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Article

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Measuring the intensity of innovation in the Brazilian food sector: a DEA-Malmquist approach

Brazilian food sector

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Abstract

Purpose – This study aims to measure the intensity of innovation in the Brazilian food sector and compares it to other manufacturing sectors in the country.

Design/methodology/approach – The authors used economic and financial data provided by the annual survey of industry [Pesquisa Industrial Anual (PIAs), in Portuguese] and other supporting data provided by the survey of innovation [Pesquisa de Inovação (PINTEC), in Portuguese] and the classification of technology intensity (TI) proposed by the Organization for Economic Co-operation and Development. The authors subsequently applied the Malmquist index in addition to the data envelopment analysis to measure innovation.

Findings – The results reveal that the Brazilian food sector is classified as a sector with low TI and investment in research and development (R&D), which represents one of the lowest rates when compared to other sectors. Thus, the Brazilian food sector is far from achieving its full potential. Nevertheless, the authors noticed that the sugar refinery industry showed an evolution in its technology frontier and presented a frequency of innovation similar to the average of high-tech industries.

Originality/value – This study contributes to the debate on innovation in the food sector, emphasizing the need to accomplish higher investments in R&D to increase the productivity of the sector.

Keywords Malmquist index, Innovation, Manufacturing sector, Food sector

Paper type Research paper

Introduction

Technological innovation is considered one of the main boosters of economic growth and business success (Fortuin & Omta, 2009; Grunert, Jensen, Sonne, Brunsø, Byrne, Clausen et al., 2008) and it facilitates the process of adaptation of companies (Cappellesso & Thomé, 2019; Gopalakrishnan & Damanpour, 1997; Marshall & Parra, 2019). It is possible to affirm that innovation is inherent in global markets and plays an important role in the development of economy, in the improvement and support of the good performance of companies, in the

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construction of industrial competitiveness and in the improvement of life standards (Gopalakrishnan & Damanpour, 1997; Li, Wang, Su & Su, 2019; Marshall & Parra, 2019; Vasconcelos & Oliveria, 2018).

It is possible to observe, nevertheless, the technological intensity as an important variable of innovation and, subsequently, productivity (Felsenstein & Bar-El, 1989; Palda, 1986; Zawislak, Fracasso & Tello-Gamarra, 2018). Literature shows that the food sector is considered a sector with low research intensity, which indicates one of the lowest rates when compared to other sectors (Bigliardi & Galati, 2013; Capitanio, Coppola & Pascucci, 2010; Cappellesso & Thomé, 2019; Martinez & Briz, 2000; Török, Tóth & Balogh, 2019; Vasconcelos & Oliveria, 2018; Zawislak et al., 2018). As pointed out by Cappellesso & Thomé (2019), the food sector is characterized by incremental innovation mostly related to production processes. The process of innovation adoption in the food sector became complex, which led to unsuccessful cases and several critical issues that encompass not only the research level but also acceptance and purchase (Capitanio et al., 2010; Cappellesso & Thomé, 2019; Earle, 1997; Werner, Koontz & Goddard, 2017).

Despite such characterization, the food sector is essential to the Brazilian economic growth. As pointed out by the Associação Brasileira das Indústrias de Alimentação (ABIA) (2018a) [1], the food sector participation in the market increased from 20.1% in 2013 to 23.4% in 2018. According to ABIA (2018b), the Brazilian food and beverage sector has a market share of 9.6% of the gross domestic product and invested R\$7.6bn in 2018. Such a sector is also responsible for the provision of 26.8% of the jobs in the Brazilian manufacturing sector. Considering the international scenario, Brazil is the second-largest exporter of processed food in the world; Asia, European Union and the Middle East are the main target markets. The trade balance of the food sector corresponded to approximately 50% of the national trade. Still, in accordance with the report published by ABIA (2018b), the food sector invests around 3% of its income in research and development (R&D) to create new products and processes to meet society's demand.

Despite the international and national market share, the Fundação Getúlio Vargas [2] (FGV, 2016) indicates that Brazil's insertion in the international trade is becoming more difficult, especially in extremely competitive sectors (e.g. agribusiness). Taking into consideration the competitiveness in the international market regarding the new social and economic reality that started in the 1990s, the food sector needs to present higher productivity and efficiency rates. It is, therefore, to mention that innovation plays an essential role in competitiveness (Raimundo, Batalha & Torkomian, 2017), especially regarding the above-mentioned rates.

Considering the economic importance of the Brazilian food sector and the demand for higher productivity and efficiency rates, our study aims to measure the intensity of innovation of the food sector and to compare it with other manufacturing sectors in the country. To meet such objective, we used economic and financial data provided by the annual survey of industry [Pesquisa Industrial Anual (PIA), in Portuguese] and survey of innovation [Pesquisa de Inovação (PINTEC), in Portuguese] – the latter produced by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese) –, in addition to data regarding technology intensity (TI) provided by the Organization for Economic Co-operation and Development (OECD). To meet the objective proposed herein, we applied the Malmquist index (MI) in addition to the data envelopment analysis (DEA).

Characterization of innovation in the food sector

Researchers from different study fields conceptualize innovation in distinctive ways and have different views regarding its impact on the industry, productivity, survival, growth and development of a company (Gopalakrishnan & Damanpour, 1997). Schumpeter (1947,

p. 151) highlights growth through innovation, defining it as “the doing of new things or the doing of things that are already being done in a new way.” On the other hand, from the resource-based view perspective, [Penrose \(2009\)](#) focused on innovation as a source of profits that could be achieved through learning the development of new applications of the current resources of a company.

By comparing innovation in the economy, organizational sociology, and technology management, it is possible to assert that innovation can be considered according to the following three different settings, as indicated by [Gopalakrishnan and Damanpour \(1997\)](#):

- product and process;
- radical and incremental; the first referring to discontinuous leaps in product and process technology, the second to daily improvements and modifications; and
- technical and administrative, which are related directly to the core of the organization; technical herein refers to products, processes and technologies used to manufacture products or to provide services, administrative refers to organizational structure, administrative processes and human resources.

Additionally, [Vasconcelos and Oliveria \(2018\)](#) systemized other innovation perspectives that go beyond products and processes and emphasize organizationally, marketing and supply chain innovations – in addition to R&D expenditures and patents. Many authors agree in terms of product and process innovation ([Gopalakrishnan & Damanpour, 1997](#); [Pavitt, 1984](#); [Vasconcelos & Oliveria, 2018](#)).

Despite the several types of innovation, each sector owns distinct innovation patterns. [Pavitt \(1984\)](#) proposed a taxonomy related to different types of industries according to the respective roles they play in the innovation process. By using the UK database, the author identified three types of sectors, namely, a sector controlled by the supplier, an intensive production sector and the scientific sector ([Pavitt, 1984](#)). Such taxonomy enabled us to perceive how different sectors interact and play different roles as producers and users of innovation.

Regardless of sectorial characteristics, TI plays a relevant role in innovation. [Palda \(1986\)](#) defines TI as the increase in productivity and revenue provided by scientific research. The more a company invests in R&D, the higher its TI. On the other hand, [Felsenstein and Bar-El \(1989\)](#) emphasize the multidimensional approach of technology. [Zawislak et al. \(2018, p. 191\)](#) indicate the existence of three dimensions; two of them refer to industrial inputs (labor and capital) and the other one to production (product). The authors highlight the traditional analysis of the relationship between capital and labor; “the more capital-intensive and industrial sector is, the more technologically intensive it will be and vice-versa.”

Considering sectorial innovation and its intensity, we observe a few singularities in the food sector when comparing it to other sectors. As pointed out by [Fisher \(1997\)](#), food-related products meet basic needs, do not present changes over time, generate a stable and predictable demand and have long life cycles. Such stability tends to generate higher competition, which leads to lower profit margins ([Fisher, 1997](#)).

Before such singularity, innovations in the food sector are often related to the productive process and considered as incremental; the innovations are mostly related to packaging and supply chain ([Cappellesso & Thomé, 2019](#)), and to the development of new ingredients and additives, functional and transgenic food ([Gouveia, 2006, p. 35](#)). The report of ABIA (2018b) supports such statements by emphasizing the innovations related to the elimination of trans fatty acids and sugar reduction, in addition to the innovation in the supply chain related to the development of important substitute products following the respective nutritional orientations and complying with food additive regulations ([Bigliardi & Galati, 2013](#)).

This way, innovation can be found in every part of the food chain. A possible categorization of food innovation could include as follows:

- new ingredients;
- innovation in fresh food;
- new manufacturing techniques;
- innovation in food quality;
- new packaging methods; and
- new distribution methods or retail (Bigliardi & Galati, 2013).

Several studies characterize the food sector as a sector with low intensity of innovation in several countries such as Italy (Bigliardi & Galati, 2013; Capitanio et al., 2010), Spain (Martinez & Briz, 2000), Hungary (Török et al., 2019), the UK (Trott & Simms, 2017) and Brazil (Vasconcelos & Oliveria, 2018; Zawislak et al., 2018). The intensity of innovation depends on several factors such as the acceptance of consumers and the supply chain, industrial policies (Martinez & Briz, 2000), use of internal tacit knowledge (Török et al., 2019), shared experiences and interactions (Trott & Simms, 2017) and different organizational capacities (Zawislak et al., 2018).

The performance of innovation in this sector is related to internal and external factors – in addition to consumer acceptance – that define the organizational model of the company and subsequently development strategies (Capitanio et al., 2010). The model by Capitanio et al. (2010) highlights the aspects that affect innovation and performance (Figure 1).

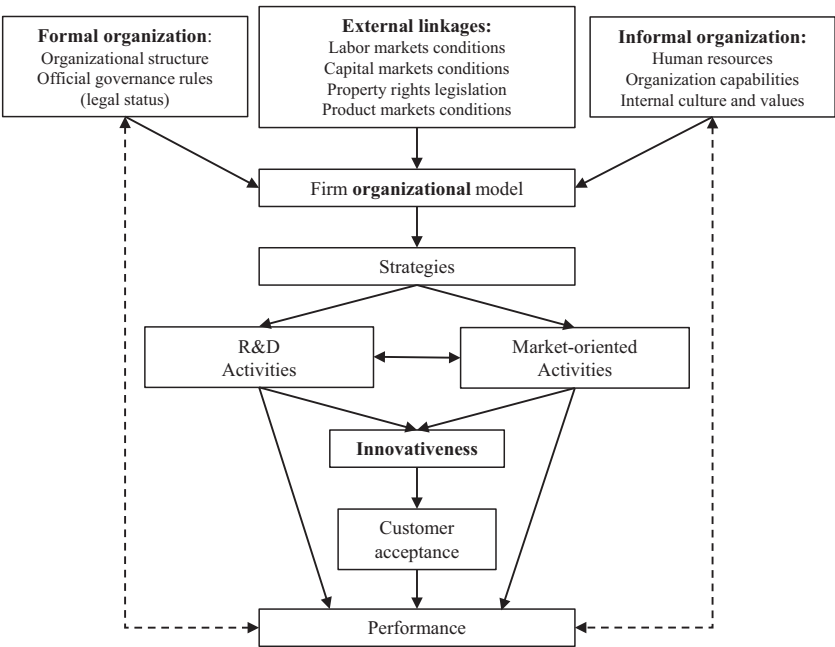


Figure 1.
Innovativeness
explanatory model in
the food sector

Source: Capitanio et al. (2010)

The internal and external factors demonstrate the complexity of adopting innovation in the food sector; there are a high failure rate and several critic issues that encompass not only the research level but also acceptance and purchase (Capitanio et al., 2010; Cappellesso & Thomé, 2019; Earle, 1997; Werner et al., 2017). We also emphasize the importance of investments in R&D, which is related to the occurrence of innovation in the company, but not to the intensity of innovation (Cabral & Traill, 2001). More specifically, “whilst a firm can innovate without engaging in R&D, it will increase its competence to innovate when carrying out R&D” (Cabral & Traill, 2001, p. 40).

We observe, in conclusion, that several factors affect innovation in the food sector. Regardless of the location, previous studies emphasize the low TI in this specific sector (Bigliardi & Galati, 2013; Capitanio et al., 2010; Martinez & Briz, 2000; Török et al., 2019; Trott & Simms, 2017; Vasconcelos & Oliveria, 2018; Zawislak et al., 2018). Therefore, our study measures the intensity of innovation in the food sector and compares it with other manufacturing sectors.

Methodology and research techniques

Charnes, Cooper and Rhodes (1978) state that the relationship between engineering and economy has been outlining new perspectives, which present new interpretations and paths to be used in distinct managerial evaluations and controls. Production engineering predicts that to evaluate every and any system, it is necessary to define the input and output variables. The inputs are also known as resources that will be transformed into an output; i.e. the desired result (or not) of this operation. According to such statements, the independent firm, which represents the object analyzed herein, can also be known as the decision-making unit (DMU).

The ratio between a measure of output and a measure of input – known as productivity – is a largely used process performance measure. Coelli, Rao, O'Donnell and Battes (2005) suggest the calculation of the total-factor productivity (TFP) of a system through only one metrics that encompasses all interest variables, which are considered according to their weights (utilities) and enable the establishment of the global performance value of the DMU under evaluation [equation (1)] as follows:

$$TFP = \frac{u_1 \times y_1 + u_2 \times y_2 \dots + u_{n+1} \times y_{n+1}}{v_1 \times x_1 + v_2 \times x_2 \dots + v_{n+1} \times x_{n+1}} \quad (1)$$

When analyzing the TFP equation, it is possible to verify that firms (DMUs) that aim at maximizing productivity must increase their outputs while the inputs proportions remain unchanged (i.e. kept at a constant level) (output-oriented model) or to minimize the inputs for a desired level of output to be achieved (input-oriented model).

According to Balk (2001), in a universe of several units under analysis, the DMUs that reach the highest value of TFP are considered efficient and are known as benchmarks. Benchmark DMUs are important because they are treated as “operational excellence.” Its identification enables the development of an improvement plan for inefficient units to achieve better productivity and better performance in processes. Based on these concepts, efficiency is the ratio between the productivity of a DMU and the maximum value that this productivity can reach in the same sector and at the same technological level. The efficiency of a system is an index that ranges from 0 to 1 (in percentage terms, from 0% to 100%).

TFP and efficiency can be evaluated in a static scenario (within only one time period) or, comparatively, over time (several time periods). In the latter case, the variation of TFP of a determined DMU can be evaluated at time $t + 1$, considering the period t . Several indexes can be used to express such variation; one of the most used ones is the MI.

In the MI, the value of TFP is divided into the following two components over time: changes in technical efficiency (CE) and changes in technology (CT) (metrics that measure

innovation of a determined DMU). Färe, Grosskopf, Lindgren and Roos (1994) calculate the MI through the geometric average of the following two ratios: the first uses the period t benchmark technology; the second uses the period $t + 1$. This indicator is a geometric average of two distance function ratios, which use technologies in different time periods (d_o^t and d_o^{t+1}) (d_o^t and d_o^{t+1}) and depend on the relation between the generated y outputs and the x inputs used. The MI is written as follows [equation (2)]:

$$MI(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)} \times \frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (2)$$

Equation (3) presents the decomposition of the MI considering CE and CT as follows:

$$MI(y_{t+1}, x_{t+1}, y_t, x_t) = CE \times CT \quad (3)$$

where:

$$CE = \frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)}; CT = \left[\frac{d_o^t(x_t, y_t)}{d_o^{t+1}(x_t, y_t)} \times \frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_{t+1}, y_{t+1})} \right]^{\frac{1}{2}}$$

where:

- CE = changes in technical efficiency;
- CT = changes in technology (occurrence of innovation or not);
- y_t = output matrix $N \times M$ for every n DMUs in the year t ;
- x_t = input matrix $N \times K$ for every n DMUs in the year t ;
- d_o = output-oriented distance; and
- t = time.

The equations (2) and (3) can be solved through a mathematical technique developed by the researchers Charnes et al. (1978) known as DEA. The authors formulated a few linear programming problems to determine the relative efficiency of productive units with multiple inputs and outputs by calculating the weights (utilities) of each variable. The calculation of the efficiency and TFP from one period to the other is enabled by the weights of the variables.

DEA presents several mathematical models; the most traditional ones are the original CCR ratio model of Charnes et al. (1978) and the BCC model (a reference to Banker et al., 1984). The CCR model operates with constant returns-to-scale; i.e. any variation in the inputs causes a proportional variation in the outputs. On the other hand, the BCC model operates with variable returns-to-scale; i.e. it considers growing and decreasing returns to scale. The CCR model estimates technical efficiency, while the BBC model enables us to calculate the pure technical efficiency and scale efficiency. Both mathematical models can be input- or output-oriented. The output-oriented CCR model is presented in equation (4) as follows:

$$\begin{aligned} [d_o(x, y)]^{-1} &= \max_{\phi, \lambda} \phi \\ \text{s.t.} \quad & -\phi y_i + Y\lambda \geq 0 \\ & x_i - X\lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \quad (4.)$$

where:

- y_i = output vector $M \times 1$ of the “ n -th” DMU;
- x_i = input vector $K \times 1$ of the “ n -th” DMU;
- Y = output matrix $N \times M$ for all n DMUs;
- X = input matrix $N \times K$ for all n DMUs;
- λ = vector of weights (utilities) $N \times 1$; and
- ϕ = productive efficiency.

Application of the data envelopment analysis-Malmquist model

To use the DEA-Malmquist model in our research, we determined the input and output variables of the model according to the data provided by the PIAs. The definition of the variables is registered in Table 1, in which the values were deflated according to as follows:

- the producer’s price index (IPP, in Portuguese; data from 2009) for revenue and costs, customized for each industry; and
- the consumer’s price index (IPCA, in Portuguese; data from 2009) for the salaries.

The PIA identifies the basic structural characteristics of the industrial activity in Brazil based on the National Classification of Economic Activities (CNAE, in Portuguese). Based on the International Standard Industrial Classification of All Economic Activities, the CNAE is a classification structured hierarchically in 5 levels, with 21 sections (1-digit), 87 divisions (2-digit), 285 groups (3-digit), 673 classes and 1,318 subclasses.

According to the information provided in the previous topic, we analyzed herein only the manufacturing sector – section C of the CNAE. More specifically, section C of the CNAE includes 24 manufacturing sectors (divisions, two-digit), selecting 100 industries (groups, three-digit). The following three of them had to be eliminated due to missing data:

- (1) 30.3 – manufacturing of railway vehicles;
- (2) 30.4 – manufacturing of aircraft; and
- (3) 30.5 – manufacturing of military fighting vehicles.

The values obtained from the resolution of the DEA-Malmquist model of the manufacturing sectors, which will be presented and discussed herein, are geometric averages of the values obtained from the industries; e.g. the results obtained for the food sector are geometric averages of its nine industries mentioned below as follows:

Variable	Unit	Description
<i>Output</i>		
Net sales (REC)	$1.000 \times (\text{R\$ net sales})$	Gross revenues minus canceled sales and taxes by the total number of industries
<i>Input</i>		
Depreciation (DEP)	$1.000 \times (\text{R\$ depreciation})$	Total assets depreciation expense (operational or administrative use) by the total number of industries
Labor cost (LC)	$1.000 \times (\text{R\$ salary and labor charges})$	Total labor cost, the sum of salaries, withdrawals and other remuneration with social charges, labor indemnities and benefits granted to employees
Operating costs (OC)	$1.000 \times (\text{R\$ operating costs})$	Total cost involved directly and indirectly in production, excluding DEP and LC

Table 1.
PIAs’ variables used
in DEA-Malmquist
model

- (1) Processing and preserving of meat (10.1);
- (2) Processing and preserving of fish (10.2);
- (3) Processing and preserving of fruit and vegetables (10.3);
- (4) Vegetable and animal oils and fats (10.4);
- (5) Dairy products (10.5);
- (6) Grain mill products, starches products (10.6);
- (7) Processing and refinery of sugar (10.7);
- (8) Roasting and grinding of coffee (10.8); and
- (9) Other food products (10.9).

The DEA-Malmquist model used in our research presents an output orientation. We chose such approach to calculate the CT of the food sector and to compare such measures with the values presented by other manufacturing sectors, considering a standard scenario of maximum production of outputs keeping the inputs at a constant level. The values of CT, CE and MI were calculated through the program DEAP, version 2.1, of the center for efficiency and productivity analysis from the University of Queensland, Australia. The variables selected are presented in Table 1. Conforming to literature, we defined the revenue as one output and three inputs based on depreciation, personal, operational and economic costs (Chen & Ali, 2004; Färe et al., 1994, 1998; Gitto & Mancuso, 2012; Odeck, 2009). The economic and financial data were provided by the PIAs.

Regarding the analysis and interpretation of the values of CE, CT and MI as follows:

- When $CE > 1$, efficiency increased during the period analyzed; when $CE = 1$, efficiency remained the same; when $CE < 1$, efficiency decreased during the period under analysis;
- When $CT > 1$, changes in technology (also considered as a synonym for innovation) occurred; when $CT = 1$, technology remained the same (non-occurrence of innovation); when $CT < 1$, technology declined; and
- When $MI > 1$; TFP increased among periods; when $MI = 1$, TFP remained the same among periods; when $MI < 1$, TFP declined during the periods under analysis.

To classify the manufacturing and food sectors regarding their level of performance in innovative activities, we used the following pre-defined classification: high innovative performance (Group 1, which encompasses the highest values); medium innovative performance (Group 2, which encompasses intermediate values); and low innovative performance (Group 3, which encompasses the lowest values). The OECD presented such configuration to analyze the technological intensity of sectors.

In addition to the OECD classification to analyzing the TI, we also used additional data provided by PINTEC from the years 2008, 2011 and 2014, which bring information necessary to create national indicators on the innovation activities accomplished by Brazilian companies. Conforming to IBGE (2016), the data provided by PINTEC focus on product and process innovation, and even includes marketing and organizational innovations. According to the Oslo manual, it is necessary to expand the concept of innovation – including marketing and organizational innovations – because the technology developed in low-tech manufacturing sectors are often not encompassed by the concept of product or process innovation.

Results and discussion

We observed several singularities in the food sector when comparing it to other manufacturing sectors through the analysis of the economic and financial data used in the measurement model of CE and CT through the DEA-Malmquist method. We will analyze the outcomes found in the food sector in the following two different ways:

- (1) sectoral evaluation, in which we analyze the manufacturing sectors by comparing the food sector (two-digit analysis); and
- (2) industrial evaluation, in which we analyze the industries of each sector and compare the nine food industries with the other ones (a three-digit analysis).

Our first analysis will present outcomes related to the classification provided by OECD and to the data provided by PINTEC.

Sectoral investigation: Manufacturing

Using IBGE-CNAE classification, at its two-digit hierarchy level, the food sector (10) presented a geometric mean of the MI of 0.989, suggesting that, on average, there was a decrease in the TFP over the period analyzed. Such value is lower than the average MI of the other manufacturing sector (0.992). Of 24 sectors, only four presented an increase in the TFP (Table 2).

However, conforming to the information displayed in Table 2, the group with high TI – conforming to the classification of OECD – presented the highest average MI (1.015), which indicates that this is the group of sectors with the highest TFP average increase. Among this group, sector 26 (computer, electronic and optic equipment) presented the highest average MI (1.037). On the other hand, the sectors with medium and low TI presented a decrease in their TFP ($MI < 1.000$); respectively, 0.990 and 0.989. Therefore, we can infer that the sectors with high TI, on average, present the highest increase of TFP over the period under analysis.

When evaluating the CT (innovation proxy) of the food sector, according to Table 2, we verify an average of 0.990. This value is slightly superior to the average CT of the low TI manufacturing sectors (0.989). During the period under analysis, we demonstrate that this sector presented a setback in technology ($CT < 1,000$) and the average of the manufacturing sector. Besides, as observed in Table 2, of 24 sectors, only three presented an increase in CT (26, 20 and 17).

By ranking the average values of CT of the 24 manufacturing sectors, of the 17 available positions (considering that there was a tie between some sectors), the food sector ranked 10th. When we analyzed the group with low TI, of the 11 industries, the food sector ranked 5th. In both cases, we verified intermediate positions; slightly below the average of the manufacturing sector (0.991).

Additionally, as observed in Table 2, the manufacturing sectors with high TI – according to OECD – presented the highest average CT (1.005), being the only one observed technological progress ($CT > 1,000$) over the period analyzed, resulting in innovation in the sector. Sector 26 (computer, electronic and optic equipment) presented the highest CT (1.029). As emphasized by Pavitt (1984), this sector relies on science-based companies, in which the main sources of technology are R&D activities.

On the other hand, the groups with medium and low TI presented a setback in technology (0.990 and 0.989, respectively). We suggest that – such as the MI indicates – the sectors with high TI tend to expand their technology frontiers, promoting technological progress and innovation; the high level of TI works as an inductor in this process.

Table 2.
Technology intensity
(TI), changes in
efficiency (CE),
changes in
technology (CT),
Malmquist index
(MI) and investments
in R&D of the
manufacturing
sectors

TI (OECD)	Manufacturing sectors	Means (2009–2016)				Rank	Group rank (TI)	Inv. (%) R&D (2008–2014)
		CE	CT	MI				
High	21: Pharmaceutical-chemical products	1.012	0.982	0.994	14	2		6.64
Means	26: Computer, electronic and optic equipment	1.008	1.029	1.037	1	1		4.66
		1.010	1.005	1.015	–	–		5.37
Medium	19: Coke and refined petroleum products	0.995	0.996	0.991	5	3		2.65
	20: Chemicals and chemical products	0.999	1.002	1.001	2	1		3.01
	22: Rubber and plastics products	1.007	0.992	0.999	8	4		3.10
	23: Non-metallic mineral products	1.000	0.997	0.997	4	2		2.53
	24: Basic metals	1.011	0.989	1.000	11	6		2.77
	25: Fabricated metal products, except machinery and equipment	0.997	0.991	0.988	9	5		3.01
	27: Electrical equipment	1.008	0.980	0.988	16	9		4.07
	28: Machinery and equipment	1.005	0.981	0.986	15	8		3.09
	29: Motor vehicles, trailers and semi-trailers	0.974	0.991	0.965	9	5		4.09
	30: Other transport equipment	1.002	0.989	0.991	11	6		8.71
Means	33: Repair and installation of machinery and equipment	1.000	0.983	0.983	13	7		2.48
		1.000	0.990	0.990	–	–		3.31
Low	10: Food products	0.999	0.990	0.989	10	5		1.99
	11: Beverages	1.000	0.983	0.983	13	8		2.58
	12: Tobacco products	0.988	0.997	0.985	4	2		2.28
	13: Textiles	1.005	0.993	0.998	7	4		2.31
	14: Wearing apparel	1.000	0.957	0.957	17	9		1.89
	15: Leather and related products	1.006	0.994	1.000	6	3		2.69
	16: Wood and products of wood and cork	1.001	0.997	0.998	4	2		3.24
	17: Paper and paper products	1.017	1.001	1.018	3	1		2.37
	18: Printing and reproduction of recorded media	1.013	0.989	1.002	11	6		4.61
	31: Furniture	0.989	0.985	0.974	12	7		2.93
Means	32: Other manufacturing	0.999	0.989	0.988	11	6		3.34
		1.002	0.989	0.990	–	–		2.21
Manufacturing means		1.001	0.991	0.992	–	–		3.06

There is a coherence between the classification of the level of TI and the representation of the total financial investment in R&D as a percentage of the net income. The group with high TI presents the highest average percentage investment (5.37%), followed by the group with medium TI with an average percentage investment of 3.31%. The group with low TI presents an average percentage investment in R&D of only 2.21%.

When specifically analyzing the financial effort toward innovation in the food sector, between 2008 and 2011, in accordance with PINTEC, this sector invested 1.99% of its revenues in R&D. When comparing this value with the average of the group with low TI and with the average of the manufacturing sector, this value is below the averages, which were 2.21% and 3.06%, respectively. Among the 24 manufacturing sectors analyzed by PINTEC, the food sector ranks 23th, which is ahead of only wearing the apparel industry, which presented the lowest investment in R&D (1.89%). This investment emphasizes the studies of Pavitt (1984), who claims that this sector relies on innovations made by other sectors.

Therefore, we suggest that the low percentage of investment in R&D in the food sector leads to an intermediate position in terms of technological efficiency and progress and, consequently, TFP. The share of higher investments in R&D as a percentage of the net income indicates a possible strategic action to be implemented in the management of the food sector to increase not only the TFP but also the technological process, leading to innovation. Such an outcome is in accordance with the studies of Raimundo et al. (2017), in which the authors claim that the investments in R&D are still relatively low; the main technology strategy is imitation, i.e. there is a more incorporative characteristic instead of the generation of new technologies.

These low investments in R&D can be related to the characteristics of the innovations in the sector, which are largely related to incremental processes (Bigliardi & Galati, 2013; Capitanio et al., 2010; Kumar & Basu, 2008; Martinez & Briz, 2000; Raimundo et al., 2017). As pointed out by Kumar and Basu (2008), the Brazilian food sector is also far from achieving its full potential, with a technological regression and inefficiencies of companies. It is, therefore, necessary to stimulate investments in R&D to ensure technological progress in this sector (Kumar & Basu, 2008).

Besides, according to the model presented by Capitanio et al. (2010) (Figure 1), several internal and external factors define the organizational model of the company and, consequently, its investment in R&D. This way, it is also relevant to study these different factors to understand how they influence the different R&D activities of the food sector.

Industrial investigation: Manufacturing and food industries

By using the classification IBGE-CNAE, at its two-digit hierarchy level, when analyzing the 100 manufacturing industries listed, we verified that industries 17.1 (pulp, paper and paperboard), 25.5 (military equipment, weapons and ammunition) and 26.8 (magnetic and optical media) presented the three highest average results of CT; respectively, 1.038, 1.024 and 1.023. Of 100 industries analyzed, we observed that only 18 presented technological progress. In Table 3, we demonstrate the maximum and the minimum of each technological intensity group.

According to Table 3, only 10 industries are part of the group with high TI, in which the remaining industries are divided into groups of medium TI (50 industries) and low TI (40 industries). We emphasize that, despite fitting as an industry with low technological intensity, the pulp, paper and paperboard industry (17.1) achieved the highest evolution of its technology frontier, with a CT of 1.038.

Regarding the low technological intensity, it should be noted that the minimum corresponds to industry 10.4 (vegetable and animal oils and fats) of the food sector, ranking

Table 3.
Technology intensity
(TI), changes in
efficiency (CE),
changes in
technology (CT),
Malmquist index
(MI) and sectors rank

TI (OECD)	CT	N	Industries	Means (2009–2016)			Rank
				CE	CT	MI	
High	Maximum	1	26.8: Magnetic and optical media	1.034	1.023	1.058	3
	Minimum	1	21.2: Pharmaceuticals products	1.016	0.984	1.000	30
		10	Means	1.016	1.003	1.019	–
Medium	Maximum	1	25.5: Military equipment, weapons and ammunition	0.981	1.024	1.005	2
	Minimum	1	27.3: Electricity distribution and control apparatus	1.001	0.974	0.975	36
		50	Means	1.001	0.993	0.994	–
Low	Maximum	1	17.1: > Pulp, paper and paperboard	1.000	1.038	1.038	1
	Minimum	1	10.4: Vegetable and animal oils and fats	1.000	0.969	0.969	37
		40	Means	1.002	0.991	0.993	–
		100	Industries means	1.003	0.993	0.998	–

37th in the general ranking, in which, due to ties between divisions, it is the last placed. Specifically, the food industries are summarized in Table 4.

According to Table 4, the processing and refinery of the sugar industry (10.7) were the only ones among the food industries to demonstrate an evolution in its technology frontier, with a CT of 1.012. In addition, to the production of ethanol (Silva et al., 2019), sugar cane is an input used in the sugar refinery industry. As we analyzed, the main innovations of the food sector are based on the formulation of ingredients (Gouveia, 2006) meeting nutritional orientations and regulations (Bigliardi & Galati, 2013). The new orientations and regulations – in addition to the current demand for sugar reduction (ABIA, 2018b) – boost such evolution in the technology frontier. Besides, only industries 10.8 and 10.7 (MI of 1.004) indicated an average increase in their TFP during the period under analysis. In the first industry, the increase in the TFP was due to CE; in the second, CT.

Additionally, we elaborated a comparison in years (Table 5). Such comparison enabled us to realize that the processing and refinery of the sugar industry (10.7) presented 57.14% of evidence of technological progress ($CT > 1,000$). Such value is precisely the same as the average of industries with high TI, according to OECD classification. Therefore, we suggest that there is a behavior of innovation frequency like the average of industries with high TI.

When ranking the 100 manufacturing industries – in decreasing order and according to the average values of IM –, of the 37 positions reached (due to ties between some industries) the processing and refinery of the sugar industry (10.7) ranks 6th, which is the best result among food industries. On the other hand, the oil and vegetable and animal oils and fats industry (10.4) rank 37th (last position), as observed in Table 5.

Finally, considering the classification proposed by OECD to group industries according to their TI, we verified that companies belonging to the group with high TI have the highest average evolution of TFP, with an average MI of 1.019. These industries also present the highest average of evolution in the technology frontier, with an average MI of 1.003. These outcomes, at a granular level (industry), corroborate the results at a macro level (sectors), suggesting that higher financial investments as a percentage of the net income in R&D are responsible for providing higher average increases in productivity and innovation.

It is, therefore, important to understand the internal and external factors that define the organizational model of the company, according to Capitanio et al. (2010) (Figure 1). Besides, it is also relevant to investigate the investments in R&D of each division, especially 10.7. The size of the company (Cabral & Traill, 2001; Ettlie, 1983), the networking and the market power involved in the division (Karantininis, Sauer & Furtan, 2010, p. 119) are also relevant features.

Table 4.
Changes in efficiency
(CE), changes in
technology (CT),
Malmquist index
(MI) and industries
ranking

Food industries	Means (2009–2016)			Rank
	CE	CT	MI	
10.7: Processing and refinery of sugar	0.992	1.012	1.004	6
10.6: Grain mill products, starches products	0.990	1.000	0.990	15
10.8: Roasting and grinding of coffee	1.021	0.995	1.016	19
10.5: Dairy products	0.996	0.993	0.989	21
10.1: Processing and preserving of meat	1.004	0.991	0.995	23
10.3: Processing and preserving of fruit and vegetables	1.001	0.989	0.990	25
10.9: Other food products	1.005	0.989	0.994	25
10.2: Processing and preserving of fish	1.004	0.983	0.987	31
10.4: Vegetable and animal oils and fats	1.000	0.969	0.969	37
Food industries means	1.001	0.991	0.993	–

Table 5.
Changes in
technology (CT)
evolution in food
industries

Food industries	2010 x 2009		2011 x 2010		2012 x 2011		2013 x 2012		2014 x 2013		2015 x 2014		2016 x 2015		Means				CT				% cases with CT > 1,000
	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CE	CT	MI	Max.	Min.	Rank				
10.7: Processing and refinery of sugar	1.006	0.983	0.922	1.111	0.908	1.145	1.032	0.992	1.012	1.004	1.145	0.908	6	57.14									
10.6: Grain mill products, starches products	1.072	0.955	0.980	1.020	0.969	1.020	0.990	0.990	1.000	0.990	1.072	0.955	15	42.86									
10.8: Roasting and grinding of coffee	0.998	0.975	1.016	0.932	0.970	1.102	0.978	1.021	0.995	1.015	1.102	0.932	19	28.57									
10.5: Dairy products	1.068	0.929	0.993	0.995	0.950	1.014	1.008	0.996	0.993	0.989	1.068	0.929	21	42.86									
10.1: Processing and preserving of meat	1.012	0.962	1.037	0.911	0.968	1.103	0.958	1.004	0.991	0.996	1.103	0.911	23	42.86									
10.3: Processing and preserving of fruit and vegetables	1.016	0.960	1.044	0.927	0.958	1.132	0.904	1.002	0.989	0.990	1.132	0.904	25	42.86									
10.9: Other food products	0.980	0.984	0.985	0.986	1.001	1.052	0.934	1.005	0.988	0.993	1.052	0.934	25	28.57									
10.2: Processing and preserving of fish	0.952	0.969	1.015	0.947	0.962	1.131	0.922	1.004	0.983	0.987	1.131	0.922	31	28.57									
10.4: Vegetable and animal oils and fats	0.883	0.957	0.963	0.886	0.998	1.065	1.047	1.000	0.969	0.969	1.065	0.883	37	28.57									
Food industries means	0.997	0.964	0.994	0.966	0.965	1.084	0.974	1.001	0.991	0.993	1.084	0.964	-	14.29									
High TI industries means	1.030	0.954	0.980	1.023	0.963	1.072	1.003	1.016	1.003	1.019	1.072	0.954	-	57.14									
Medium TI industries means	1.003	0.985	0.978	0.985	0.976	1.081	0.936	1.002	0.991	0.993	1.081	0.936	-	28.57									
Low TI industries means	1.012	0.980	0.978	0.982	0.979	1.083	0.944	1.001	0.993	0.994	1.083	0.944	-	28.57									
Industries means	1.010	0.979	0.978	0.987	0.976	1.081	0.946	1.003	0.993	0.996	1.081	0.946	-	28.57									

Conclusions

The methodological construction is an advance achieved by this study, which analyzes the intensity of innovation-oriented to the improvement of the economic development of the food sector in Brazil in comparison with the other manufacturing sector in the country. Based on the application of the MI, especially regarding CT, we demonstrated a low occurrence of innovations oriented to the improvement of the economic development in most of the periods under analysis.

First, at a macro level, we observed that the food sector has – according to OECD and PINTEC – a low level of TI and investment in R&D, respectively. Additionally, the results affirm that there was a technological setback in the food sector, despite its superior position among the group with low TI. Generally, we noticed a setback in almost every sector; only the industries of computers, electronics and optical devices (26), chemical products (20), cellulose and paper (17) presented an evolution of CT.

We confirmed the statements by [Bigliardi and Galati \(2013\)](#), [Capitanio et al. \(2010\)](#), [Martinez and Briz \(2000\)](#) and [Raimundo et al. \(2017\)](#), who affirm that the food sector is typically classified as a sector with low research intensity, representing one of the lowest rates when compared to the other sectors. This way, the Brazilian food sector – represented by technological setbacks and inefficiency – is far from achieving its full potential.

Considering an evaluation at a micro level, the processing and refinery of the sugar industry (10.7) were the only ones among the food sector to show an evolution in its technology frontier. This division presented 54.17% of evidence of technological progress (CT > 1,000), which is value exactly equal to the average of the sector with high TI, according to the OECD classification. There is, therefore, a frequency of innovation like the average of the sector with high TI.

The participation of larger investments in R&D over the net income is a possible strategic action to be implemented in the management of the food sector, to increase both TFP and technological progress, leading to innovation.

In addition to investments, several internal and external factors define the organizational model of the company and, therefore, its investments and strategies. We suggest, as further research, a deeper study on the internal and external factors that make the innovation rates of the food below the average of the manufacturing sector in general such as the size of the organizations, networking, market power and, especially, consumer acceptance ([Bigliardi & Galati, 2013](#); [Cabral & Traill, 2001](#); [Capitanio et al., 2010](#); [Earle, 1997](#); [Ettlie, 1983](#); [Karantininis et al., 2010](#); [Werner et al., 2017](#)).

The methodological construction, despite being a goal achieved, is also a limitation of this study. Considering the particularities of the food sector, we emphasize that this method does not focus on the level (e.g. creation or imitation) and the nature of the innovation found in literature such as product, process, radical, incremental, technical, administrative, organizational, marketing and supply chain innovations. This way, we also suggest further research to investigate the nature of the innovations in the food sector. Another limitation found herein is that not every innovation arises from investments in R&D; the database used herein, however, only presented innovation stemming from this specific economic data.

Notes

1. In English, Brazilian association of food industries.
2. In English, Getúlio Vargas Foundation – often abbreviated as FGV.

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