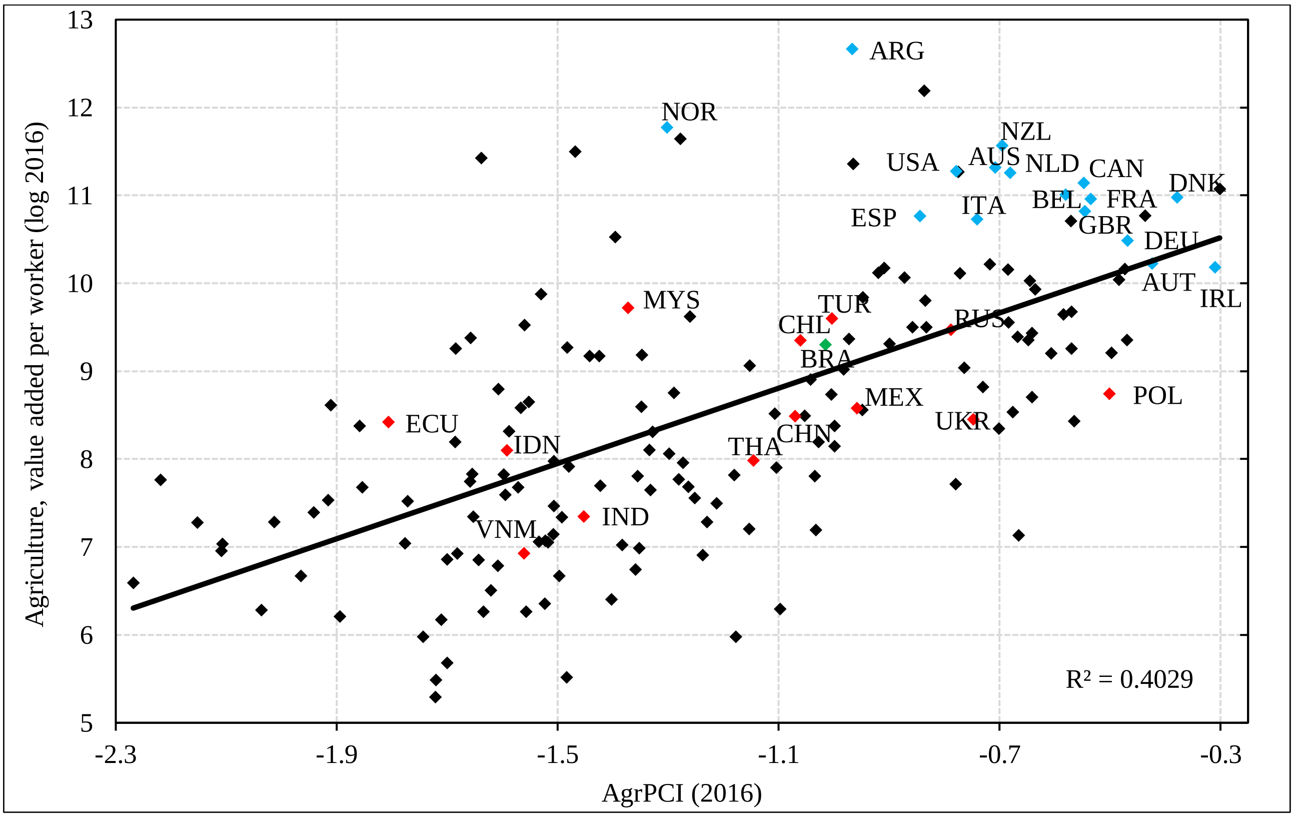

Figure 5: Agribusiness Complexity Index (AgrPCI) and value added per worker in agriculture - 2016

Source: Authors and World Bank (2018)

Note: All values correspond to three-year averages.

The comparative analysis of Brazilian exports with that of the countries that lead the ranking of labor productivity in agriculture reveals significant differences in terms of the diversification and composition of the export basket. While New Zealand, United States and Netherlands have a broadly diversified agribusiness exports and manufacture products mainly to final consumption, Brazil continues specialized in the supply of agricultural raw materials whose main attribute of competitiveness is the low production cost. Among the leading countries in productivity, New Zealand is the most specialized, however, this occurs in products of greater complexity, such as cheeses, butter, wines, meats, malts 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 products are similar to those in Brazil (soybeans and corn), but occupy a much smaller share of total agribusiness sales. On the other hand, in Brazil the trend has been to intensify the exports of an increasingly narrow set of products, especially the soy complex (Figure 6). By 2016, the eleven most exported agribusiness products accounted for 78% of Brazilian sales. In the Netherlands, to achieve the same share it is necessary to account for the 52 major exported products of agribusiness (The Atlas of Economic Complexity 2018).

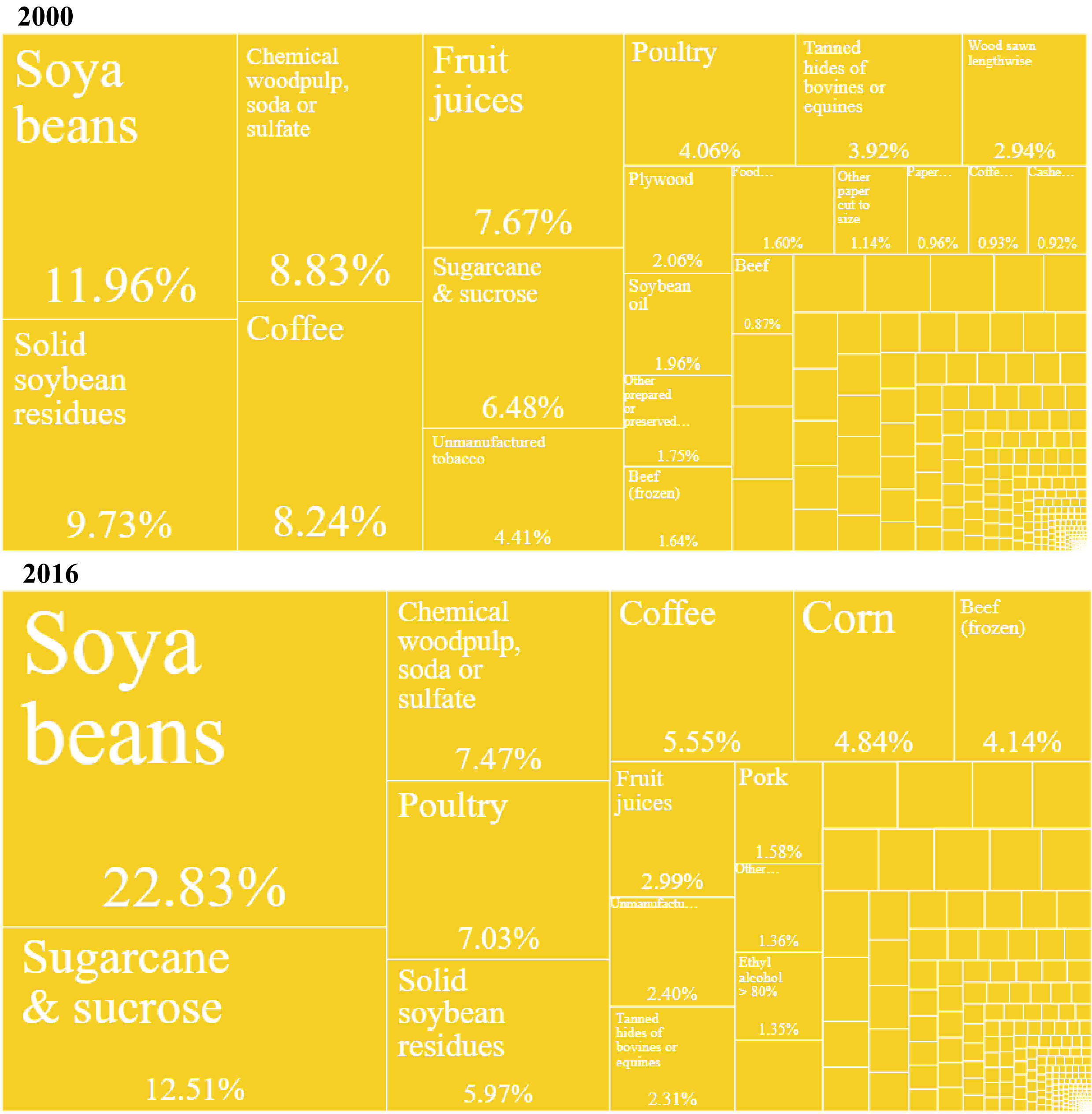

Figure 6: Brazilian exports of agribusiness products – 2000 and 2016
Source: The Atlas of Economic Complexity (2018).

Paradoxically, it was from 2010, when the complexity of its products declined, that the labor productivity more grew in Brazilian agriculture. 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 another countries (Figure 7).

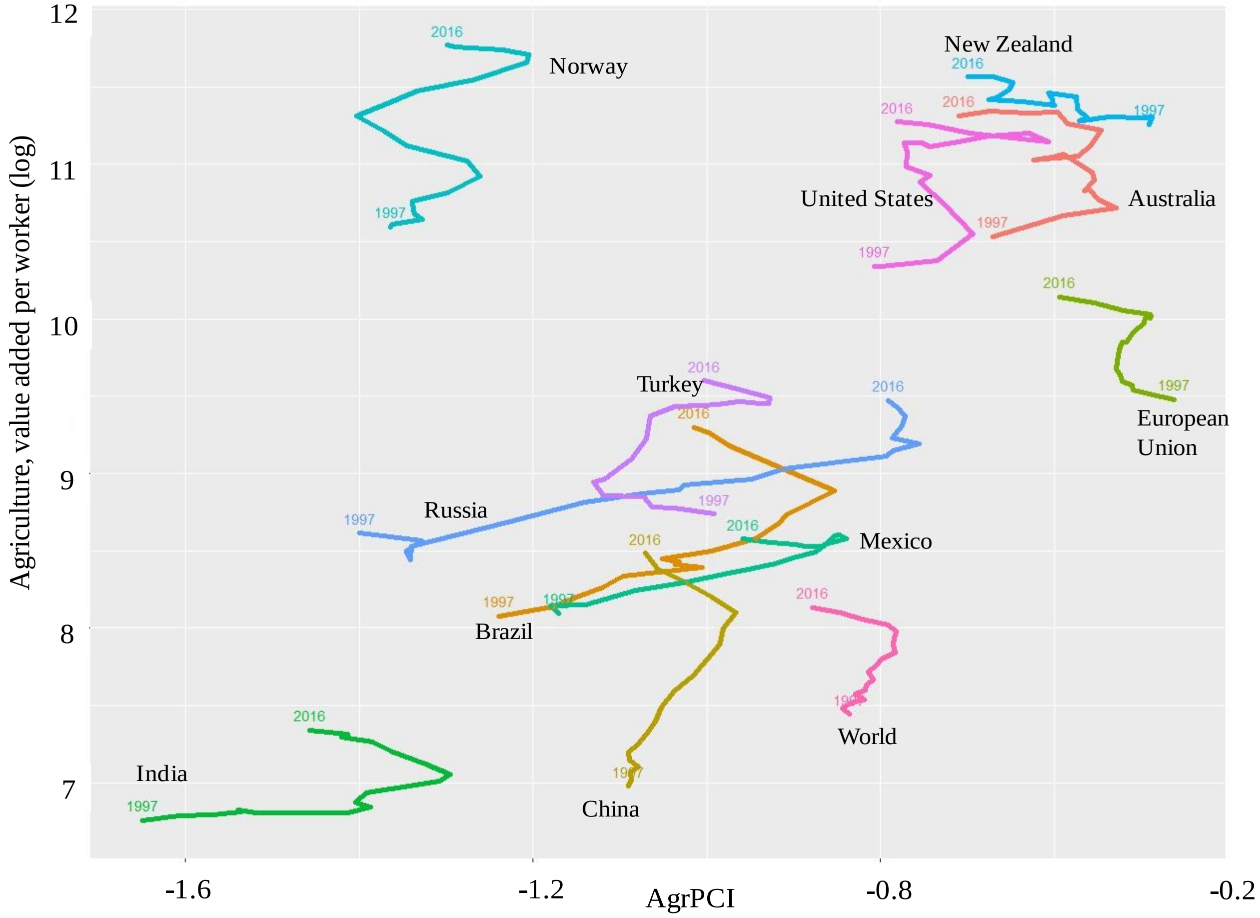

Figure 7: Productivity in agriculture and complexity of agribusiness products - changes over time for selected countries

Source: Authors and World Bank (2018)

Note: All values correspond to three-year averages.

If we consider the power of complexity indicators to predict the growth rate, that is not a good news. The theory predicts that less complexity today tends to result in value-added growth in the future, which can mean lower income for farmers. In fact, as previously mentioned, Brazil's trajectory in the recent years has been to concentrate its exports in a reduced set of agribusiness products. In addition, these products are of low complexity. Therefore, if the empirical relationship between economic complexity and productivity in agriculture is correct, this trend may jeopardize the 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 grow labor productivity 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 that undermines diversification. 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.

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 technological sophisticated as it is popularly widespread and that this situation is associated with the productive and technological development structures in the country.

Therefore, even though agro is pop, it is not appropriate to define it as high-tech, especially if the reference is the labor productivity and product complexity of leading countries. This recognition may constitute an important step towards the definition of a research and policy agenda oriented to innovation and building complexity in Brazilian agribusiness. This still needs to be built.

The application of economic complexity perspective to explain agricultural productivity differentials between countries constitutes the main methodological novelty of the article. There is no record in the literature of another attempt undertaken in this sense. Possibly, this is due to the fact that the authors aligned to the economic complexity approach focus their studies on the manufacturing industry and its segments most connected to the prevailing techno-economic paradigm. The results also offer robust new evidence that even within agriculture productivity growth is not product-neutral: specialization in products that are at the end of the complexity ranking seems to mean less possibilities of raising the average income in this sector.

Despite the complexity improvement during the first years of the series (1995-2010), the Brazilian exports continue to be dominated by low complexity products, which consequently limits the possibility of increasing productivity in agriculture. While United States and European countries have specialized in offering products that demand differentiated knowledge, accessible to a limited number of firms, such as Nestlé, Heinz, Pepsico and General Mills, Brazil has a leading role in commodity production, such as soybeans, corn and poultry. Competitiveness in these sectors is anchored in low production costs for the supply of standardized products, which in the long run usually means low profit margins and production scales incompatible with family farming..

Since 2010 the country has regressed and re-specialized in the supply of less complex 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 the analysis of the connections and proximities in the product space can show the country's opportunities for diversification based on what it currently exports, even in the case of products that are in the product space periphery, such as those that Brazil exports. In agribusiness sector the policies may be partly geared towards transition from low to high complexity products who are nearby to the first ones in know-how.

In this route of analysis, the local specialization in related activities can 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 the 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 still necessary the policy makers understand that the scientific and sectoral systems of innovation are important to determine their place in the product space and where they can reach. In this way, additional and strategically defined investments in agricultural R&D become important to break the technological standard and, most importantly, to expand the export activities by moving into export products that are related to their present portfolio and creating a wide range of related technology and developing "localized capabilities" that are regional intangibles assets with a high degree of tacit knowledge that are difficult to replicate in other places.

Some limitations and methodological weaknesses can be identified in the study. An important limitation, related to the method used in the analysis of economic complexity, is the impossibility of analysis at product level. Because the analysis was restricted to the product baskets (HS-4 chapters), we did not see the real product complexity, like Barilla pasta or the Haagen Daz ice cream, but its simulacrum. What we see are just pasta and ice cream and the difference in complexity between these product groups. Recently The Atlas of Economic Complexity has also recently released export data and complexity indices for the Harmonized System's six-digit level of detail (HS-06), which allows further analysis. Another way to circumvent this limitation is to consider price differentials between countries for the same product groups which can be done in future work. In addition, labor productivity differentials in agriculture may be derived from factors other than complexity. In Brazil the precarious logistics infrastructure decreases the prices paid to producers and raises production costs, for example. Finally, it should be noted that the value-added in agriculture is also affected by the countries' agricultural and tax policy, but this was not analyzed in sufficient depth.

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