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Felipe Figueiredo Silva[1], Marcelo Jose Braga[2], Joao Carlos Garcia[3]

Link between R&D intensity and market concentration: analysis of Brazilian corn and soybean seed markets

[1] Department of Agricultural Economics, University of Nebraska – Lincoln
[2] Departamento de Economia Rural, Universidade Federal de Viçosa - UFV
[3] Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA - Brazil

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Innovation in the Brazilian seed markets is one of the main driver of the Brazilian agricultural expansion during the last decades. However, these markets also experienced a market reconsolidation in the form of a market concentration. In this paper, we test the hypothesis that there is an inverse relationship between innovations and market structure at the seed market. We use a Generalized Method of Moments model applied to a theoretical framework that allowed us to determine the direction of this relationship. Our results suggested that this link depends on market characteristics, such as the introduction of genetically modified organisms (GMO). For corn (soybean), we find a positive (negative) relationship between these factors that has become negative (positive) in the period post-GMO introduction.

1. Introduction

Agriculture has long been one of the most important and dynamic sectors in the Brazilian economy. Some crops have consistently maintained their importance such as oranges and coffee, while others such as soybeans and, mainly, corn have become essential commodities in Brazilian domestic and external supplies in the last three decades. In 2012, Brazil was the third largest producer of corn and the second largest producer of soybeans (Food and Agriculture Organization of the United Nations - FAO, 2014).

One of the reasons for this agricultural expansion was the productivity enhancements and the cost-reduction found at the bottom of the agricultural chain, the seed market. Marin *et al.* (2015b) assert that up to 50% of the increase on agricultural productivity was generated in seed improvements. The use of biotechnology in the United States' agricultural industry in the 1990s enhanced seed production, which enabled the creation of such innovations as herbicide-tolerant seeds; these creations became known as genetically modified organisms (GMOs). By 2005, the National Technical Commission on Biosafety (CTNBIO) released this technique in Brazil, and, in 2011, the CTNBIO allowed 15 species of corn and 5 species of soybean to be produced as GMOs (CTNBIO, 2011).

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For instance, corn and soybean seed markets are highly concentrated, as the *Herfindahl-Hirschman Index* (HHI)[1] indicates. The corn seed market displays high HHI (above 2500) mainly after the legally introduction of seeds with GMOs technology in the market. The soybean seed market has a volatile HHI across the period (1999 to 2010) but mainly on the moderately market concentration classificatory. Medina *et al.* (2016) indicate that the international soybean seed market, especially the portion with GMO, has been controlled mainly by six firms, and in Brazil, mainly by one firm, Monsanto.

Although these markets display high market concentration, the firms also have high rates of Research and Development (R&D). Corn and soybean seed markets have shown an increase on R&D mainly led by private firms. In 2010, 1677 and 784 new cultivars were registered since 1999 on the National Cultivar Registration (NCR[2]). Medina *et al.* (2016) indicate the commercial agreements to transfer technology to national and other firms as a mechanism to incentivize the development of new seeds in Brazil. Marin *et al.* (2015b) calculated an average growth rate of 14% for the new seed of varieties in Brazil (two times larger compared to Argentina) for the period 1999-2013, which also corroborates our analysis. These authors also indicate that the majority of the new seeds are for soybean (27% of the new cultivars) and maize (54%).

The link between market concentration and R&D has been vastly investigated in the literature. There is no consensus on its direction since it depends on specific market characteristics such as product specificities. Brazilian soybean and corn seed markets have different market and R&D structure, and specific characteristics like commercial agreement fulfilments, which we expect to affect the link between these factors. For instance, Schimmelpfennig, Pray and Brennan (2004) investigated this link in the United States seed industry and they found an inverse relationship between these two factors. Other authors, described later, found a different impact of market concentration on R&D intensity.

In this paper, we estimate the link between intensity of research and market concentration on Brazilian corn and soybean seed markets. We also estimate the impact of public research on the intensity of research in these markets. This paper is a first step towards the investigation of this relationship.

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[1] It is the sum of the square of the market share of all companies in the market. See the Horizontal Merger Guidelines for more details (http://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c). The United States Department of Justice uses this document as base for anti-trust policies. On section 5 of this document, unconcentrated markets have HHI below 1500, moderately concentrated markets have between 1500 and 2500, and highly concentrated market have above 2500.

[2] In Portuguese, it is known as Registro Nacional de Cultivares.

Since agriculture is highly dependent on seed markets and even more on this sector's innovative outcomes, our results contribute to anti-trust policy investigations of these markets performance by the Brazilian government, and indirectly address social welfare.

The reminder of this study will be organized in the following way: section 2 will present a characterization of the markets; section 3 presents the economic model; section 4 the empirical specification and the data; section 5 discusses the results; and finally section 6 summarizes the results.

2. Brazilian soybean and corn seed market

Although exits a straight link between firms from different countries (headquarters on United States and firms in Brazil), geographic and edapho-climatic characteristics of Brazil do not allow an extreme interchange of seed among countries (or regions). As we will describe, the Merger and Acquisition (M&A) process led by foreign firms that occurred in the 1990s was mainly aiming to obtain the local technology. The Brazilian institution that investigates anti-trust actions, Economic Monitoring Department (SEAE[3])[4], also uses this market definition to evaluate the process.

Until the mid-1990s, the companies that dominated and innovated in the Brazilian seed market were mainly public firms such as EMBRAPA, Brazilian Agricultural Research Corporation[5]. This situation stemmed from private firms' difficulty in garnering a return on investment in research and development. However, with the creation of the Law of Protection of Plant Varieties (LPC) in 1997, the M&A process, and later, the introduction of GMOs on the market created the conditions for a reconsolidation process within seed markets. International groups such as Monsanto, Dow Agroscience, Pioneer, and Syngenta were the main firms involved in this process that transformed the market.

The process of M&A for international firms was essential to achieve the distribution and marketing networks for the already established businesses. Furthermore, the process enabled the formation of an essential tool for the development of new seeds: cultivar banks (germplasm), which were characterized by a rich source of material for the development of seeds with specifications for climate/soil types in Brazil. In addition, the technology transfer from the headquarters of international companies to Brazil contributed to the per-

3 In Portuguese is known as Secretaria de Acompanhamento Econômico.

4 Between 2000 and 2010, this institution evaluate more than 30 process. In all of them, they approved the process of acquisition, agreement (commercial), licensing or cooperation.

5 In Portuguese, is known as Empresa Brasileira de Pesquisa Agropecuária.

Tab. 1. *Herfindahl-Hirschman Index* (HHI), Concentration Ratio for firms (CR4), accumulated number of registered cultivars at the NCR and participation of public firms on accumulated number of registered cultivars.

Year	Soybean seed market				Corn seed market			
	HHI	CR4	Registered Cultivars	% Reg. Public	HHI	CR4	Registered Cultivar	% Reg. Public Firms
1999	3.359	89	211	*60*	2.233	79	451	*16*
2005	1622	74	457	*53*	1.592	74	721	*15*
2010	1.714	70	784	*41*	2.692	82	1677	*11*

Source: Own elaboration.

petuation of their research as well as to an intensification of market concentration in the seed market.

The reconsolidation of these markets affected both market concentration (Bruch *et al.*, 2005) and innovative activities by transforming the associations (M&A and agreements) between foreign and domestic firms. In the late 1990s, the expansion of international firms demarcated the beginning of market concentration, especially in Brazilian corn and soybean seed markets. These markets stood out for their relevance to Brazilian agriculture and for their innovative activity.

Table 1 displays market structure (concentration) and intensity of research (measured by the number of registered cultivars) oscillation over 2000s, and the *Herfindahl-Hirschman Index* (HHI) and the Concentration Ratio for the larger four firms (CR4) measure market concentration[6]. It is estimated[7] based on the amount produced of each cultivar (seed) not on sales (value). In this paper, we consider the number of cultivars as the outcome of firms' Research and Development (R&D). It is well known that before bringing a product to the market several versions of its final product are developed. The number of cultivars at the NCR represents this number of trials since, in 1999, for example, only 27% of the registered corn cultivars were commercialized in the Brazilian seed market.

The new seeds (registered in the NCR) are endowed with new features and received code-names of cultivars[8]. By 2010, corn held the largest number of

[6] It is the sum of the shares (firm participation in the market) for the four larger firms.

[7] It is conventionally estimated based on sales (value) and not quantity. The fact that we are using quantity might mask the real market concentration measure since it assumes that seed are homogenous.

[8] Certain requirements are necessary to register a cultivar: distinctness, uniformity, stable and novelty. (AVIANI, 2011).

registers – with 1677 on record – while soybean had 784. Both the LPC and the NCR also acted to ensure the appropriateness of the return on investment in research for the companies developing these seeds.

These innovations can have further differentiation according to their level of development. Santini and Paulillo (2001) define an innovation as "radical"[9] if it includes genetic modifications to the organism (i.e., GMO) and "marginal" if the process for creating the seed included the traditional method of genetic breeding. Within the corn hybrid market, the innovative intensity can be distinguished from that of others by the presence of the industrial-secret as a mechanism of appropriation; hybrid seeds prevent farmers from replanting with the same yield and quality of the first crop, and the manner in which they are obtained takes place by means of the industrial secret. Such innovations not only mark the change in the seed themselves, but demonstrate the change in the market structure.

Brazilian anti-trust institution, SEAE, suggests that a CR4 higher than 75% might lead to market power exercise, which also corroborates the importance of an analysis of these markets. Figure 1 shows HHI and accumulated variation of registered cultivars at NCR for a long period, corroborating the oscillation of market concentration but also showing a link between it and the intensity of research.

Public firms such as EMBRAPA and universities have shown a decreased participation in the seed markets compare to its importance on late 1990s. However, they still play an important role in taking technology to regions of Brazil where private firms do not reach. Santini and Paulillo (2001) cconfirm its importance and point out its relevance in soybean expansion in the late 1990s.

Figure 1 presents the market concentration and the variation[10] in the number of registered cultivars (innovative activity) over time. The corn seed market shows a concentrating tendency and a marked expansion in the number of registrations since 2008 due to the introduction of GMO seeds. Mainly this transformation happened by the M&A process and by the introduction of GMOs in this market. The roll of public firms in the corn seed market (i.e., their share of cultivars registered) decreased in the period from 1999 (24%) to 2010 (6%); simultaneously, their share of seed sold in the market also decreased. The graph also shows that the vast number of cultivars in the NCR provided more variety for implementing the genetic modification, resulting in more outcomes (registers).

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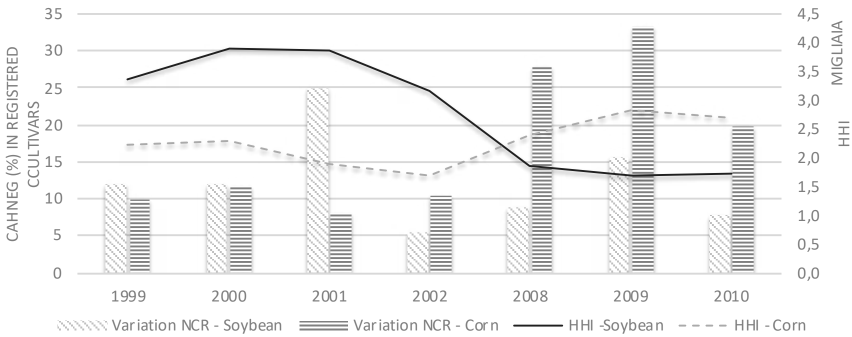
[9] Lapan and Moschini (2007) also discussed about radical innovations but related to labeling issues on genetically modified products.

[10] It consists of a percentage change of registered cultivars with respect to the previous year. For corn, in 2009, registered cultivars increase around 10% with respect to 1998.

Fig. 1. Herfindahl-Hirschman Index (HHI) and annual variation of the registrations of cultivars for corn and soybeans.



Source: processed by the author using data from the Ministry of Agriculture, Livestock and Supply (MAPA) and from the RNC.

Figure 1 corroborates the research evolution wherein foreign companies with GMO seeds gained domestic space, which suggests a concentration also in this factor. During this same period, the soybean seed market shows a declining trend in its market concentration, and the annual variation of registrations oscillated over the period in consideration. After the insertion of GMO seeds in 2005, the concentration rate stabilized, although it remains high due to the loss of market share of EMBRAPA and to the expansion of international companies. The number of registrations shows oscillating behavior with similar reactions. We can clearly identify a relationship between research and market concentration with a game change between 2002 and 2008, when the use of GMO was authorized.

In addition, several agreements such as technology transfers between foreign and Brazilian firms occurred increasing the geographical area of operation of foreign firms. They occurred due to the large geographical area of Brazil and the impossibility of the firm to realize research for each Brazilian edaphoclimatic area. These agreements occurred more often in the soybean seed market since this market does not have the hybrid[11] characteristic that corn seed market has. For example, Benetti (2002) describes the importance of the agreement between Monsanto and EMBRAPA on the 1990s to increase the former operation in Brazil.

[11] It works as natural way of firms obtain the returns of research since the second generation of its plantation (re-utilizing/planting from the same seed) shows lower productivity.

The M&A process led to a decrease in public firms importance due to the incorporation of national private firms by foreign firms, such as FT Sementes and Agroceres, which affected both the public firms' research and market structure. Both corn and soybean markets experienced reconsolidation in Brazil after the creation of the LPC, and both markets experienced an M&A process and the introduction of GMOs. However, the reconsolidation was not uniform in both the corn and soybean seed markets and resulted in different outcomes in each of the markets.

Medina *et al.* (2016)[12] assert that although the agricultural sector has been highly productive also due to the innovations in the seed industry, this sector and its innovative process has a large participation of international companies. Only 16.5% of the seed production is on national firms' hands and 0% of the GMO seeds are on national firms' hands. Marin *et al.* (2015b) also argue that domestic seed firms accounted for less than 20% of the new seed varieties while in Argentina it was almost 50%. In addition to the current structure, Faria (2018) indicates that Monsanto seeks to increase its participation on the soybean market by introducing six new varieties of soybean seeds that have specific regional characteristics. She asserts that Monsanto will be able to double its market share with these new varieties and that this company is currently doing research with more than 25 varieties varieties of this crop.

Marin *et al.* (2015b)[13] studied the seed market[14] in Brazil and Argentina qualitatively and quantitatively. They concluded that domestic firms[15] had more opportunities to develop in Argentina compared to Brazil. In addition to examine data from NCR, they performed a case study of three large companies in these countries: Tropical Melhoramento e Genetica (TMG), Nidera and Don Mario/Brasmax. They also conclude that domestic firms have served the market providing seed diversity; producing seeds with regional or climatic specific characteristics.

The analysis of the Table 1 and Figure 1 clearly reveals an impact on innovation that resulted from the market concentration, with visible reactions diverging according to the market being investigated. All of these facts raise the question: what is the link between innovative activity and market concentration in each of these markets? Does it depends on each market? Does it change with the innovations?

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[12] Medina (2017) also discuss the agricultural sector, the national public policies and the dynamic interaction with international markets and organizations.

[13] Marin and Stubrin (2015) also performed a similar analysis to the Argentine seed industry.

[14] The seed markets: maize, soya, wheat, sunflower, cotton and rice.

[15] They argue that Brazilian domestic firms contribute more to new seed varieties in the wheat and sunflower seed markets.

3. Economic model

Schumpeter (1984, 1985) and Arrow (1962) stood out for extensively discussing the role of innovation as a propulsion engine for economics. However, these two authors present almost antagonistic views of the relationship between innovation and market structure. Schumpeter (1984) argues that innovative activity does not occur in firms under perfect competition conditions but rather in large firms operating in imperfect markets. With regards to agriculture, he states that large firms enable innovation, concluding that these firms contribute to improving the standard of living rather than to obstructing it.

On other hand, Arrow (1962) states that there are incentives for innovation under perfect competition in product markets. The author emphasizes that such incentives occur especially in cases where invention reduces costs, though Arrow assumes that royalty payments do not distort the natural structure of the competitive industry in question. He ignores the difficulty of appropriation of information and assumes that the costs will be constant both before and after the innovation. From these assumptions, the author concludes that the competitive structure fosters innovation.

Several papers study this relationship, such as Arvanitis (2008), Becker and Dietz (2004), Gottschalk and Janz (2001), Cohen and Levin (1984), Levin *et al.* (1985), Levin and Reiss (1989), Farber (1981), Lunn (1986), Lunn and Martin (1986), Levin and Reiss (1984), Link (1980), Dasgupta and Stiglitz (1980), and Scherer (1965). Specifically, Levin and Reiss (1984, 1989) developed a structural model that considers market structure endogenous. Our economic model is based on this model and it will be described in the next paragraphs. Gottschalk and Janz (2001) applied a similar theoretical framework based on Levin and Reiss (1989) to a panel data of industries in Germany and they found that increasing market concentration decreased research and development on these markets.

Schimmelpfennig, Pray and Brennan (2004) also used this theoretical framework to evaluate the link between market concentration and intensity of research for the seed market on the United States. They found that increasing market concentration decreased research on these markets during the 1990s. Levin and Reiss (1984) and Schimmelpfennig, Pray and Brennan (2004) framework is adopted since it is suitable to the Brazilian corn and the soybean seed market structure.

Assume that the industry inverse demand for seed for each market is $P(Q)$ where $Q=\sum_{I=1}^{N} q_i$ and q_i is the output produced by firm i. Also assume that the cost of firm i can be represented by $c_i(x_i,X)$ where x_i is the amount of research and development conducted by the firm i, and is the knowledge of the whole industry available for firm i $\sum_{i=1}^{N} x_i = X$. We also assume that $\partial c_i/\partial x_i > 0$, $\partial c_i/\partial X > 0$, that second order derivatives are negative, and $\partial X_i/\partial x_i = \theta$ as in Schimmelpfennig, Pray and Brennan (2004).

As in Levin and Reiss (1984, 1989) and Schimmelpfennig, Pray and Brennan (2004), we assume that firms are profit maximizing and behave with a Cournot-Nash equilibrium relative to the amount produced and to the decision of other firms' R&D and that spillover does exist. This can be represented by

$$max_{q_i, x_i,} \pi_i = \left(P(Q) - c_i\left(x_i, X\right)\right) q_i - x_i \qquad (1)$$

We assume that all companies are faced with the same decision problem, and therefore a symmetrical equilibrium is taking place. The three first-order conditions and the condition of zero profit for firm i are:

$$P\left[1 - \frac{1}{\varepsilon N}\right] = c \qquad (2)$$

$$-\left[\frac{\partial C}{\partial x} + \frac{\partial C}{\partial X}\right] q = 1 \qquad (3)$$

$$\left[P - C\right] q = x \qquad (4)$$

where ε represents the price elasticity of demand. From (2) and (4)[16], we can find the equation that explains the market concentration. To do so, we multiply (4) by N (the number of firms) so as to obtain the condition of profit for all firms. Afterwards, we replace (2) in (4), finding:

$$H = \varepsilon R \qquad (5)$$

where $H = 1/N$ stands for *HHI* for identical firms; and R, the ratio between the R&D and sales of the firm.

Levin and Reiss (1984) and Schimmelpfennig, Pray and Brennan (2004) present an equation for the R&D intensity[17] using the first order conditions.

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[16] Equation (2) is derived as $\partial\pi_i/\partial q_i$, equation (3) is $\partial\pi_i/\partial x_i$, and equation (4) is the zero profit constrain.

[17] Levin and Reiss (1989) and Gottschalk and Janz (2001) shows equations for each type of R&D, in product or in process sphere, and the unified equation.

Following Levin and Reiss (1984) and Schimmelpfennig, Pray and Brennan (2004) we can find an equation for the R&D intensity using Eq. (3). To obtain this equation, multiply by $R = x_i/pq_i$, multiply the left hand side by c/c and rearranging we find

$$-\left[\frac{\partial c}{\partial x}\frac{x_i}{c}+\frac{\partial c}{\partial X}\frac{x_i}{c}\right]\frac{c}{p}=R \tag{6}$$

Using $x_i = X/N$ and $c/c = 1–R$[18] we can find

$$\frac{R}{1-R}=\alpha+\gamma\theta H \tag{7}$$

where α represents the technological opportunity; γ is the elasticity of cost with respect to industry R&D (X) keeping constant firm own R&D constant (Schimmelpfennig, Pray and Brennan, 2004). It measures the extent to which research is appropriated by the innovator or by other firms (spillovers).

4. Data and specification

4.1 Data

Our dataset consists of firms on each seed market, soybean and corn, for the period 1999 to 2010 but with gaps. We have data on public and private firms. Most of the data is confidential given its source. The panel data constructed in this paper is not perfectly balanced since some firms do not appear in all years; however, the most important firms – summing at least 80% of the market share – are in all years used in this empirical part.

Market concentration is based on the *Herfindahl-Hirschman Index* (HHI)[19], y_1 It is obtained by estimating the production[20] of cultivars[21]. These

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[18] You can obtain this equation from Eq. (4), dividing both sides by p and dividing though by q.

[19] HHI estimation is well known and disseminated. It estimation is the sum of the square of shares of each firm on the market $HHI=\sum_{i=1}^{N}s_i^2$.

[20] Production of cultivars refers to firms' fields of seed development before going to sales (market).

[21] Unfortunately, we did not have access to sales data to estimate the HHI based on monetary values. An HHI based on quantities implies assuming homogeneous products, which might affect the results once seed markets are described by having differentiated products.

data are constructed from the Superintendents of the Ministries of Agriculture, Livestock and Supplies (SMAPA) and the EMBRAPA Milho e Sorgo (EMBRAPA Maize and Sorghum) database. The database of SMAPA refers to the years 2007, 2008, 2009, and 2010, while the one from EMBRAPA includes the years 1999, 2000, 2001, 2002, and 2004. In addition, we use data from SEAE for the soybean seed market for 2005.

The ratio of the number of registrations to the estimated production of each firm stands in for the research (innovation) intensity (y_2) which is similar to a measure developed by Schimmelpfennig, Pray and Brennan (2004). In addition, the number of registrations also represents a protection mechanism to the cultivar developed, which disables other firms from creating and obtaining similar cultivars.

The public research measured as a technological opportunity (α) is represented by the number of registrations of cultivars filed by public institutions (x_1). We include two factors that might reflect approapriability and access to industry R&D. Productivity (y_1) of spillovers is represented by the number of species the firm realize research (z_1) number of registered species at the NCR. It aims to find complementarity on R&D. It indicates whether there are spillovers between species R&D; i.e. effect of research on cotton over soybean research developed by the same firm. Extent of spillovers (y_2) is represented by the number of registrations of private firms (z_2) as demonstrated in Schimmelpfennig, Pray and Brennan (2004). Table 2 summarizes the variables as well as reports and indicates the source.

Table 3 displays the overall (*pool*) average, minimum and maximum of each variable described in Table 1 for each of the seed markets. As described on the previous section, HHI (y_1) on average is 0.22 (or 2200) and 0.26 (or 2600) for corn and soybean, which is considered moderately and highly concentrated, respectively. Intensity of research (y_2) has a smaller average[22] for soybean as expected, since research is more intense on corn seed market due to the existence of a natural appropriability mechanism (hybrid).

The expansion of private firms, occasioned mainly in the late 2000s, increased the market concentration, leading to a HHI index with high values – such as means of 2.242 and 2.610 for corn and soybeans seed markets, respectively. In 2010, the market for corn seeds showed the HHI equivalent to 2692 – which is considered a high level of concentration–while soybean was 1714. However, in both markets, there were firms with more than 25% of market share.

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[22] Keep on mind that intensity of research is calculated as the number of registered cultivars divided by the estimated production.

Tab. 2. Variables used on empirical specification, description, and source of the data.

Variables	Description	Source
y_1	*Herfindahl-Hirschman Index*	EMBRAPA SEAE [c] SMAPA[b]
y_2	Intensity of Research – ratio between the number of registrations in RNC and the amount produced	NCR [a] SMAPA[b]
Technological Opportunity		
x_1	Public Research – number of registrations of public companies in RNC	NCR [a]
Appropriability		
z_1	Differentiation in Research and Development –number of species registered in RNC	NCR [a]
z_2	Patents of private companies – number of registrations of private companies in RNC	

[a] NCR – National Cultivar Registration; [b] SMAPA – Superintendents of the Ministries of Agriculture, Livestock and Supplies; [c] SEAE – Economic Monitoring Department.
Source: processed by the authors.

Tab. 3. Descriptive statistics for seed markets during the 1999-2010 period.

Variables	Corn seed market			Soybean seed market		
	Overall Average	Minimum	Maximum	Overall Average	Minimum	Maximum
y_1	0.22	0.16	0.28	0.26	0.16	0.39
y_2	0.02	0.00	2.17	0.00	0.00	0.07
x_1	123.48	72.00	185.00	231.06	126.00	319.00
z_1	9.67	0.00	61.00	11.40	0.00	61.00
z_2	804.70	366.00	1492.00	254.88	75.00	465.00

Source: processed by the authors.

The number of registered cultivars by public firms in 2010 was 185 and 319, respectively, for corn and soybeans seed markets; alternatively, for private firms, the number of innovation registrations was 1492 and 465. It was attenuated in the late 2000s with the introduction of GMOs, which led to a decreasing market share for public firms in their innovating activity.

Number of registered cultivars made by public firms (x_1) is on average higher for soybean even though the overall number of registered cultivars is higher on corn seed market. For example, for corn, the yearly larger number of registered cultivars was 185 while in soybean seed market was 319. This shows an expressively higher importance of public firms on research and development of seed on soybean than in corn.

4.2 Empirical specification

The econometric procedures consist of estimating the equations of concentration (6) and product R&D (7) simultaneously. Dasgupta and Stiglitz (1980) point to the existence of simultaneity between the variables' concentration and technological innovation. In this sense, the equations were estimated using instrumental variables methods.

Equation 6 was estimated as in Levin and Reiss (1984, 1989), Gottschalk and Janz (2001), and Schimmelpfennig, Pray and Brennan (2004). We estimated this equation in logarithm, which imposes, as the last paper, that the price elasticity of demand is constant over the period and unitary (it does not have a parameter to be estimated)[23]. Therefore, the model to be estimated is:

$$\ln(y_1)_{it} = \beta_0 + \beta_1 \ln(y_2)_{it} + \beta_2 \ln(y_2)_{it} * D_{ogm} + \varepsilon_{it} \tag{8}$$

where y_1 stands for the *HHI*; y_2 is the research intensity; D_{ogm} is a dummy that represents the GMO introduction in the market; and ε_{it} is the error term. There is no consensus in the sign of the explanatory variable. We inserted a multiplicative dummy (D_{ogm}) aiming to investigate whether the GMO introduction affects the relationship - D_{ogm} has a value equal to 1 for the years after the first year of registration of GMO at NCR. GMO technology was introduced in 2008 for corn seed market and in 2005 for soybean seed market. We believe a modification in the link between intensity of research and market concentration occurred due to insertion of seeds with GMO technology in the market, as Figure 1 illustrates.

The R&D intensity equation (7) is parametrized as

$$\frac{y_2}{1-y_2} = \delta_0 + \delta_1 x_1 + \delta_2 \theta z_1 y_1 + \delta_3 \theta z_2 y_1 + \varepsilon_{it} \tag{9}$$

[23] This equation is in logarithm to impose constant demand elasticity, once a linear equation would not impose it.

where y_2 refers to the intensity of research R, x_1 represents the technological opportunity α displayed in Table 2; z_1 and z_2 represent productivity (γ) variables displayed in Table 2 and 3; and δ_0, δ_1, δ_2 and δ_3 are the parameter estimated. In the results section, we discuss more about the interpretation of these coefficients, including δ_2 and δ_3 which includes an interaction of two variables.

Equations 8 and 9 were estimated simultaneously as system of equations. A GMM two-step approach was used, where for the weight matrix we use a HAC Barlett approach to correct for autocorrelation and heteroskdasticity. In this model, dummies identifying each firm, a trend and other variables[24] were used as instruments.

5. Results and discussion

We first present the empirical estimation results then we analyze it. Table 4 presents estimation, as in Schimmelpfennig, Pray and Brennan (2004). In short, for the corn seed market, the elasticity of market concentration with respect to research intensity is positive and becomes negative after the GMO introduction in the market. For soybean seed market, the elasticity is negative and becomes positive after the GMO introduction.

The coefficient estimated is the elasticity of market concentration with respect to intensity of research since all variables are in logarithm. For corn seed market, before the GMO introduction in the market (2008, when it became legal), the elasticity was 0.026 and after it was -0.05. It means that a one-percentage increase on intensity of research (number of registered cultivars over estimated production) led to a 0.026 percentage increase on market concentration (HHI) before GMO introduction and a percentage decrease of 0.05 after the GMO introduction.

On the other hand, a different behavior was found for soybean seed market. A negative elasticity before GMO introduction in the market (2005), around -0.12, and a positive after its introduction, around 0.05. An increase on market concentration would lead to higher research. The results for soybean seed market support Schumpeter's ideas; markets that are more concentrated induce more intensive R&D. On the other hand, the results for the corn seed market support Arrow's ideas.

In the corn seed market, the industrial-secret and lack of cooperation among firms led firms with the GMO technology to increase their market

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[24] The logarithm of: Brazilian soybean and corn production, agricultural gross domestic product (GDP), agricultural input part of the GDP, production of seed, total number of registered cultivars, and supply of fertilizers.

Tab. 4. Empirical estimation of concentration and research equations to corn and soybean.

	Corn	Soybean
Concentration Equation (8)		
Research (y_2)	0.02662*** (0.00089)	-0.12344*** (0.01583)
Research ($y_2 * d_{OGM}$)	-0.08016*** (0.00149)	0.17547*** (0.01644)
Constant	-1.53456*** (0.00339)	-1.46733*** (0.04286)
R&D equation (9)		
PUBLIC FIRMS (x_1)	0.00153*** (0.000027)	-0.00011*** (0.000027)
MKETS (z_1)	0.00072*** (0.000083)	-0.00085*** (0.00022)
PRIVATE NCR (z_2)	-0.00035*** (0.000024)	0.00042*** (0.00011)
Constant	0.12705*** (0.00675)	0.00667*** (0.00102)
Obs. (#)	190	126
Hansen's J	29.21	40.59

Source: Own elaboration.

share and, at the same time, intensify research on these cultivars, as shown on Figure 1. As suggested in the discussion of the data, EMBRAPA and public firms lost market participation to foreign firms that own the GMO technology, increasing the market concentration in this market.

Schimmelpfennig, Pray, and Brennan (2004) also found a negative (inverse) relationship between market concentration and intensity of research for the corn market in the United States. In this case, anti-trust policies realized by the Brazilian institution (SEAE, for example) have to take in account a negative effect on research of controlling merger and acquisitions.

In the soybean seed market, there is also an alteration in the relationship between concentration and research intensity. Despite the market concentration, the fulfillment of licensing agreements and the technology transfers that occurred after the introduction of GMOs led to an increase in the intensity of research. Medina *et al.* (2016) highlight the importance of this mechanism to transfer new technologies in the soybean seed market[25].

These results seem to arise largely from the absence of an industrial secret since the hybrid technology present in the corn market is not available in this market and suggests that policies toward enhancing agreements between firms would increase society welfare. Hence, policies that enhance the research and development activity would have a double effect on society welfare: increase the number of innovations and decrease[26] the market concentration.

The participation of domestic, public, and private firms in the research of GMO seeds in the soybean seed market is possible manly due to cooperative agreements with international companies (Silva *et al.*, 2012). Therefore, the results after the introduction of GMOs indicate that concentrated markets do not inhibit the intensity of research.

Overall, these results differ from that found by Schimmelpfennig, Pray, and Brennan (2004) for the soybean market in the United States. However, they evaluate this relationship in a different context, namely market structure, since in US the competition is more intense and moves towards the innovation. In addition, the Brazilian seed market is characterized by a strong presence of public companies in the market.

It is worth noting that in literature we can find differences in the results found by the authors. Levin and Reiss (1989), when dealing with different industries, found a direct relationship between concentration and innovation, while Schimmelpfennig, Pray, and Brennan (2004) found an inverted relationship for corn, soybean, and cotton seed markets. These distinct results corroborate the non-consensus about the hypothesis of the relationship between research and market concentration.

The results of the R&D equation stress the relevance of public firms for the development of new cultivars as well of the NCR as an appropriability mechanism, especially in the corn seed market. The outcome of public research increases intensity of research on the corn seed market while it decreases on the soybean seed market.

Despite the stronger presence of the private sector in the corn seed market, the R&D conducted by public enterprises proves to have an important effect on its research. Fuck and Bonacelli (2007) portray the importance of public research and point out that EMBRAPA is responsible for the transfer and spread of technology to small foundations and domestic private firms. It is notewor-

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[25] They also highlight that the international firms, owner of the technology, receive two-thirds of the sales with royalties.

[26] It does not invert the link between market concentration and intensity of research but increasing the intensity of research, after GMO introduction, leads a smaller increasing on market concentration than before it.

thy that this action is reflected in the geographical size of the country.

Interpretation of productivity and extent of appropriability is not simple as for technology opportunities given the way these factors enter in the research equation (non-linear). Overall, productivity affects both markets. Assuming a unitary Cournot-Nash conjecture $\theta = 1$ our results suggest that number of species registered by private firms, z_1 (number of patents registered by private firms, z_2 and concentration, y_1 are complements (substitutes) in the corn seed market. The reverse is found on the soybean seed market. In the soybean market, more concentration is associated with more registration of cultivars (patents) by private firms. On the other hand, in the corn seed market, greater concentration is associated with lower registration of cultivars (patents).

The registrations of cultivars by private firms as an extension of appropriability have a unique impact upon each crop. Carvalho (2003) and Santini and Paulillo (2001) indicate that the Plant Variety Protection Act and registration of cultivars had less impact on the corn seed market since the industrial-secret works as a natural mechanism in hybrid seed production. Our results support the idea proposed by Fuck and Bonacelli (2007), Carvalho (2003), and Santini and Paulillo (2001) that the registration of cultivars exerted less impact on the corn seed market as compared to the soybean seed market. These results highlight what was discussed before, namely the importance of the appropriation mechanisms to enhance R&D efforts.

The distinct characteristics of each market persisted in determining the results found. In the corn seed market, the industrial-secret and the participation of private firms led to the substitution between patents (cultivar registration) and market concentration. Alternatively, in the soybeans seed market, the licensing agreements and technology transfers were important to determining the extent of appropriability results.

6. Conclusions

Innovation and market concentration often follow different directions. In Brazil, the seed industry has high rates of market concentration but also high rates of research and development of new seeds. In this paper, we investigate the relation between research and market concentration using readily available aggregated data. Our results shed light on the relationship between market concentration and intensity of research, which has changed for both soybean and corn seed markets during the 2000s.

For the corn seed market, we find that this relationship was direct (positive) and then turned to inverse (negative) after the introduction of the GMO seeds. On the other hand, for the soybean seed market, we found a different behavior – the relationship was inverse, but with the introduction of GMOs, it became less direct. We conclude that the introduction of GMOs changed the way research was conducted in both markets and its effect on market structure. Our study of the role of public firms in these markets and their impact on market structure highlighted this fact.

The results regarding the intensity of research equation point out the existence of a relationship between technological opportunity and appropriability. We found that public research has positively affected the intensity of research in the corn seed market. Also, we found that the cultivar registration by private firms and market concentration are substitutes (complements) in the corn (soybean) seed market.

Our results represent a starting point for such research topics and serve to support the Brazilian government antitrust policies and R&D analysis in the seed industry. These findings suggest that public research proves essential to some markets and, thus, the government should stimulate public research, mainly EMBRAPA. We also believe that commercial agreements possibly were responsible for modifying the relationship between concentration and intensity of research for the soybean seed market and allowed the existence of spillovers.

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