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Techno-economic Evolution of Soybean Production in Brazil and Argentina

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Abstract

Brazil and Argentina, respectively the second and third largest producers of soybean in the world, consider this oilseed one of the most important products in their economy, whose significance is easily perceived in their commercial balance because, in addition to income generation, this product is also responsible for the creation of several jobs. Based on such a perspective, our research aim is to present the historical evolution of production costs and technological parameters (productivity) of soybean considering the most productive territories in Brazil and Argentina over 20 years. Our findings indicate that technology was the main relevant factor in the Brazilian case and, in Argentina, production cost. We also emphasize the great impact of exchange rates and market factors on the cases analyzed.

Keywords: agribusiness, production cost, productivity, soybean

1. Introduction

The economic liberalization occurring in recent times allows the exchange of many products and services among several countries in the world and with greater facility. Soybean is highly relevant in international business because it is a global agricultural product and benefits from an already established market.

Historically, agriculture and livestock production exerted a relevant influence on the economy of some countries, like Brazil and Argentina. The cultivation and incorporation of the soybean into the economy of both countries triggered a real transformation in the agricultural and livestock sectors (Pessoa, 2019).

Specifically regarding Brazil, the incipient cultivation of soybean in the past became in a relatively short period one of the main products of the national economy and in the commercial balance of exports in the country, placing Brazil in the first position of largest world producer with 138,153 million tons and with a productivity of 3,525 kg/ha in the harvest 2020/2021 according to a survey conducted by CONAB in April 2022 (CONAB, 2022).

Argentina, in turn, is the third-largest world producer; the estimated harvest for 2020/2021 was approximately 44.5 million tons (USDA, 2022). Thus, despite the differences and singularities between economic, political, and scientific trajectories, soybean production and market are extremely relevant for both countries. This way, the search for historical elements of the economic development encompassing the soybean sector in Brazil and Argentina allows the conceptualization of its historical evolution and the analysis of transformations that occurred.

Considering the importance of understanding and analyzing the historical and economic context of soybean in both countries, our study proposes to answer the following research question: Which techno-economic parameters determined the evolution of soybean production in Brazil and Argentina over the past 20 years (1999-2018)?

To answer this question, we intend to analyze historically and comparatively the techno-economic parameters of soybean production in Brazilian and Argentine territories over the past two decades.

We also present a few specific objectives, whose purpose is to help clarify the aforementioned research aim: to analyze according to the time series and geographic areas (territories) the production of soybean in both countries; to collect data referring to production costs and productivity in the selected areas and periods; and to carry out a historical and comparative analysis between conjunctural elements and the periods analyzed.

For such, we made use of some elements for conjunctural comparison that provide support for the historical perspective and relate to production costs and technological parameters (productivity) of soybean in three of the most important producing regions in Brazil—a north-western region of the state of Paraná, south-western region of the state of Mato Grosso, and the region known as Matopiba (which refers to the intersection between the states of Maranhão, Tocantins, Piauí, and Bahia); and in the most important producing region in Córdoba-Argentina—in the period that encompasses soybean harvests since 1999 until 2018 (20 years). For the accomplishment of the historical and comparative analysis, we used specific research methods.

By making such a comparison, we aim to better understand the reasons that lie behind the several pro-soybean movements in both countries. The article, therefore, provides a dynamic understanding of the creation and consolidation between the systems, and, to meet the research aim, we chose document analysis as a qualitative research approach, which will be carried out based on the conjunctural characteristics of each producing region in the above-mentioned period.

We present here, therefore, an analysis little or practically absent in the literature considering the comparative and historical territorial element in this work. Different studies allow the analysis of competitiveness or cost of soy production in territories between countries (Meade et al., 2016), but do not explore their comparison (Costa & Puricelli, 2009; Klein & Luna, 2021); others, however, do not advance to territorial analysis or do not emphasize the longitudinal (historical) aspect. Practically no study associates institutional aspects with the parameters of competitiveness or productivity, as explored here.

2. Soybean Farming Business in Brazil and Argentina

Soybean farming business is one of the most important crops for world economies, which is attributed to the development and structure of the international market, consolidation of the soybean as a relevant vegetable protein, and generation of new technologies that enabled the expansion of production in several regions in the world (Hirakuri & Lazzarotto, 2014).

In addition to its economic importance, studies have considered soybean production an important means to guarantee food and environmental sustainability of the planet, as a provider of protein for human consumption, and in the fixation of nitrogen in the soil (Lima et al., 2019; Jia et al., 2020; Islam et al., 2022).

Over the past few decades, the cultivation of soybean in Brazil and Argentina presented significant advances boosted not only by the increase of planted areas but also by the application of innovative and advanced management practices that allowed for an increase in productivity (Garay, 2015).

In Brazil, the soybean yield for 1985/86 was 1,369.4 kg/ha; in the crop year 2009/10, the production reached 2,927.0 kg/ha. The soybean production increased 114.77% over this period, with an expansion of the cultivated area from 9.6 million to 23.6 million hectares in the same period, as pointed out by Freitas (2011). According to CONAB (2022), the current Brazilian soybean production is 138,153 million tons with productivity of 3,525 kg/ha.

In Argentina, from a practically zero productivity growth from the 1980s until the 1990s, in the subsequent 10 years, the country's production increased from 12 million tons to 39 million tons in 2005; thus, soybean was responsible for 50% of all seeds yielded and represented 20% of all exports in the same year (Federizzi, 2005). In 2016, the country exported more than US$18,550 million of soybean products, which represents 32% of Argentine sales abroad, with a forecasted cultivated area corresponding to around 60% of the land (Bender, 2017).

Hence, slowly soybean gained ground and representativeness through the development of cultivars adapted to the different biomes, with techniques of soil management, reduction of acidity in the soil, balanced fertilization, and integrated pest management, among others. Such transformations enabled the soybean crop to show great potential under diversified climate conditions in the respective territories (Silva, 2018).

Soybean was originally cultivated in Brazil in the so-called traditional region, which encompasses the states of Rio Grande do Sul, Santa Catarina, Paraná, and São Paulo. Afterward, the cultivation spread into the so-called consolidated expansion region, comprising the states of Mato Grosso, Goiás, Minas Gerais, and Mato Grosso do Sul. The recent expansion regions that present great potential for growth comprise the states of Bahia, Piauí, Maranhão, and Tocantins, among others, which together form the “new agricultural frontier” for soybean cultivation, evidencing these areas in the national agribusiness scenario (Pessoa, 2019).

To carry out the historical comparison in this research, we selected the three most relevant regions in the production of soybean, namely: the north-west region of the state of Paraná, the south-west region of the state of Mato Grosso, and Matopiba.

In Argentina, the soybean spatial distribution has also changed over the years and, despite well-distributed cultivation, the traditional region of Córdoba was chosen in our analysis due to its strong potential and representation of national production.

Hence, the soybean has consolidated as the most explored crop in both countries and has presented increasing economic importance in overcoming traditional crops, such as coffee and cotton in Brazil, and boosting progress and development over the several cultivation areas.

One may observe, however, that a few variables affect the current positioning of soybean cultivation in the above-mentioned countries. The most cited ones in the literature are production cost and productivity; the latter occurs mainly through the technology adopted.

Every agricultural and livestock production entails some costs mostly related to seeds, fertilizers, defenders, machinery, technology, and workforce, among others. Based on the costs of agricultural production, it is possible to evaluate the efficiency and profitability of the production and the system used by rural producers (Richetti, 2016).

According to Menegatti and Barros (2007), analyzing and understanding production costs is relevant not only at the agricultural but also at the government level. From then on, the farmer can better allocate resources to obtain maximized results from a better understanding of production processes.

Thus, the agricultural expansion and the predominance of soybean crops in Argentina and Brazil are partially explained by the evolution of the relationship between costs and profit, which has made agriculture a viable activity in areas previously considered peripheral, and in many cases with better results than other activities (Paruelo et al., 2005).

In line with Cáceres (2015), agribusiness is still highly dependent on technology due to the pursuit of greater efficiency and productivity of the natural resources employed in production processes. This way, agricultural producers end up adopting some new technologies, such as the genetically modified soybean, as a way to improve product performance and enhance competitiveness; with open efficient management, these producers—and their respective countries—will be better positioned in a more globalized and competitive market scenario (Leitão, 2009).

As pointed out by Federizze (2005), the development of agricultural technologies for the soybean triggered the emergence of a set of cultivars with modified agronomic characteristics that promoted the growth and development of larger plants with higher yields and productivity, which allowed a greater efficiency for their use in human and animal nutrition, in addition to withstanding challenging environmental conditions, such as heat, drought, and humidity without losses in yield.

3. Material and Methods

Comparative historical research stands out as an opportunity to find—through time-space analysis—elements that lead to or justify a greater understanding of phenomena, adding information that an isolated analysis does not allow for perception. This way, it is necessary to delimit the place and time implicitly or explicitly (Ragin, 1987).

Mahoney and Terrie (2008) also suggest that research of this nature should be modeled over time by explaining the sequencing of change processes that affect the dependent variable and/or the analysis process of the effects of the trajectory on events.

In our study, time was limited to twenty years, considering the period of greatest evolution of soybean production in the territories analyzed. These territories comprise (1) the north-west region of the state of Paraná, (2) the south-west region of the state of Mato Grosso, and (3) the Matopiba region (*i.e.*, the intersection between the states of Maranhão, Tocantins, Piauí, and Bahia) in Brazil, and (4) the Argentine region of Córdoba (Figure 1). The purpose of this comparison is to identify the evolution of production costs and technological parameters of soybean production in these areas.

Legend: (1) Paraná, (2) Mato Grosso, (3) MATOPIBA, and (4) Córdoba

Figure 1. Location of soy production territories used in the survey

Source: Adapted from Google Maps (2020).

To achieve such a research aim, our study was segmented by a time-space division characterized by 'cases', as suggested by Ragin (1987) in this sort of analysis. Brisola and Guimarães (2015) add that studies based on case studies require the association and combination of patterns previously established.

After the collection of data and historical evidence, the information was grouped to identify the causes and effects of the variations in the product, production cost, and market dimensions.

After analyzing each case, we present a summary table classified by an impact intensity scale ranging from (*) low impact, (**) medium impact, and (***) high impact of the variable in the respective dimension, according to the quantitative and qualitative sensibility identified or perceived by the authors.

The study dimensions and variables are presented in Table 1.

Table 1. Study dimensions and variables

Dimension	Variables	Data Sources
1. Production Cost	(a) Exchange Rate (b) Agricultural Inputs (c) Labor (d) Logistics	Brazil: Companhia Nacional de Abastecimento—CONAB Argentina: Instituto Nacional de Tecnologia Agropecuária—INTA
2. Productivity	(a) Technological Variables (b) Climatic Factors	
3. Market	(a) Internal Policies (b) Foreign Policies	Brazil: Centro de Estudos Avançados em Economia Aplicada—CEPEA/ESALQ Argentina: Instituto Nacional de Tecnologia Agropecuária—INTA

Source: Research data.

We detail the dimensions and work variables used:

3.1 Dimension 1: Production Cost

Theoretically, production costs are defined as the sum of the values of all resources, that is, inputs and services, used in the production process of agricultural activity in a certain period, in the long or short term. In addition, production costs are linked to the efficient allocation of productive resources and knowledge of the prices of these resources, as well as on the quantity produced, or variables, which are directly related to the quantity produced (Reis, 2002).

In this study, the set of variable costs of soybeans in Brazilian (official data from the National Supply Company—CONAB) and Argentine (official data from the National Institute of Agricultural Technology—INTA) territories will be used as a basis for the analysis.

Therefore, the determining variables that make up this dimension are:

- The exchange rate: the establishment of prices paid for the products of the soy complex is strongly dependent on international conditions linked to the supply and demand of these products. Since the inputs for production are quoted in dollars, the increase in the exchange rate causes an increase in the price of inputs followed by an increase in the cost of production.

- The use of inputs: the number of inputs, such as seeds, fertilizers, etc., determine the cost of production. If fewer inputs are spent, the cost of production will also be lower, consequently, if more inputs are used, the cost tends to be higher.

- Labor costs are not treated as inputs, however, they are important in the elaboration of production costs, as the amount of labor used in production can make it more expensive or cheaper, according to the degree of mechanization of the crop.

- Logistics issue: the flow of production significantly affects the cost of production and impacts the international competitiveness of soybean exports due to the distances traveled, the mode of transport, the quality of these modes, and the losses arising from the deficiencies of these means.

3.2 Dimension 2: Productivity

Productivity has different names depending on the study area, but in general terms, productivity can be defined as the relationship between products and inputs (Gasques & Conceição, 1997). In agricultural production, productivity is thus an economic indicator that relates production values to the number of production factors used and is calculated by dividing agricultural production by the amount of planted area (Domingues, 2019).

In other words, productivity or average yield is a measure of the economic performance of a given agricultural crop. It is the quotient obtained by dividing the agricultural production by the planted area, that is, the average productivity is the amount of product obtained due to the most fundamental input of agricultural production, the area. It is, therefore, an important agricultural indicator, and its reduction, or even stability, arouses the attention and interest of all parties involved in the production process.

Therefore, considering soybean productivity, given in kilograms per hectare, official data from CONAB for Brazil and official data from INTA for Argentina were adopted.

The variables that are most decisive and that make up this dimension are:

- Technological variables: technological progress plays an important role in the development of advances that contribute to productivity and improvement in the quality of plantations.

- Climatic factors: excessive rainfall or drought, as well as temperature extremes, can affect crop performance, reducing productivity.

3.3 Dimension 3: Market

The marketing issue is a major influence on the amount of soy produced, so the monitoring of the price of Brazilian (CEPEA-ESALQ) and Argentine (INTA) soy, for years, and in dollars, will also be included in this work.

In this dimension, the main variables that influence markets are:

- Internal policies: government actions to promote and encourage production, such as reducing taxes on inputs, or the lack of such policies, are factors that influence soybean markets.

- External policies: the external scenario is also very decisive for the markets, as it generates impacts on the prices paid to producers, as well as on the prices of raw materials to produce soy.

As for the research sources, the following are the sites and publications from which the data and evidence were collected:

In Brazil:

National Supply Company (CONAB)

Institute of Applied Economic Research (IPEA)

Ministry of Agriculture, Livestock, and Supply (MAPA)

Brazilian Association of Soy Producers (APROSOJA)

Brazilian Agricultural Research Corporation (EMBRAPA-SOJA)

In Argentine:

National Institute of Statistics and Censuses (INDEC)

National Council for Scientific and Technical Research (CONICET)

National Institute of Agricultural Technology (INTA)

Ministry of Agriculture, Livestock, and Fisheries (MAGyP)

As it is a study based on documentary sources and with data and content analysis, the collection of data and information was developed by exhaustion and not by sampling.

3. Results and Discussion

3.1 Case 1—The State of Paraná, Brazil

The first case to be analyzed—Paraná from 1999 to 2018—refers to the productive territory located in the Brazilian state of Paraná. It is possible to observe in Figure 2 the fluctuation between the variable production cost and the productivity of soy in the period.

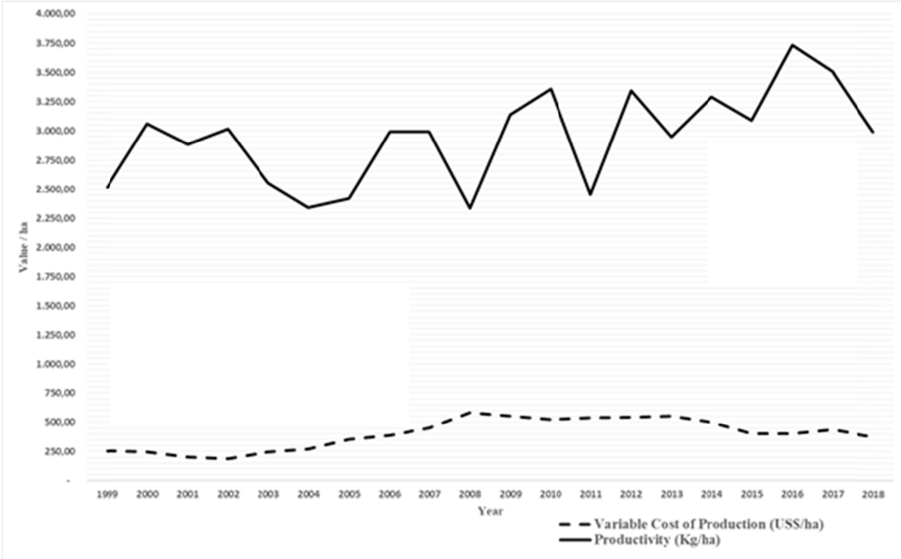

Figure 2. Paraná—production cost and productivity

Source: Adapted from CONAB (2019).

The first issue to be highlighted in Figure 2 is the intense variation in productivity and the slow growth of the variable production cost. One may observe a slight increase in productivity throughout the time series along with a drop in costs and a rise in productivity from 2011 onwards.

Several factors justify the growth in the productivity dimension, including technological advances, the availability of labor, agricultural research and experiments, the availability of rural credit, favorable climatic factors, and an increase in exports. These factors allowed for improvements in crop management, greater cultivation efficiency, and, consequently, greater productivity.

When looking at the production cost dimension in Figure 2, there is a more prominent increase in costs between 2000 and 2008, followed by a drop until 2018. The main explanatory variable of the cost dimension according to the analyses is the exchange rate and, consequently, the price per bag of soy. For this reason, we present Figure 3 below, which demonstrates the exchange rate versus national currency values.

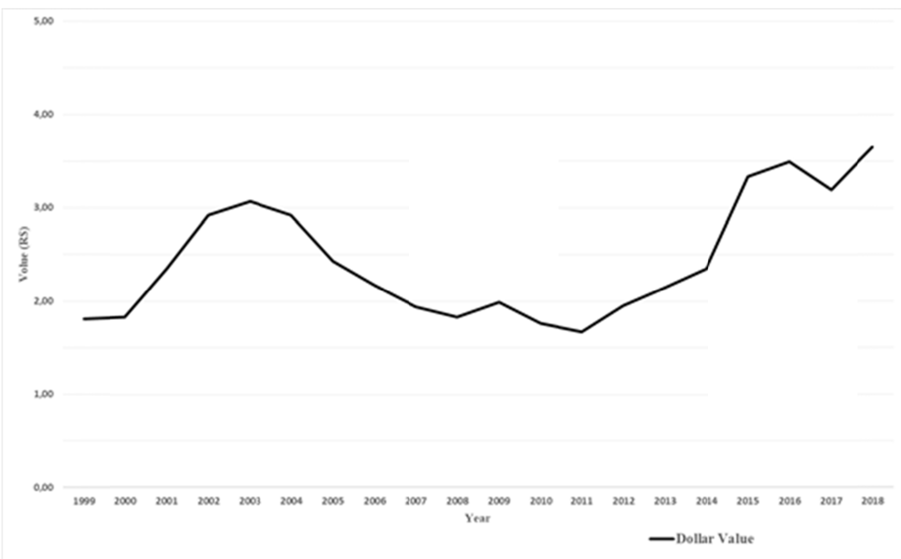

Figure 3. Dollar's appreciation against the real

Source: Research data.

In Figure 3 it is possible to notice the evolution of the value of the US dollar in Brazil, showing an increase at the beginning of the time series until 2003—where it reached approximately R$3; then there was a constant decrease until 2011. From then on, the exchange rate gradually increased until reaching R$3.50 in 2016, with a slight decrease in 2017 followed by an increase until 2018, when it reached approximately R$3.70.

As previously mentioned, several factors generate fluctuations in exchange rates. Considering the changes occurring in the exchange rate over the years, the historical evolution of the price paid per bag of soy in Brazil can be observed. Figure 4 indicates what happened with the territory dimension, as well as the main variables that were decisive in such a path.

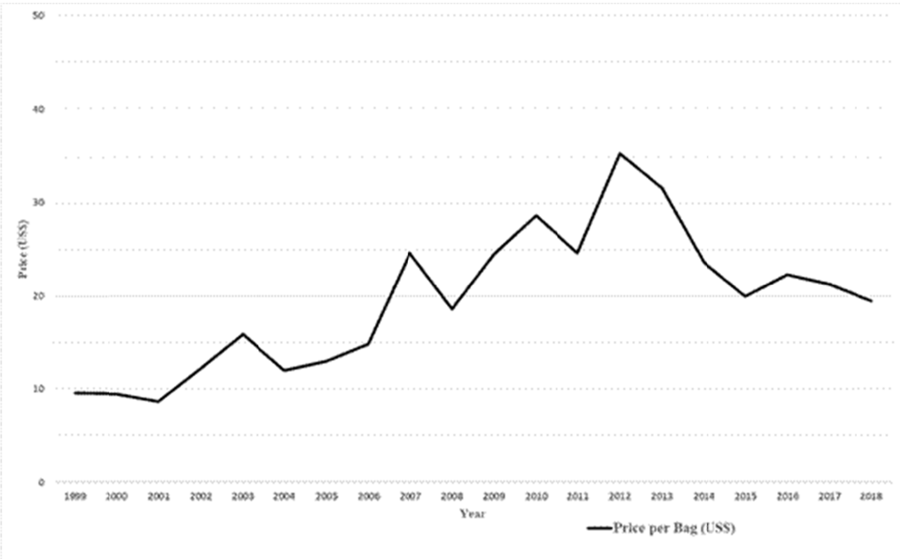

Figure 4. Price per bag of soy in Brazil

Source: Adapted from CEPEA ESALC (2019).

The establishment of the prices paid by soy-based products strongly depends on the international conditions related to the supply and demand for these products. There is, therefore, a trend toward the increase in the value of the cost per bag for soybean production; at the same time, there is an appreciation of the dollar against the real over the years. This relationship between variables is expected and justified by the fact that the price of the main inputs used—as fertilizers and pesticides—are quoted in foreign currency, which ends up encumbering the production of soy.

Accordingly, it is possible to understand that the establishment of the price of soybeans in the domestic market occurs from the outside in. In other words, the price of the seed in the producing region depends to a large extent on international prices, which, in turn, depend on the price of soy and its derivatives on the Chicago Board of Trade (Machado, 2010).

The market issue is influenced not only by foreign policies—through import barriers whether to favor a few countries or due to sanitary or phytosanitary issues, as occurred with the production of Brazilian meet due to the outbreak of the foot-and-mouth disease in 2005—but also by internal policies through tax incentives for soy production and access to credit, such as the Minimum Price Policy and Kandir law (Note 1).

One of the main causes identified as a determinant of international soy price movements is the Chinese demand. Thus, Chinese growth and its demand for soy, especially for swine feed production, influence these prices. The historical series (Figure 4) indicates that the price of the bag of soy increased from 1999 to 2003 due to the Chinese economic opening (the largest soybean importer) and the Argentine crisis between 2001/2002, which affected the exports from this country.

In addition to being influenced by the foreign market, the price of a commodity can also take into consideration other elements that affect production, such as climatic factors and seasonality considering the cyclical nature of agriculture production.

Table 2 summarizes the main variables that influence Case 1: Paraná from 1999 to 2018, classified by an intensity scale.

Table 2. Dimensions and variables of Case 1—Paraná

Dimensions	Production Cost			Productivity		Market	
Variables	Price, use of inputs, and labor	Exchange Rate	Logistical Factors	Technological Variables	Climatic Factors	Internal Policies	Foreign Policies
Case 1	**	***	**	***	**	**	***

Note. (*) Low impact, (**) Medium impact, and (***) High impact.

Source: Research data.

3.2 Case 2—The State of Mato Grosso, Brazil

The second case—Mato Grosso from 1999 to 2018—refers to the Brazilian state of Mato Grosso and indicates soy-related information between 1999 and 2018. In the middle of the 1990s, with investments in logistical infrastructure accomplished by federal programs through railway concessions and leasing port properties, soybean cultivation gained strength. Figure 5 indicates the comparison between the dimensions of production cost and productivity over the past 20 years.

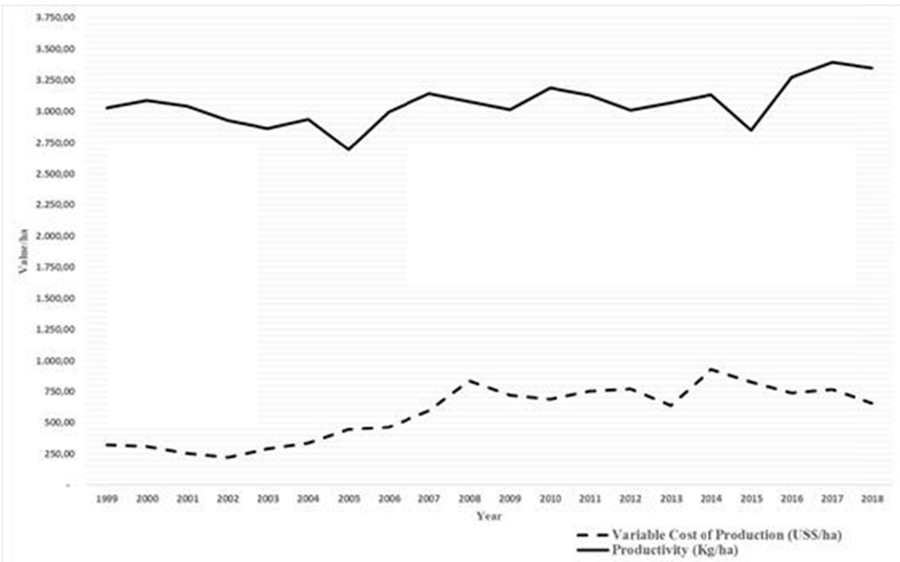

Figure 5. Mato Grosso—cost of production and productivity

Source: Adapted from CONAB (2019).

In this second case, the variable production costs (dashed line) remained relatively increasing throughout the period, especially until 2002, with a more significant increase until 2008 due to the United States subprime mortgage crisis. In the subsequent years, the costs remained stable and declined only in 2013, followed by a peak in production cost in 2014. Finally, it is possible to observe a slight decrease in costs between 2014 and 2018.

The most relevant variable, in this case, is also the exchange rate for the same reasons previously explained. There are, however, other factors that make Mato Grosso's production more expensive than Paraná's, such as the need for more correction of soil acidity, less favorable climatic factors, and, especially, the logistic issue considering there are long distances between the soybean field and the distribution of production.

In this territory, the variation of the productivity curve in the time series was lower than Paraná's, remaining between 3,000 and 3,250 kg of soy per hectare. Such yields stem from genetic improvements in agriculture (technology), emphasizing improved crop varieties and the use of more appropriate and precise chemical inputs especially designed for inhibiting pathogens or to promote better and more intense fertilization processes or improvements in productivity, shape, size, and color of products.

Regarding the market dimension, the variable internal policy is also relevant in this case. The rural credit intended for the costs of soy production went from R$1.4 billion in 1999 to R$12.2 billion in 2012 (Wesz Júnior, 2014); the cultivation of soy receives greater incentives. The market share of soy in Mato Grosso is even greater, considering the state absorbed two-thirds of the total amount allocated to rural credit, with just a bit more than 30% remaining for other agricultural products in the state (Wesz Júnior, 2014).

Considering the protectionism adopted by the Brazilian government, we understand its use was necessary at a certain time for the country to achieve self-sustained growth and generate economic development, allowing for leverage in economic development through the strengthening of mechanisms in internal production sectors (such as soy cultivation). Thus, the protectionist policy was successful when adopted during the transition from the production of primary agricultural products to industrialization, which involved protectionist instruments and economic development plans (Brisola & Braga, 2019).

Foreign policies, in the market dimension, are as important as internal measures in Case 2 because, considering that most of the production from Mato Grosso is destined for export—it represents more than 50% of the production according to IMEA (2015)—the political situation of the countries to which soy is destined (*e.g.*, China), the harvest of competing countries (*e.g.*, United States), or even trade barriers used by importing countries were always very relevant to the Brazilian soybean market. In line with Cunha (2008), in the exports from Mato Grosso between 1990 and 2006 the average participation of the soybean complex (soybeans, soybean oil, and soybean meal) reached 77% or US$1.8 billion—the total exports grew by 485%, of which only the soybean complex grew 462%, thus revealing how relevant the exports were.

Table 3 summarizes the main variables that influenced Case 2: Mato Grosso from 1999 to 2018, classified by an intensity scale.

Table 3. Dimensions and variables of Case 2—Mato Grosso

Dimensions	Production Cost			Productivity		Market	
Variables	Price, use of inputs, and labor	Exchange Rate	Logistical Factors	Technological Variables	Climatic Factors	Internal Policies	Foreign Policies
Case 1	**	***	***	***	**	**	***

Note. (*) Low impact, (**) Medium impact, and (***) High impact.

Source: Research data.

3.3 Case 3—The Matopiba Region, Brazil

Case 3—Matopiba from 2006 to 2018—describes a region considered the largest agricultural frontier of Brazil today. The area comprises 337 municipalities and covers approximately 73 million hectares. There are around 324,000 agricultural establishments in the area, 46 conservation units, 35 indigenous lands, and 781 rural settlements (Embrapa, 2019).

Figure 6 presents the variable production cost and productivity per hectare in Case 3, but only from the year 2006 onwards because the production of soy in this territory is still relatively new when compared to Paraná and Mato Grosso. It was only from this year onwards that official data regarding soy production started being disclosed.

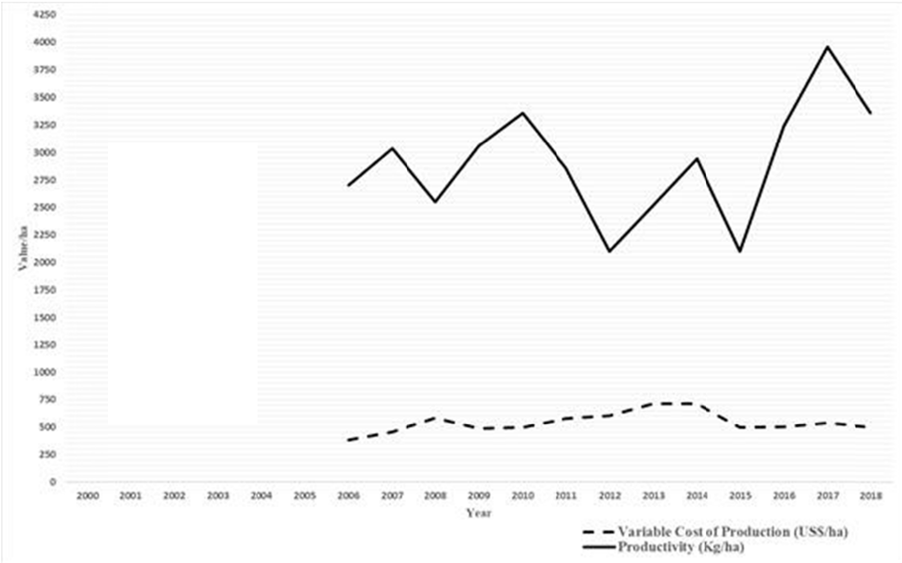

Figure 6. Matopiba—cost of production and productivity

Source: Adapted from CONAB (2019).

Regarding the productivity dimension, just like other regions of recent cultivation, the cultivation of soy had already begun (in Case 3) in a more technical way, with high yields; the availability of suitable lands for agricultural mechanization favored its intensification. Some favorable characteristics of the Cerrado—the biome that comprises almost the entire region of Matopiba—associated with lower land prices and the use of modern agricultural practices (technology variable) make the region more attractive for farmers from other states who aim at larger and cheaper areas for the development of large-scale agriculture (Porcionato; Castro; Pereira, 2018).

It is possible to observe in Figure 5 that the variation of productivity is much more intense in comparison to the other territories analyzed throughout the time series; there were peaks in production in the years 2007, 2010, 2014, and 2017, and decreases in production in 2008, 2012, 2015, and 2018, which result in a productivity variation of 2,000 to 4,000 kg per hectare.

In the production cost dimension, the region presents low values, showing little variation and close to US$500-600 per hectare. There were, however, two medium peaks in 2008 and 2013/14 due to the crises in the United States and Argentina, respectively; from 2015 onwards, one notices a more emphasized decreasing trend. One interesting point to highlight herein is that the cost presented by this region is lower than Mato Grosso's and sometimes even lower than Paraná's. This may be also a consequence of government investments in science and technology in the region, in addition to farm mechanization.

Thus, the only variable that presents more accentuated values is the exchange rate, which influences both cost and use of inputs. Labor is specifically cheap in the Manitoba region due to a great availability of workforce in the territory, however unskilled. As occurred in Case 2, logistics bottlenecks impair the cultivation of soy in the Matopiba region due to the difficulties in the distribution of production; the situation is, nevertheless, eased by the existing railway tracks used in the area.

Regarding the market dimension in Case 3, the variable internal policy had a very high impact. One relevant policy to be mentioned is the 2006 Agricultural and Livestock Plan, which ensured government support directly on the production of soy with the contribution of R$1 billion, in addition to interferences in exchange rates to benefit the complex (Brisola & Braga, 2019); such factors explain the curves observed in Figure 6.

In agricultural production, the credit provided for investments in machinery and equipment, and the cost of crops was essential. This was and continues to be an important government tool to promote production by expanding the agricultural frontier, such as Northeastern Brazil. Therefore, the agricultural credit was fundamental for Matopiba to reach the position it occupies today, *i.e.*, one of the most important grain-producing regions in the country (Bolfe et al., 2016).

Finally, the variable foreign policy must also be emphasized because, as occurred in the previous cases, the soy complex in the Matopiba region destines a good part of the soy production for exports. Brazil, in 2016, exported 67.2 million tons of soybeans and produced 113.9 million tons, indicating a growing trend of these numbers in subsequent years (Brisola & Braga, 2019).

Accordingly, the agricultural commodity prices adopted in the territory were directly influenced by global food prices and by the policies adopted, especially in the countries that massively imported Brazilian soy, such as China. Soon, external measures adopted to facilitate or hamper the acquisition of goods like soy affected the Brazilian market economy. The harvests from the main competing countries (the United States and Argentina) were also a factor of market impact due to the law of supply and demand.

Table 4 summarizes the main variables that influenced Case 3: Matopiba from 1999 to 2018, classified by an intensity scale.

Table 4. Dimensions and variables of Case 4—Matopiba

Dimensions	Production Cost			Productivity		Market	
Variables	Price, use of inputs, and labor	Exchange Rate	Logistical Factors	Technological Variables	Climatic Factors	Internal Policies	Foreign Policies
Case 1	**	***	**	***	**	***	***

Note. (*) Low impact, (**) Medium impact, and (***) High impact.

Source: Research data.

3.4 Case 4—The Province of Cordoba, Argentina

Case 4—Córdoba, Argentina, from 1999 to 2018—illustrates the situation of soy production in Argentina, more precisely, in the Córdoba region considering the variables production cost and productivity in the time series (Figure 7).

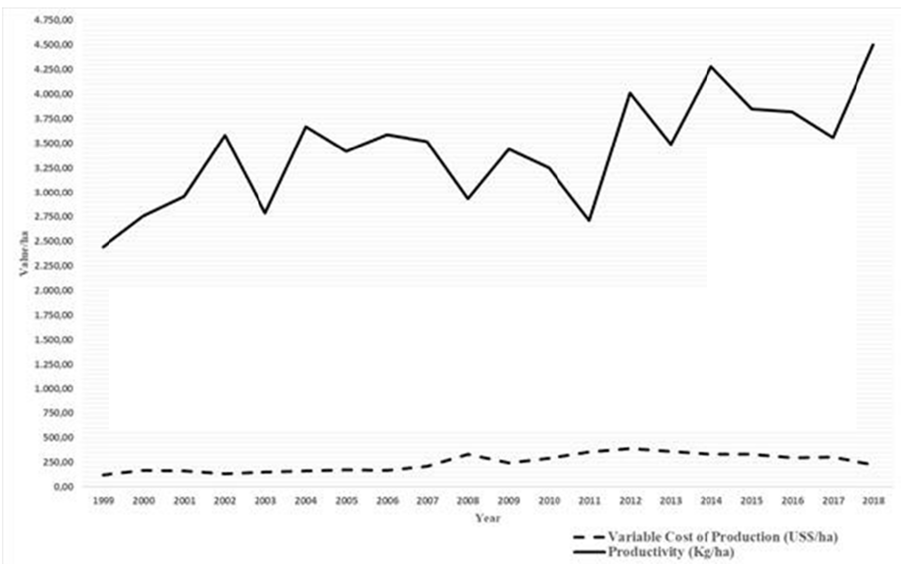

Figure 7. Córdoba—cost of production and productivity

Source: Adapted from INTA (2019).

In the Productivity Dimension, the curve presents great variations, but it is—in general—an increasing curve. There were production peaks in 2002, 2004, 2009, 2012, 2014, and 2018; and low productivity per hectare in 2003, 2008, 2011, 2013, and 2017. These variations stem from a few factors, such as technological capital, climate changes, and, especially, political issues, which will be approached later.

Thus, one of the reasons that help explain such productive yields is the technology variable due to the quick adoption by Argentine farmers of genetically modified RR-Soy, which allows—in addition to reducing expenses—a competitive advantage over competitors (Federezzi, 2005). It is therefore important to remember that the data used in our research on the productivity of Argentine soy are all related to genetically modified soy.

The Argentine data, according to the findings of Federezzi (2005), reveal that producers had an advantage of approximately US$30 per hectare due to the adoption of genetically modified RR-Soy; the farmers who had greater gains were those with properties smaller than 100 hectares.

Just as EMBRAPA in Brazil, in Argentina the INTA (Instituto Nacional de Tecnología Agropecuaria) must be emphasized as a research and development center for the development of agricultural and livestock technologies. The mission of the institute is to contribute to the sustainable development of the agricultural, agri-food, and agro-industrial sector through research and science outreach and promoting innovation and knowledge transfer to boost Argentina's economic growth (INTA, 2019). Therefore, INTA was a great generator and diffuser of technology in the territory.

It is worth mentioning the importance of the climatic factor, which is a determinant for productive yields. In some of the years of decreased productivity, such as 2009 and 2013, one of the reasons that caused such a drop was the lack of rain; rainfall amounts in the appropriate season is a very relevant aspect. In the years that indicate an increase in productivity, such as 2004, 2009, and 2012, the occurrence of rainfall occurred at the right moment and with an adequate amount, which enabled the crops to provide better results (Figure 7). Argentina is provided with favorable geography and edaphic factors (Brisola, 2014).

In the Córdoba territory, the curve of the variable production cost remains constant and tends towards a minim level; a small rising peak was however observed in 2008, but it did not exceed US$500 per hectare, which is much lower than the Brazilian variable costs.

As already mentioned in this article, the variable exchange rate has great explanatory importance for the production cost dimension because—just as in the Brazilian case—the prices of inputs are quoted in dollars—thus, if the value of the dollar rises, the cost of the bag also goes up. Therefore, the exchange rate also affects the price of the bag of soybeans according to the law of supply and demand. In Argentina, this market price is even more important due to the fully export-oriented production of grains in the country.

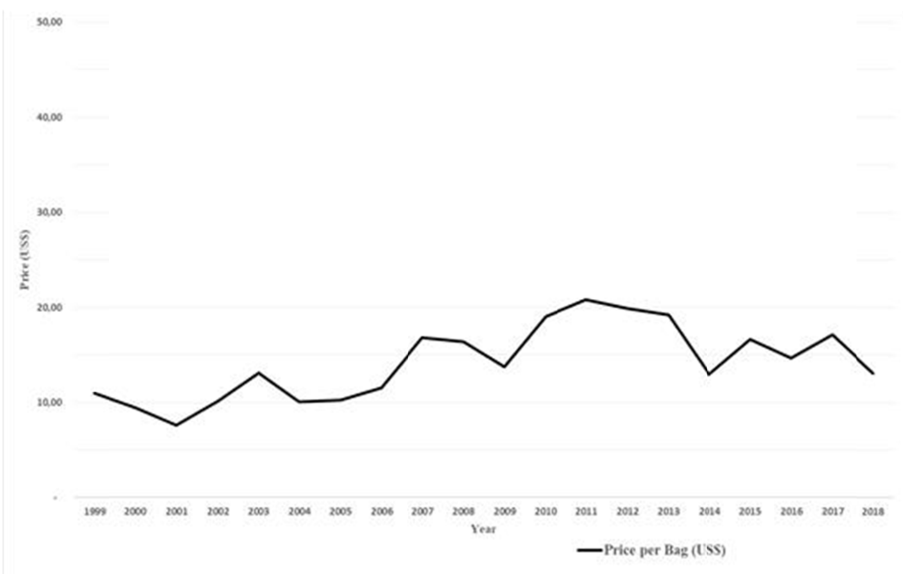

Figure 8. Indicates the fluctuations in the price of bags of soybeans in the 1999 to 2018 time series in Argentina

Source: Adapted from INTA (2019).

It can be noted that the price variation of the bag is not abrupt; despite the many problems faced by the country, the price presents only slight rises and falls. The price of soy in the region depends to a large extent on international prices, which, in turn, depend on the price of soy and its derivatives on the Chicago Board of Trade

(Machado, 2010). The highest soybean prices (per bag) were identified in 2011/12. The years that present price falls coincide with those in which financial crises occurred, such as in 2008/09 and 2014/15.

Argentina also benefits from the prices paid for pesticides widely used in soybean crops, which are cheaper due to the existence of larger quantities of generic products available in the market for a long. Thus, the competition triggered by the low value of pesticides used in genetically modified soybeans makes production even cheaper (Federezzi, 2005). It is worth mentioning that genetically modified soybeans were used in the country before the time series under investigation herein; therefore, all data on variable costs and productivity in this study refer to genetically modified organisms.

Another issue that contributes to the low cost is the variable labor—in Argentina, many producers outsource their activities and do not invest substantial amounts of capital in hiring human resources and in the purchase of machinery, which further reduces expenditures on production.

The good performance of the Argentine soybean complex is also related to more advantages acquired from companies operating in the country (in comparison with the main competitors, Brazil and United States): larger areas of land, shorter distance between production and processing areas, and shorter distance between these areas and distribution of production (Kosacoff, 2007). Hence, the other competitive advantage observed is closely related to the variable logistics, considering facilitated freight paths and shorter distances between the farm and the port.

The distance to be traveled by trucks and trains that transport the grains to agricultural industries usually does not exceed 300 or 400km with most of the harvest taking place within a radius of 200km. The opposite occurs in Brazil. For example, the distance from the soybean production in Mato Grosso to the Port of Santos is approximately 2,000 km; therefore, transport costs in Brazil are on average 94% higher than in Argentina (Bender, 2017).

In addition to road routes, the territory counts on a railway infrastructure of the Nuevo Central Argentino (NCA), which was designed in the 19th century to transport agricultural production. The favorable location of soybean crops, as well as the good storage capacity, allow a quick distribution and processing of production, reducing transport costs and benefitting from a better location than its competitors. Then, the production cost in Argentina is one of the lowest in the world (Figure 7).

There are also a few reasons and political situations that may explain such strong variations and instabilities observed in the cost and productivity curve, which are related to the market dimension. To understand them, it is necessary to give background information on Argentina's economic crises, considering they are relevant to explaining these variations and situations.

Considering that most of the exports in the country are agriculture-related, the national economy depends on this sector. Thus, when the exports of agricultural products fall, dollar inflows in the country largely decrease (Machado, 2010). It is possible to realize that the production of soy was shrouded in a scenario of uncertainty and instability; the production was affected by such a scenario because, considering that soy has always been destined for export, soy cultivation relied on protectionism and internal policies to promote the banking sector and the economy of the country (Brisola, 2014).

The main destination of Argentine soy is China, which since 2003 is responsible for 20% to 30% of the exported value, whereas in 1993 it did not reach 1%. The second main destination in Europe, which accounted for 22% of the total value of the soybean complex in 2013. India, Iran, Indonesia, and South Africa are also important markets for Argentine soy (Wesley Júnior, 2014).

Hence, the variable foreign policies also affect the market dimension because the agricultural prices adopted in Argentina were completely influenced by dollar value, as well as the policies adopted especially in the countries that massively imported soy, such as China and Europe. Then, the measures taken externally to facilitate or hinder the acquisition of commodities affected the Argentine market economy. The crop yields of the main competing countries (the United States and Brazil) also affected the Argentine market through the law of supply and demand.

Table 5 summarizes the main variables that influenced Case 4: Córdoba (Ar) from 1999 to 2018, classified by an intensity scale.

Table 5. Dimensions and variables of Case 5—Córdoba

Dimensions	Production Cost			Productivity		Market	
Variables	Price, use of inputs, and labor	Exchange Rate	Logistical Factors	Technological Variables	Climatic Factors	Internal Policies	Foreign Policies
Case 1	***	***	**	**	**	***	***

Note. (*) Low impact, (**) Medium impact, and (***) High impact.

Source: Research data.

3.5 Comparative Historical Analysis of the Cases

After conducting an isolated approach in each case, we will present in this section the comparison between dimensions and variables concomitantly. Figure 9 presents all variable production costs in the territories analyzed and the respective productivity within the time series.

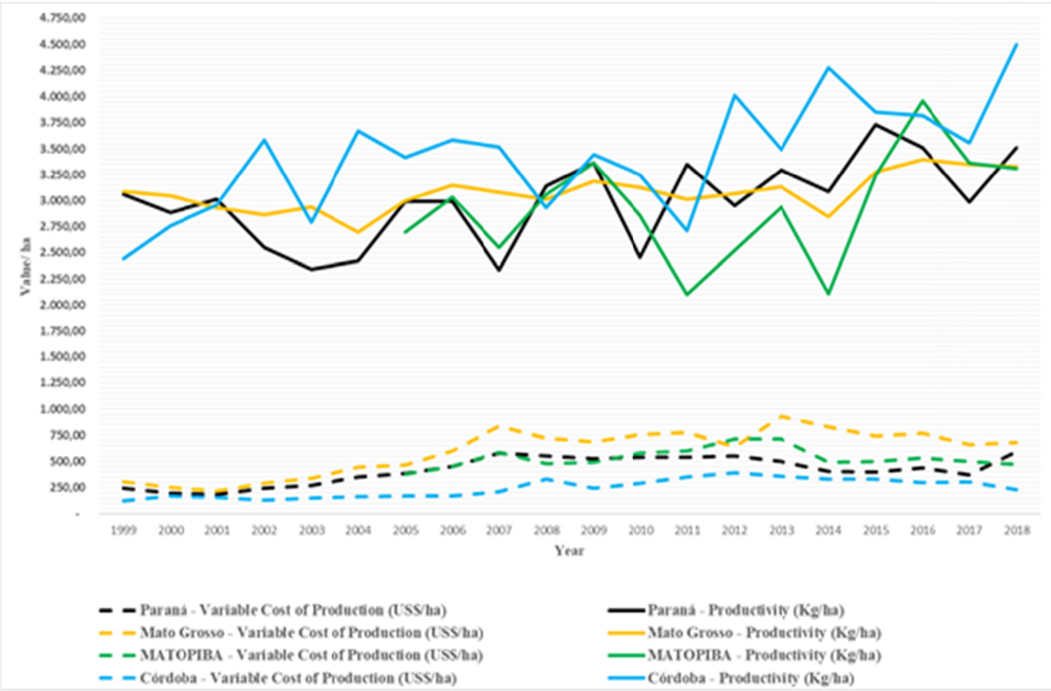

Figure 9. Paraná, Mato Grosso, Matopiba, and Córdoba—cost of production and productivity

Source: Adapted from CONAB (2019) and INTA (2019).

Also, by the information found in the cases analyzed, the influence of the price of bags is a very relevant issue that may affect production costs—due to the law of supply and demand—and, consequently, productivity. When overlapping the price of the bag of soy in the time series of both countries, Figure 10 is obtained.

Amongst the variables that influence cost, the fluctuation of exchange rates is one of the most relevant aspects to understand the functioning of the exchange-rate policy in both countries. Since 1999, Brazil adopts the floating exchange rate regime; therefore, the currency price is set by the forex market based only on supply and demand relative to foreign currencies—this regime is still in force today. Argentina, in turn, only adopted the floating exchange rate regime in February 2002—such change in the country's exchange-rate policy was implemented as a way of adjusting the economy to the continuous trade deficits (Copetti, Vieira, & Coronel, 2013).

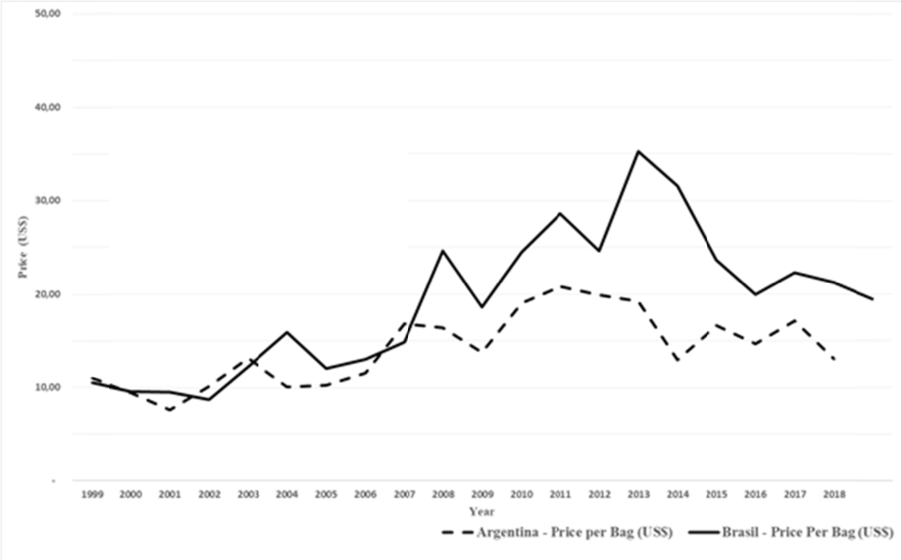

Figure 10. Brazil and Argentina—price per bag of soy

Source: Adapted from CEPEA ESALC (2019) and INTA (2019).

It is possible to observe in Figure 9 that the prices of the bags of soy are similar in Brazil and Argentina, especially until the year 2007. From then on, the price of the Brazilian bag increased, whereas the Argentinian dropped. In 2009, one observes that the prices of the bags in both countries dropped; in Brazil, the price was US$ 20 per bag, and in Argentina, 15. The same fact occurred in the years 2013/2014, which correspond to the Argentinian financial crisis. The years of greatest difference between the prices of the bag in these countries also correspond to the highest prices paid for the Brazilian soy, approximately US$35. From then on, there is a balance between both countries, tending to the reduced price paid per bag in 2018.

Generally, the price of Brazilian bags remains higher than the price of Argentine bags in the period analyzed. It is worth remembering that, in Argentina, there is no succession planting (soy/corn), which emphasizes the potential of the Brazilian soy production to reach higher levels than in other countries.

In the dimension of production cost, the impact of the variables price, use of inputs, and labor were considered medium in all Brazilian cases; in Argentina, the impact was considered high. The explanation for such an outcome is that in the latter case these variables are directly related to falling costs, which explain the relevance of price, use of inputs, and labor.

The impact of the variable exchange rate was considered high in all four cases since it is extremely relevant to explain the establishment of production costs because input prices are quoted in US dollars, as well as the bag of soy, according to the law of supply and demand. The comparison between the prices of the bag in Brazil and Argentina is illustrated in Figure 9.

The variation in exchange rates modifies the relative prices of tradable goods to domestic goods. In general, the devaluation of a country's currency lowers the prices of exports quoted in foreign currency. Brazil changed its exchange rate regime, which enabled the devaluation of the national currency in 1999; Argentina did the same in 2002 and migrated to the floating exchange rate regime. The effects of devaluation in Brazil—considering the international price of soy and the exchange rate—remained at the expected level for the period, implying the maintenance of high rates to replace pasture areas with soybean fields and the management of new areas that started being occupied (L. M. B. Sampaio, Y. Sampaio, & Bertrand, 2012).

The impact of the variable logistics was considered medium in Cases 1, 3, and 4; and high in Case 2. The high impact was observed in the Mato Grosso case (2) due to long distances and logistical difficulties found in the territory, which make production more expensive than in other regions. In Case 4, for instance, logistics is a factor that entails lower costs because in Córdoba the distance to be traveled between the soybean field and distribution is much shorter.

Copetti, Vieira, and Coronel (2013) highlight that Brazilian soy exports lose competitiveness with the United States and Argentina for presenting higher transport costs from the fields to the ports. The United States uses waterways to distribute most of its production, and Argentina uses highways, but with shorter distances to the port. In Brazil, in situations such as presented in Case 2, the distance to be traveled is above a thousand kilometers.

In the productivity dimension, the technology variable was considered a high-impact factor only in Brazilian cases (1, 2, and 3); in Case 4, the impact was considered medium. The reason for such finding relates to the emergence of agricultural technology in Brazil during the period analyzed; Argentina had already adopted genetically modified soybeans and, therefore, was more advanced in terms of technological progress. On the one hand, in Case 4, cost and political issues were more determinants than the technology variable. On the other, in Brazil, technological progress and applied research revolutionized the cultivation of soy in the country through genetic improvements in agriculture, no-till farming, improved and more effective planting techniques and management practices, and genetically modified organisms.

The variable climatic factors, in turn, are relevant for the planting and harvesting calendar in the main producing territories—climatic factors determine the best time to start seeds and the most suitable varieties of soy for a determined region and/or country. The main climatic factor that interferes with the yield of soybean crops is rainfall volume; during the entire soybean life cycle, the necessary rainfall volume must vary between 450mm and 800mm, depending on the variety of soy cultivated.

In addition, another factor of great importance that affects all phases of the crop is temperature; an average air temperature between 20 ºC and 30 ºC is appropriate for cultivation; 30 ºC is, however, considered the ideal temperature for crop development. The best soil temperature for germination and seedling emergence ranges from 20 ºC to 30 ºC; 25 ºC is, nevertheless, the ideal temperature for quick and uniform seedling emergence. The length of night (photoperiodism) is also a limiting factor for the development of the crop (IMEA, 2015). Thus, the impact of climatic factors was considered medium in all cases because, generally, it affected all territories in terms of productive yields; in other words, climatic factors were important for the development of crops but exerted less impact than other factors.

In the market dimension, we observed a few divergences in the variable internal policies. In Case 1, their impact was classified as a medium because in Paraná some policies, such as rural credit and the promotion of soy production, were significant, but less than in Case 3 (Matopiba), where these policies were of paramount importance for the expansion of soybean fields. In Case 2 (Mato Grosso), this variable had an only a medium impact because, as already mentioned, other variables exerted higher importance than internal policies in the territory; the investment of producers and agricultural technology, for example, was much more decisive to produce oilseeds in this region.

In Case 4 (Córdoba), the impact of internal policies was considered high because the political instability in the country affected soybean crops. Such a political scenario led to the devaluation of the national currency (with a 70% depreciation against the dollar in 2002) and resulted in a financial crisis followed by the collapse of the banking system. Even so, the agricultural sector reacted quickly. After the devaluation, many producers started using the product as currency: they would acquire machinery and inputs and "paying" for those with merchandise (L. M. B. Sampaio, Y. Sampaio, & Bertrand, 2012).

In the Brazilian cases, complementary policies to the production of soy were created to boost the production to feed the population and livestock. We also mention that in Brazil, from 2004 onwards, one of the main reasons for the increase in domestic consumption was the biodiesel because 2004 was the year in which the National Program for the Production and Use of Biodiesel was created, whose guidelines determined the mandatory blend of biodiesel (5%) and conventional petrodiesel (95%) (Wesz Júnior, 2014).

In Argentina, internal policies were more oriented towards protectionism, as well as financial protectionism for banking institutions, considering their troubled internal scenario. Even so, there are similarities between Brazilian and Argentine macroeconomic policies, such as stabilization, economic liberalization, and privatization, despite the different agricultural policies for regional development. The main similarity between the two countries, nevertheless, is the reduction of foreign trade tariffs (L. M. B. Sampaio, Y. Sampaio, & Bertrand, 2012).

Thus, the variable foreign policies were classified in all cases as having a high impact due to the export-oriented production in every territory under analysis. In Case 4 (Córdoba), there is a domestic demand for soybean meal used in animal feeds and mandatory use of biodiesel with soybean oil, especially after the creation of the national law no. 26093/06, which requires blend mandates for at least 7% biodiesel and/or bioethanol from 2010 onwards—even so, the country continues with its primarily export-oriented production. In the Brazilian cases, in addition to the predominant role of exports, the domestic market is still relevant for the consumption of soy and its derivatives (Wesz Júnior, 2014).

Consequently, the policies adopted by Brazilian and Argentine soy importing countries, such as trade barriers or promotion of imports with reduction of taxes, strongly influence the market of these countries. Some examples in this matter are the Chinese economic reform and the increased grain imports by Europe.

Table 6 summarizes the impacts of each variable on the dimensions analyzed in the four cases over 20 years.

Table 6. Dimensions and variables of the four cases

Dimensions	Production Cost			Productivity		Market	
Variables	Price, use of inputs, and Labor	Exchange Rate	Logistical Factors	Technological Variables	Climatic Factors	Internal Policies	Foreign Policies
Case 1 (Paraná)	**	***	**	***	**	**	***
Case 2 (Mato Grosso)	**	***	***	***	**	**	***
Case 3 (Matopiba)	**	***	**	***	**	***	***
Case 4 (Córdoba)	***	***	**	**	**	***	***

Note. (*) Low impact, (**) Medium impact, and (***) High impact.

Source: Research data.

Through the comparative historical research carried out herein in the four cases analyzed over 20 years it was possible to observe that the work dimensions - productivity, cost, and market- were influenced by variables differently in each territory; such influence relates to political, technological, climatic, logistical, and market factors, whose interference, to a greater or lesser extent, is strictly related to the aspects and contexts in which these variables are inserted. Cost, for instance, is a much more determinant factor in Argentina; in Brazil, technology was one of the most impacting variables.

Finally, monitoring the costs of agricultural production and productivity is essential to improve the management of productive activities. This way, it is essential that studies such as ours be deepened and developed, considering their importance in helping to understand and clarify factors that affect the production of soy. Further research is also necessary to understand how these factors also vary according to the respective scenarios in which the territories are inserted. In the upcoming section, we will present the final considerations of our research.

4. Conclusion

This research contributed to the analysis of techno-economic parameters that influenced the evolution of soy production in Brazilian (Paraná, Mato Grosso, and Matopiba) and Argentine (Córdoba) territories from 1999 to 2018.

Thus, our study is an imperative that can be used to potentialize opportunities to come based on lessons from the past, considering that comparative analysis brings new information and, consequently, the variables selected constitute an attribute that contributes to and supports the strengthening of the comparative historical research.

The main findings indicate that, in the product dimension, technological factors were more determinant in Brazilian cases (1, 2, and 3) than in the Argentine case (2), especially in Mato Grosso. Such discrepancy occurs because Argentina had already adopted genetically modified soy, whereas in Brazil it was only legalized in 2005—therefore, technology was a more relevant asset for Brazil in the time series analyzed. Climatic factors had a similar and milder influence on the cases, which indicates a lower impact of the variable in this dimension.

In the market dimension, foreign policies were very relevant in all cases analyzed considering that production is primarily export oriented. Thus, policies adopted in importing countries have a strong influence on the Brazilian and Argentine markets. Regarding internal policies, this variable had the greatest effect on the Matopiba region because these policies were necessary to expand the production of soy. In contrast, in Mato Grosso, this variable had less impact because the investments made by the producers themselves and technology were more determinant to produce soy. However, in Case 4 (Córdoba), despite the quick sector recovery, internal policies were extremely relevant during the period due to the political instability in the country, responsible for a 70% depreciation of the Argentine peso against the dollar. Thus, in Argentina, internal policies were more focused on protectionism, especially financial protectionism in the banking system, considering the troubled domestic scenario.

In this field, it is worth mentioning that the mobile withholding policies—a tax on production, where the price of soybeans varies according to international prices—adopted by Argentina affected exports and strongly influenced the agricultural commodities market in the country.

Finally, in the production cost dimension, the variable exchange rate was extremely relevant in all cases, since it is necessary to explain the establishment of production costs considering that inputs are quoted in dollars, as well as the bag of soy, according to the law of demand and supply. Price, use of inputs, and labor were more relevant in the Córdoba case because they significantly reduce costs in the region. The impact of logistical factors, in turn, was considered medium in the cases analyzed, except for Mato Grosso, where these factors are very relevant due to the long distances to be traveled between soybean fields and distribution, unlike Argentina, where distances are much shorter.

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Notes

Note 1. Kandir law (Lei Kandir, in Portuguese) refers to the exemption of ICMS, a tax on sales and services applied to the movements of goods, transportation, communication services, among others, for goods destined for export. The law was created to boost exports in the country.

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