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# Diffusion of technologies: a longitudinal analysis of the Brazilian agricultural machinery sector

**Difusão de tecnologias: uma análise longitudinal do setor de máquinas agrícolas no Brasil**

**Difusión de tecnologías: un caso de largo plazo del sector de maquinaria agrícola en Brasil**

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**Abstract**
The importance of adopting technology innovations, mainly in food production contributing to food safety, is significant. This study aims to analyze the diffusion of agricultural production technologies in Brazil, mainly the use of wheel tractors, grain and sugarcane harvesters by producers. A quantitative approach is used to understand the market-level factors that influence the adoption of technologies. A supply response is estimated based on the Bass diffusion model. Data were collected from the National Association of Vehicle Manufacturers (Anfavea), which includes Brazilian monthly sales information for wheel tractors, grain and sugarcane harvesters. For each agricultural machine, 700 months of sales records were collected. The imitator's coefficients were higher than innovators for all types of machines studied. The data showed that, for wheel tractors and grain harvesters, the diffusion curve presented S format (S-curves). However, sugarcane harvesters had a different pattern of diffusion. The distribution of the investigated technologies in Brazil was an imitation process; the market saturation was observed for wheel tractors and grain harvesters. This study helps to comprehend the supply response of agricultural machinery and presents suggestions for the diffusion of agricultural production technologies in Brazil. The experience has shown that several factors can constrain technology adoption, such as lack of credit, limited access to information and inputs, and inadequate infrastructure.
**Keywords:** Technology diffusion; Innovation; Agriculture mechanization; Agriculture change; Agribusiness.

**Resumo**
A importância da adoção de inovações tecnológicas, principalmente na produção de alimentos, contribuindo para a segurança alimentar, é significativa. Este estudo tem como objetivo analisar a difusão de tecnologias de produção agrícola no Brasil, principalmente o uso de tratores de rodas, colheitadeiras de grãos e de cana-de-açúcar pelos produtores. Uma abordagem quantitativa é usada para entender os fatores em nível de mercado que influenciam a adoção de tecnologias. A resposta da oferta é estimada com base no modelo de difusão de Bass. Os dados foram coletados da Associação Nacional dos Fabricantes de Veículos Automotores, que inclui informações mensais de vendas brasileiras de tratores de rodas,

colheitadeiras de grãos e de cana-de-açúcar. Para cada máquina agrícola, foram coletados 700 meses de registros de vendas. Os coeficientes dos imitadores foram superiores aos dos inovadores para todos os tipos de máquinas estudadas. Os dados mostraram que, para tratores de rodas e colheitadeiras de grãos, a curva de difusão apresentou formato S (curvas S). No entanto, as colheitadeiras de cana-de-açúcar tiveram um padrão diferente de difusão. A distribuição das tecnologias investigadas no Brasil foi um processo de imitação; a saturação do mercado foi observada para tratores de rodas e colheitadeiras de grãos. Este estudo auxilia a compreender a resposta da oferta de máquinas agrícolas e apresenta sugestões para a difusão de tecnologias de produção agrícola no Brasil. A experiência mostrou que diversos fatores podem restringir a adoção da tecnologia, como falta de crédito, acesso limitado a informações e insumos, e infraestrutura inadequada.
**Palavras-chave:** Difusão de tecnologia; Inovação; Mecanização da agricultura; Mudança na agricultura; Agronegócios.

**Resumen**
La importancia de adoptar innovaciones tecnológicas, principalmente en la producción de alimentos que contribuyan a la inocuidad de los alimentos, es significativa. Este estudio tiene como objetivo analizar la difusión de tecnologías de producción agrícola en Brasil, principalmente el uso de tractores de ruedas, cosechadoras de granos y de caña de azúcar por parte de los productores. Se utiliza un enfoque cuantitativo para comprender los factores a nivel de mercado que influyen en la adopción de tecnologías. Se estima una respuesta de oferta basada en el modelo de difusión de Bass. Los datos fueron recopilados de la Asociación Nacional de Fabricantes de Vehículos (Anfavea), que incluye información de ventas mensuales brasileñas para tractores de ruedas, cosechadoras de granos y de caña de azúcar. Para cada máquina agrícola, se recopilaron 700 meses de registros de ventas. Los coeficientes del imitador fueron más altos que los innovadores para todos los tipos de máquinas estudiadas. Los datos mostraron que, para tractores de ruedas y cosechadoras de granos, la curva de difusión presentó formato S (S-curvas). Sin embargo, los recolectores de caña de azúcar tenían un patrón de difusión diferente. La distribución de las tecnologías investigadas en Brasil fue un proceso de imitación; se observó la saturación del mercado para tractores de ruedas y cosechadoras de granos. Este estudio ayuda a comprender la respuesta de la oferta de maquinaria agrícola y presenta sugerencias para la difusión de tecnologías de producción agrícola en Brasil. La experiencia ha demostrado que varios factores pueden limitar la adopción de tecnología, como la falta de crédito, el acceso limitado a información e insumos y la infraestructura inadecuada.
**Palabras clave**: Difusión de tecnología; Innovación; Mecanización de la agricultura; Cambio de agricultura; Agroindustria.

## 1. Introduction

The adoption of technology innovations has transformed many industries and their ways of production, particularly in agribusiness. Many countries have programs to encourage the use of technological innovations in agricultural production (Barth et al., 2021). According to the Food and Agriculture Organization of the United Nations (2017), approximately 5.9 billion tons of food are produced worldwide each year. When agricultural land is observed, a large number of agricultural machines with various utilities are present: tractors, combines, and planting, seeding, and tillage equipment. From Pingali's (2007) point of view, the adoption of mechanical technologies helped to enhance agricultural productivity and decrease the unit cost of crop production, even in densely populated countries of Asia, alleviating energy bottlenecks.

Considering only tractors, the World Bank (2017) estimated that there were over 25 million agricultural machines distributed worldwide in 2000. Looking at the manufacturing sector, the impact of the industrial revolution on increasing productivity and improving product quality is remarkable. Technological changes have been the main factor shaping agriculture since the late twentieth century (Schultz, 1964).

The growth of the agricultural sector in Brazil illustrates the role of advances in products and processes. The Brazilian share in global production and exports of soybeans was, respectively, 3% and 2% in 1970. Projections made by OECD/FAO (2018) indicate that global soybean production will be continuously dominated by the United States and Brazil for the coming years: "In Brazil, higher cropping intensity will sustain the country's position, as it produces soybeans as a second crop on land cultivated with maize" (p. 42). An important point in this context is the shortage of labor in the agricultural sector, where manual labor is no longer able to meet the demand and innovative technologies are necessary to support the sector's activities (Aryal et al., 2021).

According to the Brazilian Institute of Geography and Statistics (2010), in 1960, around 55% of the population lived in rural areas, while in 2010 the number had changed to 16%. The urbanization process can be considered as an effect and a cause of structural changes in the agricultural sector in Brazil. The data presented is due to the introduction of new technologies in agricultural production systems, such as mechanization, chemical inputs, communication, and information technology.

Another important factor is the need for investments in research and development (Betarelli Junior et al., 2020), which will promote innovation and agricultural economic growth in Brazil in addition to fostering the agricultural machinery sector. Despite the increased use of new technologies in agricultural production systems, several aspects remain unclear in the distribution of the agricultural machinery sector in Brazil. Further investigations may contribute to revealing how agricultural machinery has been diffused over the recent decades since Brazil went from a food importer to a major producer and exporter. To address this question, this study aims to analyze the diffusion of agricultural production technologies in Brazil, mainly the use of wheel tractors, grain and sugarcane harvesters by producers.

The database adopted for this research presents a long-term series of data about sales, production, imports, and exports of agricultural machinery. The Bass diffusion model was used to analyze data collected from 1960-2017. For example, the first sample for wheel tractors was made in January 1960. In that month, the total sales were one tractor in Brazil as a whole. Compared with January 2017, when the total number of sales was 2263 units, this represents 0.04% of sales.

## 2. Theoretical Background

Innovations are central to the process of economic development. Nowadays, we are observing the fourth industrial revolution, the objective of which is to solve problems in production and make it more effective, enabling competitive gains (Rodrigues et al., 2016; Jankowska et al., 2021; Ribeiro et al., 2021). For example, in the Brazilian agribusiness sector, rural producers are now using innovations such as big data, the internet of things, and robotics (Ferneda, 2018; Jankowska et al., 2021). Considering this context, many authors have used the concepts Agro 4.0 and Livestock 4.0 to refer to these technologies in the agriculture yield (Casarotto, 2019; Ribeiro et al., 2021).

Pioneering work on technology adoption was conducted in 1940, which led to a study on the diffusion of hybrid corn seeds with farmers in Iowa, USA. This sparked an interest in the diffusion curve of innovation (curve S), elaborated on by Tardes in 1903 (Ryan & Gross, 1943). Using this curve, the authors ranked Iowa farmers in categories based on the amount of time required to adopt an innovation.

Since 1940, several studies have been conducted to predict or describe the adoption of new products. Among the possible models proposed was the Bass model (Bass, 1969). In this case, the main benefit of measure adoption was to provide indicators of timing and the extent of new technology utilization by individuals, while the diffusion can be interpreted as aggregate adoption. The Bass model is considered robust and can be used to compare diffusion patterns across a range of technologies and products. The Bass model assumes that the population of potential buyers is composed of a small group of innovators influenced only by external factors (e.g., mass media, promotion), and a large group of imitators influenced by internal factors (Duval & Biere, 2002). Considering the existence of the two adopter groups (innovators and imitators) in a social system, the Bass model assumes that the diffusion process is defined by the interaction mechanism between them.

The condition to describe or predict the diffusion of innovations proposed by the Bass model assumes that the probability of an innovator buying falls to zero rapidly over time and that the number of innovator buyers when a new product is introduced is

small enough to be ignored. When the increasing adoption of an innovation is plotted over a period, the S-shaped cumulative curve is formed (Bass, 1969).

The theoretical basis developed on the diffusion of innovation has provided advances in studies of development economics and collaboration for quantitative analysis of the process of technological change in several areas, such as consumer durables. Regarding the research into agricultural innovation, a central theme has been the mathematical modeling of the diffusion of different types of technologies under various assumptions (Feder & Umali, 1993).

### 2.1 Agricultural machinery sector in Brazil

The agricultural machinery sector in Brazil originated through the establishment of the first four-wheel tractor manufacturing plants in the middle of 1950. The evolution of this industry depended on tax incentives and financing programs aimed at producers and industry players, with the expansion of the cultivated area and the increase in production and productivity rates in the field. Technology development focused on a few large foreign-owned companies in the automotive tractor and harvester sector, concentrated in the South-Southeast areas of Brazil (Lima et al., 2017).

Demand for agricultural machinery was influenced by expectations generated by the government through agrarian policy, considering projected crop estimates and the volume of financing for the subsequent year. This dependence may indicate the low competitiveness of machines produced in Brazil, which cannot maintain an export level, as well as the low value attributed by the producers to the technology or the low financial capacity of these producers in acquiring it (Gaffney et al., 2019).

According to Lima et al. (2017) and Gaffney et al. (2019), the machine sector has evolved in innovation and technology development, even though its participation in the foreign market is disproportionate to its productive capacity. This process highlights the importance of large companies and their research and development departments in contributing to the dynamic sector, given its high capacity for cumulative technological knowledge. The adoption of agricultural machinery is growing, and over the years, numerous countries including Brazil have sought to increase food production, as well as the efficiency of inputs in the agricultural sector. As a result, innovation and technologies have been gaining strength and contributing to the improvement of productivity (Aryal et al., 2021).

## 3. Methodology

In order to understand the factors that influence the response to the adoption of innovation in Brazil, the article first estimates a supply response based on the Bass diffusion model. The paper uses a quantitative approach to understand the market-level factors that influence the adoption of technologies. The adoption of innovation in Brazil has specificity, varying according to time and government policy. According to the Bass diffusion model, the adoption of innovation is based on:

$$\frac{f(t)}{1-F(t)} = p + \frac{q}{M} A(t) \quad (1)$$

Here, $f(t)$ denotes the portion of M that adopted at the time $t$ and $F(t)$ the portion of that adopted by time $t$; M represents the total potential adoptions during the whole process. Parameters $p$ and $q$ are the coefficient of innovation and coefficient of imitation, respectively. The most frequently used representations for the Bass model are as below (Meade and Islam, 2006), and can be seen in a curve fitting and obtained through algebraic manipulation (Bass, 1969).

$$a(t) = Mp + [q - p]A(t) - \frac{q}{M} A(t)^2 \quad (2)$$

Here, $a(t)$ is the adoption from time $t-1$ to $t$, and $A(t)$ has the same meaning as in (1).

The mixed influence diffusion model introduced by Bass includes both internal and external influences. The parameters of the Bass diffusion model are a coefficient of imitation and a factor of innovation that is related to the critical dimensions of social dynamics in the diffusion process.

The data were collected from the National Association of Vehicle Manufacturers (Anfavea), which includes Brazilian monthly sales information for wheel tractors, grain harvesters, and sugarcane harvesters. The period analyzed comprised from 1960 to 2017. In total, 700 months of sales and production records were collected for each type of agricultural machine in Brazil.

Matlab was used to do parameter fitting with LSE and have the results categorized by different machines. From the relationship between the coefficient of innovators (p) and the coefficient of imitators (q), it is possible to infer the integral shape of the curve: i) the closer p is to zero, the smaller it is relative to q, and the more of an S format the diffusion curve will have; ii) for the opposite, the more concave the curve of diffusion will be. The saturation point (m) compared to the last point of the curves indicates which segment the distribution is in (Ferreira et al., 2018).

## 4. Results and Discussion

The descriptive analysis of the data is shown in Table 1. We identified that on average, 2,447 wheel tractors were negotiated for in Brazil each year during the period analyzed. Wheel tractors have had an important role in agricultural development in Brazil since 1960. On the other hand, sugarcane harvesters are an addition to Brazilian agriculture (2013), although sugarcane has a long and ongoing history in the country. Grain harvesters appeared shortly after the wheeled tractor in 1976, with an average of 338 units sold each year.

**Table 1.** Data description.

| Machine | Period | Record | Average | Variance | Median | Range |
|---|---|---|---|---|---|---|
| Wheel tractors | 1960-2017 | 693 | 2447.7576 | 2355036.2 | 2262 | 7103 |
| Grain harvesters | 1976-2017 | 501 | 337.77844 | 41046.353 | 320 | 1209 |
| Sugarcane harvesters | 2013-2017 | 57 | 79.789474 | 1956.1335 | 72 | 177 |

Source: Elaborated by authors based on Anfavea.

The imitator effect is more significant than the innovator effect for wheel tractors and grain harvesters. The coefficients shown in Table 2 indicate that the relationship between p and q meets the condition “i” as mentioned before, because the ratio of imitators (q) is higher than innovators (p), which indicates that the curves of the product diffusion have an S format. For wheel tractors and grain harvesters, the development of innovations and investment in advertising to spread to innovators is also essential. Agricultural machinery companies tend to invest in innovation in their products and use agricultural fairs to communicate and reach early adopter farmers.

**Table 2**. Parameters estimated using Bass model.

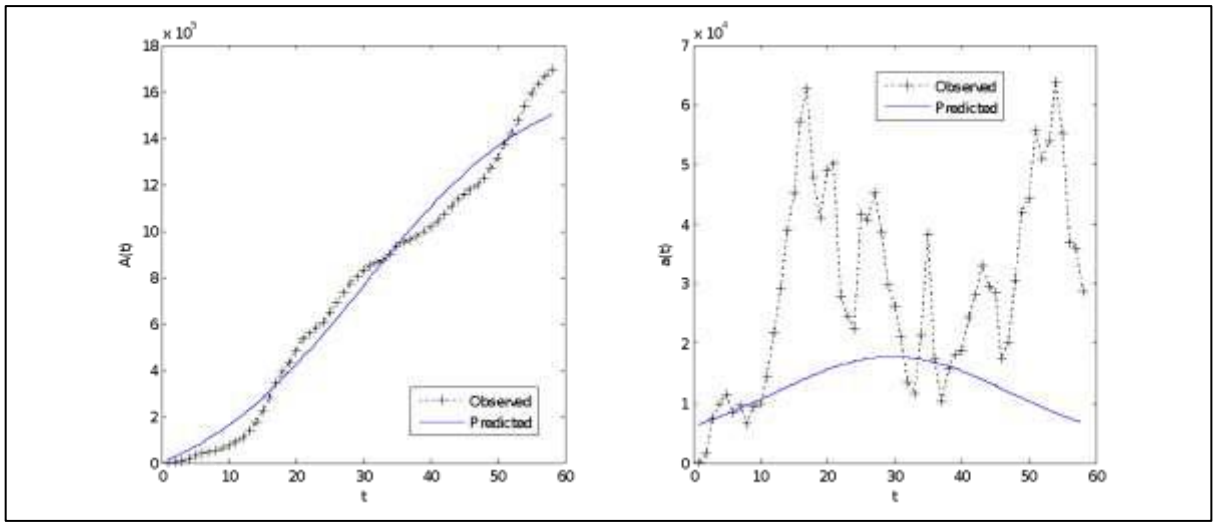
| Machine | Period | MAD | M* | *p*** | *q**** | *p+q* | *q/p* |
|---|---|---|---|---|---|---|---|
| Wheel tractors | 1960-2017 | 3,844,668 | 1696296 | 0.0070303 | 0.069245 | 0.0762753 | 9.8495 |
| Grain harvesters | 1976-2017 | 284,649 | 169227 | 0.022075 | 0.053197 | 0.075272 | 2.4098 |
| Sugarcane harvesters | 2013-2017 | 871 | 4548 | 0.24761 | 0.50773 | 0.75534 | 2.0505 |

Notes: * Mean absolute deviation (MAD), ** Innovators coefficient, *** Imitators coefficient. Source: Authors.

The parameters are obtained from the diffusion model with the data, a diffusion curve can be drawn using parameters $p$ and $q$ as listed in Table 2. The curves (Figures 1, 2 and 3) are the increasing adoptions and adoption periods for Brazilian wheel tractors, grain harvesters, sugarcane harvesters.

The diffusion of wheel tractors began with the introduction of the policy of modernization in Brazilian agriculture. The government has provided incentives for the shift from manual and animal-powered production to mechanized agriculture. This process has been occurring since 1960 with the adoption of technological innovations in the production process (agronomic, chemical, and biological changes) and the constitution of agro-industrial complexes, which generated a new socioeconomic and spatial configuration for Brazil's rural areas (Lima et al., 2017).

**Figure 1.** Wheel tractors.




Source: Elaborated by authors.

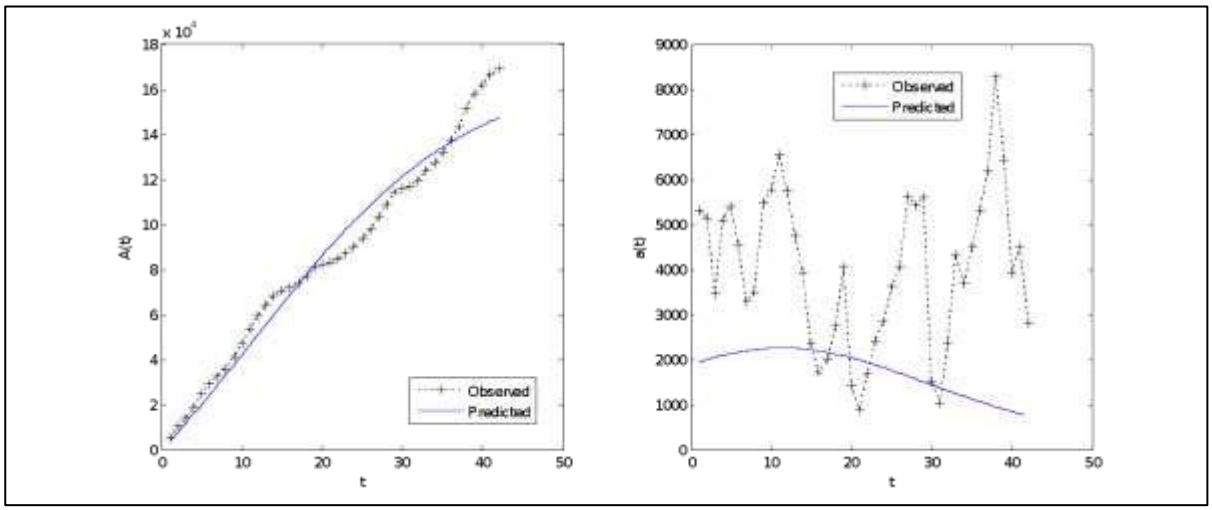
The diffusion of wheel tractors occurred mainly in the South and Southeast regions during the years 1960-1970. Extensive use of capital goods changed the technological standard of Brazilian agriculture (Delgado, 1985). We noted that early adopters used tractors on their farms and provided services to other farmers. The second period from 1970 to 1980 showed the continuing process of diffusion with wheel tractors. With the increase in food demand in Brazil and the expansion of soybean cultivation, the spread of tractors remained high. After 1970, the diffusion curve became less steep due to the lower demand for new equipment by rural producers and to crises in the Brazilian economy.

From 2000 to 2010, there was an increase in the diffusion of wheel tractors, especially based on the public policies of the Ministry of Agrarian Development, such as the "Programa Mais Alimentos" ("More Food Program", in English). These policies

stimulated the acquisition of tractors with lower engine power for small rural producers, and further incentivized manufacturers to undertake a technology renewal movement in the direction of improved orchard tractor designs for cultures such as coffee and fruit crops.

The "Programa Mais Alimentos" is a line investment credit for food production created in 2008. Its main purpose is to increase the productivity of family farming by allocating resources for investments in productive infrastructures, such as agricultural machinery and equipment on rural family properties (Camara et al., 2020). In the most recent period (2010-2017), we observed saturation of the market, which is when the final number of adopters has been reached, or the point where diffusion is complete. The demand for wheel tractors continues because of the expansion of agriculture into new areas and the substitution of old tractors for new and more complex technology, such as autopilot guides and electronic motors. Grain harvesters have a similar pattern to wheel tractors (Figure 2).

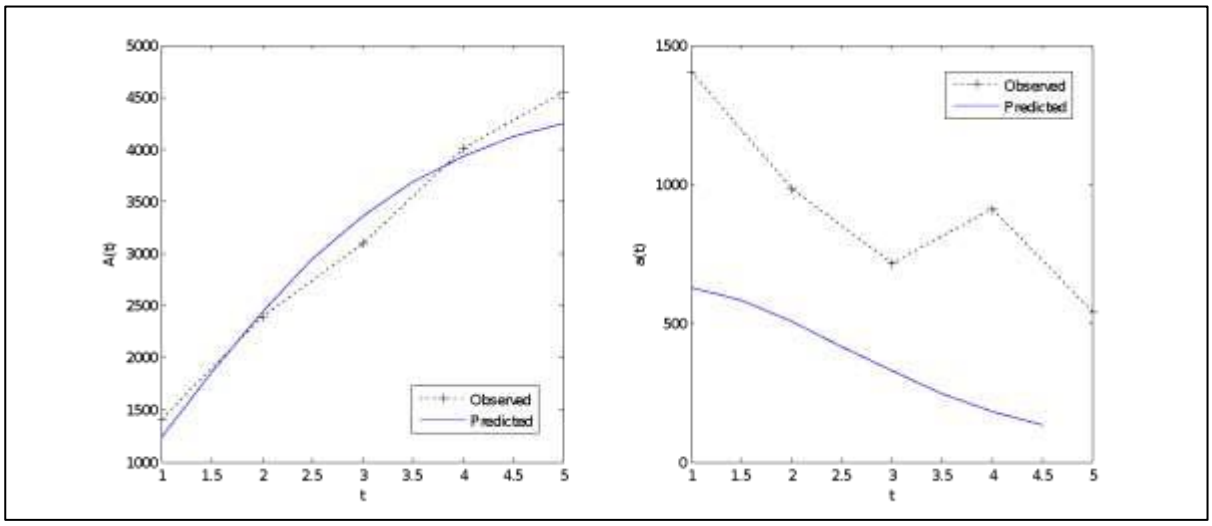
**Figure 2.** Grain harvesters.




Source: Elaborated by authors.

As for sugarcane harvesters, we noted a different pattern when compared with wheel tractors and grain harvesters (Figure 3). The coefficients shown in Table 2 indicate that the relationship between p and q meets the condition "ii" as mentioned before, making the diffusion curve mostly concave, probably because the technology for harvesting has evolved over the last 60 years.

**Figure 3.** Sugarcane harvesters.




Source: Elaborated by authors.

Data derived from Anfavea (2019) showed that the number of sugarcane harvesters has been increasing since 2013. For example, 649 units of sugarcane harvesters were negotiated in 2019, while in 2018, 643 units were negotiated. Contributions to the increase in sugarcane harvesters include: i) the increase of sugarcane production; and ii) prohibition of sugarcane burning that in turn encouraged mechanized harvesting.

## 5. Final Considerations

This study aimed to analyze the diffusion of agricultural production technologies in Brazil, mainly the use of wheel tractors, grain harvesters, and sugarcane harvesters by producers. We noted that the imitators' coefficients are greater than innovators' for all types of machines studied. The data showed that for wheel tractors and grain harvesters, the diffusion curve had an S format. However, sugarcane harvesters had a different pattern of diffusion.

Most adopters of the three technologies were made up of imitators, and this group plays an essential role in the diffusion process. That is, the dynamics found evidence that the diffusion of the investigated technologies in Brazil is an imitation process. For some products, such as wheel tractors and grain harvesters, market saturation was observed. Another point is the verification that the Bass-based diffusion approach also applies to the Brazilian context when identifying a diffusion behavior characterized by an S curve. Moreover, the results indicated the importance of considering the economic and political specificities of the country.

In general, the faster a superior technology is diffused, the more significant the improvement of social welfare, as higher income (or larger consumption) can be obtained earlier. However, experience has shown that several factors can constrain technology adoption: lack of credit, limited access to information and inputs, and inadequate infrastructure. As a suggestion for future studies, we recommend elaborating on public policies that technologically favor the production of food, contributing in some way to food security. In some cases, public policies can also be more responsive concerning the distribution of public resources.

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