Brazilian agriculture
Innovation and production distribution[1,2]

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Abstract – This study aims to analyze the evolution of Brazilian agricultural production from the 1960s to now. We will summarize some of the main findings from the historical view of Brazilian agriculture development. The arguments should rest here on how technical change and the national system of innovations have built an institutional environment to boost the agricultural sector, particularly in the past few decades. It is not easy to describe the path of Brazilian agricultural development, but organizing some important historical facts can help creating a full picture. The future challenge is to include marginalized farmers into the technology revolution. From the standpoint of public policy-making, the internal diversity of farming therefore requires specific actions to promote production and reallocate resources to the different segments and regions. There needs to be a clear policy for increasing technology absorption capacity, which entails making progress in rural extension outreach and education.

Keywords: agriculture, development, economic growth.

Agricultura brasileira: inovação e distribuição da produção

Resumo – O objetivo deste estudo é analisar a evolução da produção agrícola brasileira da década de 1960 até o momento. Faz-se um resumo das principais conclusões da visão histórica do desenvolvimento da agricultura brasileira. Os argumentos devem repousar sobre como as mudanças técnicas e o sistema nacional de inovações construíram um ambiente institucional para impulsionar o setor agropecuário, particularmente nas últimas décadas. Não é fácil descrever o caminho do desenvolvimento agropecuário brasileiro, mas a organização de alguns fatos históricos importantes pode ajudar a criar um quadro completo. O desafio futuro é incluir os agricultores marginalizados na revolução tecnológica. Do ponto de vista da formulação de políticas públicas, a diversidade interna da agricultura requer ações específicas para promover a produção e realocar recursos para os diversos segmentos e regiões. É necessário que haja uma política clara para aumentar a capacidade de absorção de tecnologia, o que implica avançar no alcance da extensão rural e na educação.

Palavras-chave: agricultura, desenvolvimento, crescimento econômico.

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Introduction

This study aims to analyze the evolution of Brazilian agricultural production from the 1960s to now. We will summarize some of the main findings from the work written by Vieira Filho & Fishlow (2017). The arguments should rest here on how technical change and the national system of innovations have built an institutional environment to boost the agricultural sector, particularly in the past few decades. It is not easy to describe the path of Brazilian agricultural development, but organizing some important historical facts can help creating a full picture[4].

In order to understand the economic view, one needs to discuss two different but correlated processes. The first relates to the source of knowledge, for which the case of Brazilian Agricultural Research Corporation (Embrapa), created in 1973, is an example of institutionally induced innovation (Hayami & Ruttan, 1985; Alves, 2010). The second is related to technology adoption and its diffusion. The innovation generated by public atmosphere cannot be understood as a separate step from the rural extension services and the educational system. Technology transfer is successful only when the role of public research organizations reaches the core of production units increasing the absorptive capacity (Cohen & Levinthal, 1989; Lundvall, 1992).

Brazil was a net importer of food in the 1960s. At that time, there was a pessimistic scenario in food production regarding the imbalance of the supply side (low productivity and food scarcity) and the demand side (fast growth of population and economy). Afterwards, in the following decades, research was conducted on improving degraded tropical soils, plant breeding, genetic engineering, integrated management of pests, intensive use of mechanization, and multi product diversification in the same harvest land.

Since the 1970s, development of agricultural knowledge and its effective use by local producers was central to the spread of productivity gains. From 1961 to 2012, the food production index increased more than eight times, while, during the same period, the size of the Brazilian population grew around 2.5 times. In 1961, the Brazilian population was around 75 million people. More recently the latest demographic census estimates the population at roughly 200 million. This means that Brazil increased its agricultural production *per capita*. This performance, consequently, helped to improve domestic food security and boost foreign trade.

The country became a net exporter and a global player in agribusiness. However, just a small part of producers benefited from this tropical agriculture revolution. Data shows, according to agricultural census, that from roughly 5.1 million of agricultural exploitations in 2006, only 10 percent of farms (medium and high income) generated 85 percent of the gross value of production. In contrast, 90 percent of farms (classified as in extreme poverty and low income) accounted for only 15 percent of production (Alves & Rocha, 2010).

This discrepancy is related to the diffusion process associated to market failures. While a small part of farmers was able to contract private technical consulting, around 4 million farm units were out of the market. Farms with small-scale production sell their output in the domestic market at a lower price and import input at a higher price. On the other hand, large-scale production offers its output into the international market at a better price and negotiates lower costs (inputs) with the supplier segment. It is clear that rural extension and education that connect learning and innovation to growth require closer attention through policy design in the years ahead.

This paper is organized as follows. The first section characterizes the theoretical approach based on the evolutionary theory. The following section presents the evolution of Brazilian production and shows us how a cluster of agricul-

[4] To deeply study Brazilian agriculture, we recommend a reading on several documents that were published in the past few years, such as Gasques et al. (2010), Buainain et al. (2014), and Vieira Filho & Gasques (2016).

tural technologies has changed the productive environment since the creation of Embrapa. The third section analyzes the production inequalities in Brazil as it is the biggest problem to be faced by the government in the forthcoming period. Finally, there are concluding remarks.

Theoretical approach

The idea that I will present here on production and agricultural growth relies on the evolutionary theory of economic change as supported by Nelson & Winter (1982). It is the core theoretical concept of my main studies, which I then apply towards the agriculture sector. On one hand, motivation for relying on the evolutionary theory lies in the traditional criticism of orthodox theory as being based on unrealistic and highly constraining assumptions like rationality, profit maximization, and market equilibrium. For example, the definition of agriculture by the mainstream theory as a sector that faces a kind of *treadmill effect*[5] is a very restrictive assumption as it implies that technological change would be given. Agriculture cannot only be understood as a sector that imports exogenous technology.

On the other hand, thoughts based on evolutionary theory examine industrial innovation and economic change under more realistic hypotheses. From my point of view, technical change is understood as a part of a process that begins outside the farm (external knowledge) but is increasingly embodied within the unit of production (Vieira Filho et al., 2005; Vieira Filho & Silveira, 2011, 2012). Nonetheless, there are also feedback effects from the unit of production that influence the parameters of technological innovations in the supplier industry, thus modifying adoption and diffusion of technology. Chiaromonte & Dosi (1993) developed a model to explain the learning process between the interactions of two sectors: suppliers and receptors of knowledge. The coevolution of sectors is at the heart of analyzing agricultural innovations. To support this argument, we should think differently about the learning process and the absorptive capacity of recognizing new knowledge in agriculture (Srinivas & Vieira Filho, 2015).

Technological competition for productive resources in the agricultural sector leads to persistent searches for innovations, characterizing an evolutionary dynamic enhanced by agents, and to higher regional concentration of capital. The science and technology play an important role in a dynamic context as well as in the importance of regional interaction and sustainable development. The main assumptions are: i) local learning determines regional growth in agriculture and ii) the development of social productive networks increases the spread of knowledge, thus raising productivity. It should be emphasized that innovation in the agricultural sector depends on an institutional framework that stimulates public knowledge and technological opportunities, as theorized by Lundvall (1992) through the concept of "national system of innovation". This is the example of Embrapa. In addition, the producers'

[5] Pure, or perfect, competition embodies very restrictive assumptions. On this basis, Cochrane (1958) develops a model of technological change in agriculture. Innovation results in a reduction of cost and a shift up in the production frontier. Likewise, with the same amount of inputs it is possible to produce larger output moving the supply function to the right. Total economic welfare increases as a consequence of technological progress. Its allocation between producers and consumers depends on supply and demand price elasticities. If producers are able to increase profit by larger sales and thereby compensate for the decline of revenue by a fall in price, their welfare will increase. Consumers will also gain because their consumption will be at a lower price. When demand elasticity is zero, a large decline of price cannot be compensated by any increase in sales. So there is a sharp fall in total revenue resulting in a net loss to producers. In this extreme case, the entire welfare increase is transferred to consumers paying a lower price for the same quantity. Technological change does not benefit the adopters; the only beneficiaries are consumers. When introduction of new technologies increases the quantity supplied and pushes down product prices, producers seek innovation in order to reduce their production costs. First movers and early adopters gain profits. As innovation diffuses more widely, the supply curve shifts to the right, price falls and surplus profit disappears. Laggards incorporate new technology unless they decide to leave the market. To sum up, farmers unable to keep the running on the treadmill are expelled from agriculture. They move to urban areas and to the nonagricultural sector. This process helps industry and services in urban areas by lowering wage cost. In a subsistence economy, the treadmill effect transfers welfare to producers by augmenting the quantity consumed on each family farm. To develop agriculture as a business, investment in new knowledge is crucial to increase production. Mainstream economic analysis assumes that technical change is largely an exogenous process.

absorptive capacity of accumulating knowledge determined by site location also drives innovation in the agricultural sector.

Technical change is the main source of growth in the economy. Agents search for innovations to build new products (creating monopolistic market and increasing profits) and to create new knowledge or technologies (expanding efficiency and saving productive factors). According to Dosi (1984), the concept of industrial *filières* (or productive chain) illuminates a system of interdependence based on input-output and technological relations. The adoption of new technology is based on previous accumulated knowledge as well as on a mechanism of experimentation that, once successful, influences the diffusion of this new technology. The diffusion process is important to the supplier segment in order to increase sales and expand profits. When adapting the new technology into specific regional productive conditions, the interdependency between the unit of production and the supplier industry is defined by the exchange of information (Vieira Filho, 2012).

On the opposite side, the definition of agricultural activities by Pavitt (1984) as a *supplier-dominated sector* suggests that technological change would be not internally generated. It should be recognized that not all technological development and new knowledge in agriculture come with the acquisition of inputs offered by outside agents. To support the alternative ideas, as stated by Vieira Filho et al. (2005), as well as by Vieira Filho & Silveira (2011), the learning process and the absorptive capacity of recognizing new knowledge in agriculture should also incorporate endogenous processes. It is quite similar to the approach discussed by Cohen & Levinthal (1989).

The innovation process in agriculture (adoption and diffusion of technology) is organized through complex production systems in the productive chain. Foster & Rosenzweig (1995) have demonstrated how agricultural sectors with imperfect knowledge about management of the new seeds developed significant barriers to adoption, and how these barriers diminished simultaneously as farmers' experience with the new technologies increased. These are some comments sustaining the focus of this study.

We shall address the following questions: How was the creation of Embrapa an example of institutional induced innovation? Can public research increase the absorptive capacity of agricultural firms? Can local learning influence regional growth? How is this growth linked to learning and dissemination of knowledge? Can productivity growth be applied in different Brazilian regions and how? What kind of solution could be addressed to deal with production inequalities in the near future?

To answer these questions in a comprehensive manner, we focus on the explanation of the learning process and the absorptive capacity of recognizing new knowledge. Investments in research and experimentation activities in the unit of production increase the farmers' ability to exploit external knowledge, which is a critical component of innovative capabilities. The theoretical framework of innovation may be essential to show the importance of agricultural production in Brazil. However, this thinking cannot explain a huge inequality where a great number of producers are excluded from the market. The marginal producers do not incorporate technology. Furthermore, they face market failures, and need different innovation policies to evolve.

Technological clusters in tropical agriculture: the case of Brazil

Brazil used to be a net importer of food until the 1980s. However, over the past fifty years, intensive use of science and technology resulted in dramatic gains in productivity. Even though technological breakthroughs have played an important role in production, the green revolution cannot be understood solely as a transfer process of technology. Induced innovation based on local institutional change was central to Brazil becoming one of the world's largest food exporters.

Brazilian agriculture is a good case study to understand that green revolution cannot be a process separate from local transformations. Brazil was one of the few developing countries that incorporated external knowledge from international research centers to adapt new information to tropical conditions. Evolve from net food importer to self-sufficiency in the domestic and external markets, institutional changes were essential to promote research and development in the tropical agriculture. Technologies created by developed countries could not easily be adapted to the Brazilian environment. By the time, agricultural production suddenly changed. During the 1960s, there was less diversity of crops and livestock production as well as high risk of food insecurity. Since the middle of 1980s, Brazilian agriculture has experienced a huge expansion in its economic indicators.

In the 1970s, policy makers were aware of the production problem and they decided to invest in research and rural extension services. Embrapa was created in 1973 to provide solutions for research, development and innovation in agriculture in order to avoid an imminent domestic food crisis. Public investments were oriented to establish the system of technical assistance and rural extension. Institutional changes were responsible for creating national strategies (top down and universally) and for funding policy design at the state level. The main objective was to offer knowledge applied to tropical conditions, as well as essential rural extension services to producers.

While Embrapa was the core of innovation, a technical assistance system was responsible for the diffusion process to connect farm units with applied knowledge generated by research centers. In the beginning, the executive board of Embrapa invested in human resources and then decided to decentralize research centers in different parts of Brazil. It was important to improve applied research to deal with local reality. In 1975, a branch of Embrapa specializing in soybean crops was created in Paraná state. Nowadays, there are 46 decentralized units spread around the country, and divided by crop, regional environment and agricultural themes. In 1973, there was a predominance of workers without post-graduation. In 1978, this situation was reversed, increasing the share of researchers with master's degree. Since then, the evolution of PhD researchers has increased continuously, while, in 2000, this group became the most relevant in the total research staff. In 2013, there were more than two thousands PhD scientists, representing 83 percent of the scientific team. In a comparison, as noted by Correa & Schmidt (2014), the main agricultural research branch in Argentine (INTA) employed about 2300 researchers, in which less than 20 percent hold a PhD. Embrapa's success would not have been achieved if agricultural exploitations had not absorbed the new knowledge to raise productivity and reduce production costs.

Around the 1980s, development of agricultural knowledge and its effective use by local producers was central to productivity gains. Research was conducted in three main fields: i) improvement of degraded tropical soils; ii) plant breeding and genetic engineering; and iii) integrated management practices. To summarize several clusters of innovation linked to these institutional changes, Vieira Filho & Fishlow (2017) pointed some of them out to give an idea of the impact on national production:

1) Agricultural liming technique turned the acidic soil of the Cerrado into arable land. Cerrado is a biome quite similar to African savanna. For a long time, Brazilians farmers had referred to this region as "*campos cerrados*" (or closed and inaccessible land), because of inappropriate soil characteristics (with high acidity and aluminum levels) to sustain agricultural production. As land is a scarce resource and the potential for growth is restricted, the expansion of the agricultural frontier toward the Cerrado turned into one of the most productive and attractive marginal lands worldwide. From 1955 to 2014, the Cerrado incorporated more than

40 million hectares from only 200 thousand hectares of arable land. The Midwest became the most important region in Brazil to produce grains and livestock. In the same period, the regional Midwest share of gross value of total agricultural production went from 6 percent to almost one third (1/3). The largest growth of this share occurred after the 1990s. In 2011, Midwest exceeded its production compared to traditional regions, such as South and Southeast. Ranked as the third region in national production in the 1960s, Northeast lost ranking over time, from 24 to 13 percent. This region remained behind in the technological development;

2) The "tropicalization" of the soybean crop, in which seed varieties became more tolerant to tropical climates (drier and warmer at lower latitudes) with a lifecycle shorter than the traditional plant, enabled two harvests per year. Starting in 1976, the corn planting after the 1st soybean crop was called "*safrinha*", which means small harvest. In the beginning, it was a residual production, with a low quantitative importance and a high market risk. The *safrinha* planting provides a better use of soil, and represents a national comparative advantage against international competitors. In the past, the *safrinha* production involved only Paraná and São Paulo. Later, with learning advances over time, production expanded to Mato Grosso do Sul, Goiás, Mato Grosso and Minas Gerais. The expansion of *safrinha* was attributed primarily to the need of corn consumption on the farm unit, and to domestic demand in the production of pigs and poultry. Afterwards, as production was given in a more favorable season because of shorter lifecycle of soybean seed, the economic return increased. On one hand, the final price of corn became better, once the productive supply was reduced in the off-season. On the other, the costs were smaller, since the seed planted came from the previous harvest that was purchased at a lower price. Another factor was that fertilization carried out in 1st harvest still remained in the soil. In 1980, *safrinha* represented less than 1 percent of the total production (79 thousand tons). In 2001, when the production of corn began to grow exponentially, its share hit close to 12 percent (or 3.9 million tons). In 2011, *safrinha* production became superior to that in the 1st crop. The diminutive term – *safrinha* – lost its reason to exist. The vigorous harvest has achieved a status of 2nd crop, which reached roughly 54 percent, or equivalent to 39 million tons. In 2014, total production of corn (1st plus 2nd crops) reached 85 million tons, with approximate *safrinha* share of 64 percent from total corn production;

3) Biological nitrogen fixation is a technique that has been adjusted to Brazilian tropical conditions. It offers a natural means of providing nitrogen for plants, an essential nutrient for plant growth in a farming system. The inoculation of bacteria on soybean seeds that capture nitrogen from the soil allowed more production with less fertilizer use, contributing to higher yields per hectare. This technique has boosted not only the rapid growth of soybean production in Brazil but also the development of Proálcool – the biggest bioenergy program to substitute oil in the 1970s worldwide. The economic result would be enough to recover all the investment in the creation and consolidation of Embrapa. For example, in a production of 27 million hectares of soybeans, the necessary parameter for nitrogen fertilization without fixation would spend a surplus annually to nearly US$ 7 billion. Therefore, this technol-

ogy enabled resource savings, providing cheap and healthy foods to society;

4) The no-tillage system was developed to differ from the traditional techniques of soil tillage that were practiced in temperate climate farming. The organic material left in the soil becomes rich natural fertilizer, arising from decomposed straw in the previous harvests. The advantages are a less use of agrochemicals and a better control of the erosion process. Therefore, it can save water and reduce carbon emissions. With more than half of cultivated land, Brazil has become a reference in using this kind of system. It is an innovation process that results in competitiveness gains, particularly in the conservation of natural resources. In 1973, the no-tillage planting began with 180 hectares, but only since 1990 has the system intensified. In 1995, this innovation process was applied in 3.8 million hectares and, in 2012, 31.8 million hectares. Particularly in the soybean crop, planted area already represents around 90 percent nowadays;

5) The enhancement of pasture by a *Brachiaria* breeding[6] transformed the Cerrado into a region with high-yielding livestock production and reduced the average time to slaughter an animal. At the same time, it expanded the international competitiveness of Brazilian beef exports. The livestock production growth in Brazil depended on pasture land expansion until 1985. Subsequently, this growth was based on animal performance (carcass weight) and stocking rate (animal head per hectare). Currently, Brazil has become the second largest exporter of beef worldwide;

6) High-yield seed varieties were developed in the 1980s to be more resistant to diseases, reducing crop losses and expenditures on insecticides. In the 1990s, the diffusion of planting genetically modified (GM) organisms has grown in the world. In Brazil, GM soybean was illegally planted for the first time in 1997. The legalization of planting GM varieties occurred later: soybeans in 2003, cotton in 2005, and corn in 2008. The legalization of GM cropping spreads the use of biotechnology in Brazil. In 2011, Embrapa produced the first variety of GM beans, a basic food of Brazilian culture and an important crop cultivated by small farms. The planting of GM organisms simplified management and agricultural practices, reducing the use of herbicides and pest controls as well as increasing income. In 2014, the area planted with GM varieties of soybean, corn and cotton was, respectively, 93, 83 and 67 percent, high standards by international comparison. According to the national system of property rights in Brazil, as studied by Vieira Filho & Vieira (2013), in 2012, the accumulated amount of protected seeds counted for 1708 varieties in different crops. The share of Embrapa in this number was about one third of the properties. The percentage share of Embrapa was also significant when analyzing the crops separately: soybean (29.3), corn (86.3), and cotton (46.7);

7) As a result, with a new frontier for production, the marginal price of land was to a large degree kept down by competition facilitating a large scale introduction of mechanization together with geographic characteristics such as flat lands and pattern suitable rainfall. So it

[6] As viewed by Correa & Schmidt (2014), this breeding was a result of crossbreeding between an African grass called Brachiaria and a native grass, many times more productive than native species and three times higher than the African plant. Related to this, the time to slaughter was reduced from four years to less than two (around 18 and 20 months).

was possible to expand the agricultural frontier toward the Midwest in the Cerrado and sustain Brazilian production of agriculture and livestock at international levels of productivity. Mechanization in agriculture has increased, as shown by a significant reduction of crop area per tractor. Not only are more vehicles used, but their power has increased;

8) Finally, migration played an important role on learning and diffusion process of technology. Accumulated knowledge by agents in the South was essential to improve productivity in the new agricultural frontier. The capacity to answer productive problems combines, on one hand, agents' experience and, on the other hand, investment on research and science.

The Cerrado covers an area of 204 million hectares, nearly 24 percent of Brazil's surface (or even a size 34 percent larger than the Corn Belt region in the United States, 73 percent of all the Argentine territory or equal to 3.7 France). The expansion of Brazilian agriculture follows the Cerrado region over time, spreading agricultural production from South to Midwest and Northeast more recently. Before the 1980s, the land was incompatible with most crops and large-scale production of food. By the 1970s, the pioneer states were Rio Grande do Sul, Paraná, Santa Catarina and São Paulo. In the following decade, production grew to Mato Grosso do Sul, Goiás, Minas Gerais and lastly Mato Grosso. And then, during the 1990s and 2000s, there was a final push of the agricultural frontier toward the Northeast and North regions that are still developing.

To give an idea about the dimension of technical change mentioned here, quantifying the amount of land used in a situation where technological breakthrough remains constant, from the 1960s to 2010s, as measured by Vieira Filho & Fishlow (2017), the land-saving effect in the crop production is estimated at approximately 129 million hectares over this period. By analogy, the land-saving effect in livestock farming would be equal to nearly 646 million hectares. The total land-saving effect including the contribution of food crops and beef production is estimated at 775 million hectares, an area almost equal to a country the size of Brazil (851.5 million hectares). In other words, the use of technology was able to save around 91% of Brazilian surface as a strategic resource and also to supply more food to the domestic and international markets.

Production inequalities

The only factor that explains a sharp reduction of food prices is technology. The production cost does not fall without adoption of new technologies. So innovation means food supply growth and lower prices for consumers. There are two effects: one is in the producer's response to research and development to keep growing, and the other is the indirect effect on consumer income. The first effect shifts the supply curve to the right, and the second increases the demand for food. The role of agriculture should also be considered from the perspective of poverty reduction. Poor people are more influenced by a decline in food prices than rich people. If the shift in supply curve is higher than the non-price related growth in demand, prices fall and the poorest consumers represent the majority of the beneficiaries.

Nonetheless, the success of Brazilian agriculture in recent years was not sufficient to develop all regions and diminish productive inequalities. The growth in Brazilian agriculture co-evolved with structural heterogeneity and dualities, as stated by Vieira Filho (2013) and Vieira Filho & Fornarzier (2016). Despite great increases in production, some challenges still remain. The technological changes in agricultural productions that have occurred in Brazil in recent decades point to growth in productivity.

The technological changes in agricultural production that have occurred in Brazil in recent decades point to growth in productivity (Vieira Filho et al., 2012). According to Figure 1, the agricultural total factor of productivity (TFP), a

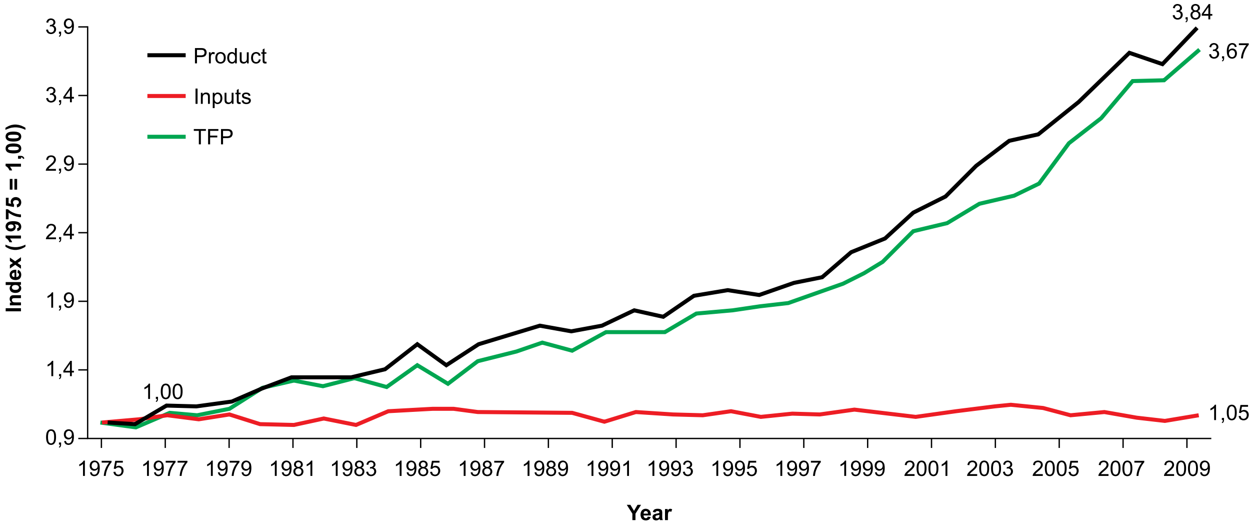

Figure 1. Indices representing growth in agricultural production, input use, and total factor productivity - TFP (1975 to 2010).

Source: Vieira Filho et al. (2012).

measure of efficiency in the use of productive factors, has increased by 267 percent since 1975. This indicates a trend of continuous growth in Brazilian agriculture. In the period analyzed, the index for input use (use of labor, capital and land) was stable (only 5 percent growth) while the production index indicates a 284 percent increase in agricultural output. Most of the growth in production is attributed to the growth in technology, showing that it is possible to produce more with fewer resources. As studied by Gasques et al. (2016), a structural change was showed after the year of 1997. Before, TFP growth was almost 3 percent, while after this year the growth rate increased to more than 4 percent.

By contrast, most producers have a rather low absorptive capacity of knowledge and thus they do not necessarily benefit from these technology efficiency gains. In addition, they continue to have limited access to new technologies[7]. TFP growth represents the technology efficiency gains for small part of farms units (the richest ones), which are responsible for a huge percentage of the gross value of production. Therefore, for comprehensive agricultural development in Brazil, one must incorporate growth with inclusive production.

As previously reviewed by Alves & Rocha (2010), the high concentration of production stands out (Table 1). According to Agricultural Census (IBGE, 2006), data shows that 10 percent of farms (medium and high income) generated 85 percent of the gross value of production. In contrast, 90 percent of farms (extreme poverty and low income) accounted for only 15 percent of production. In the group of extreme poverty, 63 percent of the unit exploitations contributed less than 4 percent of product. Variations between regions and crops indicate a very strong structural heterogeneity that makes the widespread implementation of technology more difficult.

Considering this, farm units can be subdivided into three income strata: i) extreme poverty; ii) low-income; and iii) medium and high-income. At the top of population, represented by the medium and high-income groups, the farm units are very efficient. At the lower

[7] Absorptive capacity of knowledge is the ability of agents to recognize, assimilate and apply a new knowledge to generate innovations in the production process. For its application to agriculture, see Vieira Filho & Silveira (2011).

Table 1. Farm revenue distribution by income groups (2006).

Income groups by minimum wage equivalent	Monthly minimum wage equivalent	Number of farms (in thousands)	%	Gross value of annual production (billion)	%
Extreme poverty	(0 a 2]	3.242	69.6	6.5	3.9
Low income	(2 a 10]	960	20.9	18.5	11.1
Medium income	(10 a 200]	416	9.0	59.9	35.9
High income	>200	23	0.5	81.7	49.0
Total – Brazil		**4.641**	**100.0**	**166.7**	**100.0**

Source: IBGE (2006).

Minimum wage equivalent = monthly gross value of production/monthly minimum wage.

limit, the agricultural establishments have a lack of technological content.

First, in the bottom group, extreme poverty includes about 3.2 million farm units, which are marginalized from agricultural production, as well as excluded from any sector of economic activity. This group lacks basic structures of productive organization (micro and macroeconomics). Around 60 percent of the total farm units considered to be in extreme poverty are concentrated in the Northeast. By contrast, the Midwest has the lowest percentage of extreme poverty, around 4 percent. In order to push efforts into the reduction of rural poverty, public policies should be focused on regional strategies. Regarding the data related to demographic analysis, the highest urbanization rate is found in the most developed areas like Southeast, Midwest and South. The Northeast and North have the lowest urbanization rates (approximately, 73 percent each), although the former has the second largest regional population in Brazil (28 percent) just behind the Southeast region. Thus, the Northeast has the highest percentage of extreme poverty in rural areas and the lowest urbanization rate. This means that Northeast has the highest probability to face a rural exodus in the near future.

Second, the low-income group (960 thousand agricultural units) should be assisted by the government with policies to support and promote small-scale production, usually family farming. These farm units have a low ability to use external knowledge and restricted technological content, with deficiencies on management and microeconomic levels. Access to credit and use of new technologies should be improved. The government should develop technical assistance and public research in order to reduce market failures and include more farms in production.

Finally, the agricultural wealthy includes the upper and middle incomes (439 thousand farm units). For this group, the absorptive capacity of technology becomes a secondary issue. However, they demand stable and favorable macroeconomic guidelines for sales growth. Public policy should be conducted on questions that focus on macroeconomics, such as competitiveness stimulus, export promotion, agricultural insurance, and logistics.

At the microeconomic level, although Brazilian agriculture has experienced tremendous growth in TFP, the absorptive capacity of technology on farms is still very low. According to the Agricultural Census of 2006 (IBGE, 2006), the low education levels of the majority of farm units plus the weakness in applied management of knowledge limit their capacity to absorb external knowledge, which discourages growth in productivity. Two indicators can examine this limitation: i) educational level; and ii) received technical guidance.

As for educational level, 90 percent of impoverished landowners did not have elementary education, with 27 percent illiterate and 12 percent not educated. These producers do not know how to seek technical guidance in the use of new technology, leading them to underuse or inefficiently use such innovations. In a regional comparison, Northeast has the worst performance in education, with 59 percent of landowners illiterate and not educated of which only 36 percent with elementary school, and a small number with high school and higher education. These numbers are stand in contrast to other regions and they show a huge gap between developed and non-developed regions.

In terms of received technical guidance, only 22 percent of farm managers received some kind of technical assistance in 2006. The large majority (78 percent) did not receive any technical guidance at all. Regional statistics show once more that Northeast presents a lag-behind in rural extension services compared to other regions. In Northeast, 92 percent of farm managers did not receive technical support in the production process. South has shown better indicators than other regions. While in the South and Northeast there is a predominance of small farms, in the Midwest large-scale production dominates. The small-scale production in the South has better institutions and infrastructure to develop, but this situation is not the same in the Northeast.

The challenge is to include marginalized farmers into the technology revolution. From the standpoint of public policy-making, the internal diversity of farming therefore requires specific actions to promote production and reallocate resources to the different segments and regions. There needs to be a clear policy for increasing technology absorption capacity, which entails making progress in rural extension outreach and education. This requires policy instruments that are more closely integrated across the federal, state and municipal levels. Transforming market-based extreme poverty farming will be the main challenge for agricultural planning and policy in Brazil over the next few years.

Final remarks

The general objective addressed here is to investigate the importance of learning spillovers and the ability of agents to explore external knowledge, with particular emphasis on the case of Brazilian agriculture. Specifically, it evaluates the process of technological innovation in agriculture and its regional determinants in terms of productivity gains, giving explanations for differential growth among agricultural regions in Brazil (for example, a discussion that compares the poverty-stricken regions of the Northeast *versus* the most modernized rural areas of Southern regions). A scenario of public policies to reduce structural heterogeneity in Brazilian agriculture should be developed.

This study attempts to build arguments necessary to formulate public policies designed to promote economic growth and, at the same time, attenuate the social and environmental impacts of small, medium and large crop and livestock farming production in different Brazilian regions. The results should be highly instrumental in designing extension service and planning educational polices in different agricultural areas, in order to develop potential and marginal areas. Since the creation of Embrapa, clusters of innovation have changed Brazilian production. From 1989 to 2015, the agribusiness sector also contributed positively to the trade surplus of Brazil. While the manufacturing industry experienced a trade deficit, agribusiness, crop and livestock farming jointly, generated a positive surplus in the entire period. The overall trade balance for Brazil was not worse due to the agricultural performance in the past few years. The recent commodity boom helped in this trajectory, but of course the relevant fact was the technological breakthrough, as we observed over this analysis. The balance trade of agribusiness (exports minus imports) increased from approximately US$ 11 billion in 1989 to US$ 82.9 billion in 2013, showing an annual growth rate of 8.8 percent in the period. In 2015, this agribusiness performance represented more than a half of the total Brazilian foreign trade.

The public intervention took place primarily in the institutional research construction. The diffusion was stimulated by the private sector. There are market failures that exclude a lot of farm units from modernization. We should note that the function of Embrapa was to produce technology, not sell it. Whenever the government interferes in prices, there is a market distortion, which can expand the market failures. This is what happened in the last decade when the government decided to keep the price of gasoline down, impacting negatively on the sugar and alcohol sectors. There is a strong pattern of gross income concentration, on the one hand, and a heavy burden of extreme poverty in farming, on the other. In the most backward regions, farming is more unequal and accounts for a large proportion of rural poverty. The government needs to create a favorable environment for innovation. The firm-centered knowledge networks within innovation systems as a part of institutional change are essential to developing a dynamic growth process. The example of Embrapa shows that intervention should not be targeting production but regulatory policy design trying to stimulate international trade.

References

ALVES, E. Embrapa: a successful case of institutional innovation. **Revista de Política Agrícola**, ano 19, p.64-72, 2010. Edição especial.

ALVES, E.; ROCHA, D. de P. Ganhar tempo é possível? In: GASQUES, J.G.; VIEIRA FILHO, J.E.R.; NAVARRO, Z. (Org.). **A agricultura brasileira***:* desempenho, desafios e perspectivas. Brasília: Ipea, 2010. Cap.11, p.275-290.

BUAINAIN, A.M.; ALVES, E.; SILVEIRA, J.M. da; NAVARRO, Z. (Ed.). **O mundo rural no Brasil do século 21**: a formação de um novo padrão agrário e agrícola. Brasília: Embrapa, 2014.

CHIAROMONTE, F.; DOSI, G. The micro foundations of competitiveness and their macroeconomic implications. In: FORAY, D.; FREEMAN, C. (Ed.). **Technology and the wealth of nations**: the dynamics of constructed advantage. London: Pinter, 1993. p.107-134.

COCHRANE, W.W. **Farm prices**: myth and reality. Minneapolis: University of Minnesota Press, 1958.

COHEN, W.M.; LEVINTHAL, D.A. Innovation and learning: the two faces of R&D. **The Economic Journal**, v.99, p.569-596, 1989. DOI: 10.2307/2233763.

CORREA, P.; SCHMIDT, C. Public research organizations and agricultural development in Brazil: how did Embrapa get it right? **Economic Premise**, v.145, p.1-10, 2014.

DOSI, G. **Technical change and industrial transformation**. London: Macmillan, 1984. DOI: 10.1007/978-1-349-17521-5.

FOSTER, A.D.; ROSENZWEIG, M.R. Learning by doing and learning from others: Human capital and technical change in agriculture. **Journal of Political Economy**, v.103, p.1176-1209, 1995. DOI: 10.1086/601447.

GASQUES, J.G.; BACCHI, M.R.P.; RODRIGUES, L.; BASTOS, E.T.; VALDES, C. Produtividade da agricultura brasileira: a hipótese da desaceleração. In: VIEIRA FILHO, J.E.R.; GASQUES, J.G. (Org.). **Agricultura, transformação produtiva e sustentabilidade**. Brasília: Ipea, 2016. Cap. 5, p.143-163.

GASQUES, J.G.; VIEIRA FILHO, J.E.R.; NAVARRO, Z. (Org.). **A agricultura brasileira**: desempenho, desafios e perspectivas. Brasília: Ipea, 2010.

HAYAMI, Y.K.; RUTTAN, V.W. **Agricultural development**: an international perspective. rev. ed. Baltimore: Johns Hopkins University Press, 1985.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Censo Agropecuário 2006**: Brasil, Grandes Regiões e Unidades da Federação. Rio de Janeiro, 2006.

LUNDVALL, B.-Å. (Ed.). **National systems of innovation**: towards a theory of innovation and interactive learning. London: Pinter, 1992.

NELSON, R.R.; WINTER, S.G. **An evolutionary theory of economic change**. Cambridge: Harvard University Press, 1982.

PAVITT, K. Sectoral patterns of technical change: towards a taxonomy and a theory. **Research Policy**, v.13, p.343-373, 1984. DOI: 10.1016/0048-7333(84)90018-0.

SRINIVAS, S.; VIEIRA FILHO, J.E.R. **Farms *versus* firms in economic development**: the assumptions and consequences of learning dynamics in agriculture and manufacturing. Brasília: Ipea, 2015. (Ipea. Discussion Paper, 207).

VIEIRA FILHO, J.E.R. Heterogeneidad estructural de la agricultura familiar en el Brasil. **Revista CEPAL**, v.111, p.103-121, 2013. DOI: 10.18356/7248f152-es.

VIEIRA FILHO, J.E.R. Technological trajectories and learning in agricultural sector. In: GLOBELICS INTERNATIONAL CONFERENCE, 10., 2012, Hangzhou. **Innovation and Development**: opportunities and challenges in globalisation: anais. Hangzhou: Globelics, 2012.

VIEIRA FILHO, J.E.R.; CAMPOS, A.C.; FERREIRA, C.M. de C. Abordagem alternativa do crescimento agrícola: um modelo de dinâmica evolucionária. **Revista Brasileira de Inovação**, v.4, p.425-476, 2005. DOI: 10.20396/rbi.v4i2.8648919.

VIEIRA FILHO, J.E.R.; FISHLOW, A. **Agricultura e indústria no Brasil**: inovação e competitividade. Brasília: Ipea, 2017.

VIEIRA FILHO, J.E.R.; FORNAZIER, A. Productividad agropecuaria: reducción de la brecha productiva entre el Brasil y los Estados Unidos de América. **Revista CEPAL**, v.118, p.215-233, 2016. DOI: 10.18356/06f8a4ae-es.

VIEIRA FILHO, J.E.R.; GASQUES, J.G. (Org.). **Agricultura, transformação produtiva e sustentabilidade**. Brasília: Ipea, 2016.

VIEIRA FILHO, J.E.R.; SILVEIRA, J.M.F.J. da. Modelo evolucionário de aprendizado agrícola. **Revista Brasileira de Inovação**, v.10, p.265-300, 2011. DOI: 10.20396/rbi.v10i2.8649017.

VIEIRA FILHO, J.E.R.; SILVEIRA, J.M.F.J. da. Mudança tecnológica na agricultura: uma revisão crítica da literatura e o papel das economias de aprendizado. **Revista de Economia e Sociologia Rural**, v.50, p.721-742, 2012. DOI: 10.1590/S0103-20032012000400008.

VIEIRA FILHO, J.E.R.; VIEIRA, A.C.P. **A inovação na agricultura brasileira**: uma reflexão a partir da análise dos certificados de proteção de cultivares. Brasília: Ipea, 2013. (Ipea. Texto para Discussão, 1866).

VIEIRA FILHO, J.E.R.; GASQUES, J.G.; SOUSA, A.G. Can Brazil feed the world? Not yet, but it has the potential! In: THE FUTURES of agriculture. Rome: Global Forum on Agricultural Research, 2012. (Brief No. 33 - English). GFAR.