Link Between R&D Intensity and Market Concentration: Analysis of Brazilian Corn and Soybean Seed Markets

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Abstract

As one of the main producers of corn and soybeans in the last three decades, Brazil's expanded production could be explained by productivity enhancements that have occurred with the introduction of innovations in their seed markets. However, these markets also experienced a reconsolidation in the form of a market concentration. We aimed to test the hypothesis that there is an inverse relationship between these factors at the seed market. To test this hypothesis, we applied a GMM with instrumental variables to a theoretical framework. Results suggested that this link depends on market characteristics, such as in which year GMO were introduced. In the first period for corn, the relationship between these factors was direct, but after the GMO introduction, the relationship became inverse; alternatively, for soybeans, this dynamic was inverted. In addition, we found out that the public investment and propriety-rights regulations were important to determining the R&D intensity.

Keywords: market concentration, R&D, seeds markets.
JEL codes: L130

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—like 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, following the United States and China (for corn) (FAO, 2014).

One of the reasons for the production expansion of the latter crops was the productivity enhancements and the cost-reduction found at the bottom of the agricultural chain—the seed market. 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. By 2011, the CTNBIO allowed 15 species of corn and 5 species of soybean to be produced as GMOs (CTNBIO, 2011).

Until the mid-1990s, the companies that dominated and innovated in the seed market were mainly public firms such as EMBRAPA. 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 process of mergers and acquisitions (M & A), 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 achieving 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 perpetuation of their research as well as to an intensification of market concentration in the seed market.

The reconsolidation of this term 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. The new seeds were endowed with new features, received code-names of cultivars,[1] and were registered in the National Cultivar Registration (NCR). By 2011, corn held the largest number of 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.

This background information provides a crucial context for the current discussion since one may consider the registration of cultivars as the result of an innovative action—such registration represents the development of a particular cultivar with new and distinct features as compared to other cultivars. These innovations can have further differentiation according to their level of development. Santini and Paulillo (2001) define an innovation as 'radical' 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.

Figure 1 presents the concentration rates and the variation in the number of seed registrations (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 2000 (6%); simultaneously, their share of seed sold in the market also decreased. The graph also shows that the vast number of cultivars in the NRC provided more variety for implementing the genetic modification, resulting in more outcomes (registers). Figure 1 corroborates the research evolution described above wherein foreign companies with GMO seeds gained domestic space, which suggests a concentration also in this factor. During this same period, the soybean seed

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

market shows a declining trend in its concentration rate, 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 by authorities.

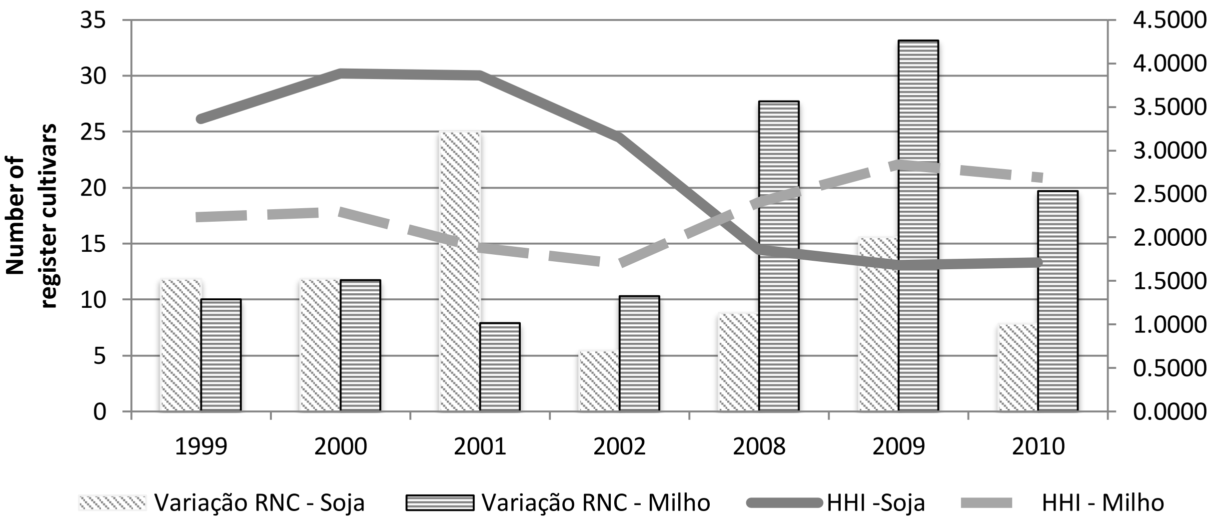

Figure 1 - Concentration Rate (HHI) and annual variation of the registrations of cultivars for corn and soybeans.

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

In the literature, studies deem the reconsolidation process as influential to research and market concentration. Benetti (2002) suggested that Monsanto reached agreements with EMBRAPA in the late 90s—when EMBRAPA had 70% of the market—so as to have access to the national market. Public companies experienced a decrease in their importance when international firms incorporated national private 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. The analysis of the Figure 1 clearly reveals a difference in innovation that resulted from the market concentration, with the 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?

This paper seeks to characterize the link between intensity of research and market concentration for corn and soybean seed markets. In addition, it analyzes the effects registration of cultivars and public research have on the intensity of research in the agricultural sector. Since agriculture is highly dependent on seed markets and since even more of this sector's innovative outcomes will enhance agricultural productivity and reduce costs, this study's aim to evaluate the impact market concentration has on innovative activity offers valuable insights into questions that directly address social welfare.

Building upon the literature review found in Silva, Braga, and Garcia (2012), this paper leverages the analytic model proposed by several papers; the models used by Levin and Reiss (1989) and Gottschalk and Janz (2001) particularly develop this paper's empirical analysis. The results corroborate the graphic analysis (Figure 1) and the literature review, both of which highlight the different effects market concentration has had on innovative activity. We test the hypothesis proposed by the theoretical debate between Schumpeter and Arrow (briefly described below) about the inverse relationship between research and market structure for these markets and whether the relationship depends on the market analyzed. Mainly, we find that for the corn seed market, the relationship between market concentration and research intensity was direct before the introduction of GMOs into the market and inverted after the introduction, whereas for the soybean seed market, the relationship was first inverted and then direct.

This paper first provides a brief theoretical review and then moves into the methodology section. It is then split into discussion of the analytical model, the econometric method, the innovation measures, and the description of the variables and data sources. We then provide our results, discussion, and, lastly, our final conclusions as they relate to the results and the given literature.

2. Brief theoretical review

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. Another point Schumpeter (1984) discusses is state regulation. Since he believes that large firms are responsible for innovative activities, splitting-up conglomerates may cause significant losses to the economic progress. Therefore, his perspective is that perfect competition is not the perfect system; rather, he argues that a smaller firm would not be able to create what a larger firm—using its size-endowed ability as a strategy—would be able to accomplish.

Arrow (1962), in contrast, 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.

In short, both authors discuss the relationship between innovation and market structure here analyzed in terms of Brazilian seed market. Our main goal is test the hypotheses suggested by them, specifically, whether research and market concentration are directly related.

Another source, Martin (2010), lists five reasons larger firms have advantages in innovation: they are more capable of diluting the cost of R & D across their sales volume; they have advantages in obtaining credits; they are more able to exploit economies of scale and scope; if diversified, they will be better able to explore unexpected discoveries (innovation); and they possess greater appropriability, especially when close to a monopoly structure. These arguments align with Schumpeter's idea of using a firm's ability as a strategy to accomplish the innovation and, therefore, suggest that large firms have higher chances of realizing research.

Silva, Braga, and Garcia (2012) elaborate on these discussions in terms of the role of LPC and NRC as important mechanisms in the appropriation of intellectual property. Appropriation mechanisms are important tool to incentivize R&D and are commonly indicated in the literature as an essential feature to exercise market power, which leads to market concentration. The Brazilian seed market evidenced in this paper exhibits both characteristics—research enhanced by appropriation mechanisms and market concentration—

so we aim to investigate how these characteristics impact the market and to map this investigation against the theories Schumpeter and Arrow developed.

3. Methodology

3.1 Theoretical Framework

The process of innovation in the corn and soybean seed markets occurs primarily in two forms: demand and cost. In the sphere of demand, this innovation appears as the introduction of new products with features distinguishable from those already in existence; buyers demand these new features and will purchase them accordingly. In the cost sphere, innovation appears as new processes that reduce cost. The analytical model used[2] in this study was first proposed by Levin and Reiss (1989) and allows the product innovation (demand) and process innovation (cost reducing) to be used, for example, by Gottschalk and Janz (2001) in a unified manner for both types of innovation. Levin and Reiss (1989) admit that, although the relationship between product innovation and process innovation is dynamic, the model is static; however, this model enables interpretations relevant to the research problem since it allows for determining the effect of research on market structure and vice-versa.

Gottschalk and Janz (2001) state that the market structure is determined by demand and cost conditions, and that, in presence of investments into innovation, these conditions can be modified. The authors argue that this expenditure depends on the market structure, which reveals interdependence between market structure and innovation.

The structure of the corn and soybean seed markets is clearly defined as oligopolistic—i.e., the markets are dominated by a few firms. Levin and Reiss (1989) shape the relationship innovation-market structure using profit maximization, and they assume that firms act in accord with Cournot-Nash equilibrium, which characterizes a simultaneous movement between firms. On the other hand, for Gottschalk and Janz (2001), firms fail to appropriate the returns on their investments in R&D due to spillovers, indicating the existence of interdependence between firms in the market. This is a simplification of the market that perfectly fits the seed market and makes the analysis easier, as shown in (11). Therefore, the production possibilities of each

[2] However, there are other papers that study this relationship, such as Arvanitis (2011), Becker and Dietz (2011), Cohen and Levin (1989), Farber (1989), Link (1980), Lunn (1986), Lunn and Martin (1986), and Scherer (1965).

firm are affected by both its own investments into innovation and by the total investment of the industry into R&D.

With these ideas in mind, we consider private investment and the other firms' investment to be perfect substitutes. The unit-cost function of each firm can thus be defined as:

$$C_i = C(x_i, X_i) \tag{1}$$

in which x_i is the amount of research and development conducted by the firm i, and X_i is the knowledge of the whole industry available for firm *i*. Levin and Reiss (1989) describe the knowledge stock of the industry available for firm *i* as:

$$X_i = x_i + \omega_x \sum_{j \neq i}^{N} x_j = x_i + \omega_x \overline{X}_i \tag{2}$$

in which ω_x is a scalar parameter representing the extent of spillovers from R&D in-process; x_j is the amount of research and development carried out by firms other than i, and the sum of such R&D is represented by $\overline{X}_i$. In short, the knowledge stock of the industry is segregated into the own firm's R&D and a weighted sum of the other firms' R&D.

Levin and Reiss (1989) show the unit cost elasticity with respect to the R&D of the firm and to the R&D of the industry:

$$\varepsilon_x = -\frac{x_i}{C}\frac{\partial C}{\partial x_i} = -x_i\frac{C_x}{C} - x_i\frac{C_X}{C} = \alpha_x + \gamma_x\frac{x_i}{X_i} \tag{3}$$

$$\varepsilon_{\overline{X}} = -\frac{\overline{X}_i}{C}\frac{\partial C}{\partial \overline{X}_i} = \omega_x\gamma_x\frac{\overline{X}_i}{X_i} \tag{4}$$

wherein the subscript of C denotes the partial derivative in relation to it, γ_x represents the cost unit elasticity related to the industry's R&D, and α_x is the cost unit elasticity related to the firm's own R&D in the absence of spillovers. It is worth noting that Gottschalk and Janz (2001) point out that if spillovers exist, the elasticity is the first equation.

Levin and Reiss (1989) state that for an oligopolistic market—Equation 3—the second term includes a productivity effect of R&D from other firms. Thus, an increase in the R&D of other firms decreases the productivity of the R&D of firm *i*. However, the authors indicate that Equation 4 represents a measure of the effect of the R&D externality**.**

With regards the consumer-side of the market, which is important once we are also investigating the product innovation, according to Levin and Reiss (1989), the aggregate utility function can be described by:

$$U(Q) = U(G_1 q_1 + G_2 q_2 + \cdots + G_N q_N) \tag{5}$$

in which

$$G_i = G_i(y_i, Y_i) \tag{6}$$

and Q represents the quantity produced by the industry, q_i conveys the quantity of each firm, y_i is the production coming from the R&D of firm i, Y_i is a weighted sum of R&D products of the industry, and G_i represents the quality perceived or the attractiveness of the product of firm i. In a similar way, the stock for product innovation in the industry can be represented by:

$$Y_i = y_i + w_y \sum_{j \neq i}^{N} y_j = y_i + w_y \overline{Y}_i \tag{7}$$

in which w_y stands for the extent of spillovers of the innovation in product, and y_j is the product coming from firms other than i as well as $\overline{Y}_i$, but in a weighted sum form. Levin and Reiss (1989) indicate that the demand is affected directly by the alteration in product quality as well as indirectly by the effect of the quality of the products of the other firms. These authors found the inverse demand using the equality between the price and the partial derivative of the consumption function:

$$P_i = \frac{\partial U}{\partial Q} G_i(y_i, Y_i) = P(Q) G_i \tag{8}$$

in which P is defined as an index of industry prices.

From that equation, it is possible to find the elasticity similar to Equations (3) and (4):

$$\varepsilon_y = -\frac{y_i}{C}\frac{\partial C}{\partial y_i} = \alpha_y + \gamma_y \frac{y}{Y_i} \tag{9}$$

$$\varepsilon_{\bar{Y}} = -\frac{\bar{Y_i}}{C}\frac{\partial C}{\partial \bar{Y_i}} = \omega_y \gamma_y \frac{\bar{Y_i}}{Y_i} \tag{10}$$

in which ω_y represents a scalar parameter of the extent of spillovers of product R&D, and γ_y is the elasticity of the perceived quality of the product as related to the sum of other firms' R&D—and also recognized by productivity of the spillovers. Levin and Reiss (1989) add to this result the fact that γ_y needs to be non-positive because increases in the rival firms' R&D could reduce the perceived attractiveness of the product of firm i.

Levin and Reiss (1989) 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. We thus use the equation:

$$max_{q_i, r_i, d_i}\big(P_i(q_i, Q_i, y_i, Y_i) - C_i(x_i, X_i)\big)q_i - x_i - y_i - f_i \tag{11}$$

in which f_i are fixed costs of production. Furthermore, as in Levin and Reiss (1989), 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 are:

$$P\left[1 - \frac{1}{\varepsilon N}\right] = C \tag{12}$$

$$-\left[\frac{\partial C}{\partial r} + \frac{\partial C}{\partial \bar{r}}\right] q = 1 \tag{13}$$

$$\left[\frac{\partial C}{\partial d} + \frac{\partial C}{\partial \bar{d}}\right] q = 1 \tag{14}$$

$$[P - C]q = x + y + f \tag{15}$$

in which ε represents the price elasticity of demand. From (12) and (15), we can find the equation that explains the market concentration. To do so, we multiply (15) by N—the number of firms—so as to obtain the condition of profit for all firms. Afterwards, we replace (12) in (15), finding:

$$H = \frac{1}{N} = \varepsilon(R + D + F) \tag{16}$$

in which 1/N stands for *HHI* for identical firms (therefore represented by H); R represents the ratio between the R&D of process and sales of the firm; D, the ratio between the R&D of product and sales of the firm; F, the ratio of the fixed cost of the firm and its sales; and ε, the price elasticity of demand. According to Gottschalk and Janz (2001), market concentration is explained by demand conditions represented by the price elasticity of demand as well as by R&D costs and by fixed costs.

We can find the equation that explains the product R&D using the third first-order condition. Multiplying both sides of (14) with d / P and dividing both sides by q enables us to find the factors that explain the ratio between R & D in product and sales of the firm (D):

$$D = \alpha_y \left[1 - \frac{H}{\varepsilon}\right] + \gamma_y \left[\frac{1}{1 + \omega_y(N-1)} - \frac{H}{\varepsilon}\right] \tag{17}$$

in which α_y represents the elasticity of the product quality in relation to R&D of the product; and, according to Levin and Reiss (1989), the second term contains the parameters of appropriability.

We can repeat the same procedures performed when obtaining the product R&D equation to find the cost-reducing R&D equation. Multiplying both sides with x/P and dividing both sides by q obtains the factors that explain the ratio between the product R&D and the total of the variable cost of production:

$$\frac{R}{1 - (R + D + F)} = \alpha_x + \frac{\gamma_x}{1 + \omega_x(N-1)} \tag{18}$$

It is worthwhile to show the aggregate form of the R&D equations developed by Gottschalk and Janz (2001) and Levin and Reiss (1989). This equation is the sum of the two equations:

$$\frac{R + D}{1 - (R + D + F)} = \alpha_x + \alpha_y + \frac{\gamma_x}{1 + \omega_x(N-1)} + \frac{\gamma_y}{1 - \frac{H}{\varepsilon}}\left[\frac{1}{1 + \omega_y(N-1)} - \frac{H}{\varepsilon}\right] \tag{19}$$

in which α_x and α_y are concerned with the technological opportunities of firms in realizing R&D, γ_y, and γ_x represent appropriability conditions, and ω_y and ω_x represent productivity and the extent of spillovers (Gottschalk and Janz, 2001).

Levin and Reiss (1989) point out that by assuming only cost-reducing innovation, the concentration and R&D would increase with technological opportunities as well as with the price elasticity of demand and the increase in the productivity of spillovers, but it would decrease with the increasing extent of spillovers. These are the factors we will explore in the following sections to investigate the relationship between research and market structure.

3.2 Specification and Data

The econometric procedures consist of estimating the equations of concentration and aggregate R&D. 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.

i) Concentration equation

We estimate this equation in the same way as Levin and Reiss (1984, 1989), Gottschalk and Janz (2001), and Schimmelpfennig, Pray and Brennan (2004). We use the logarithmized variables to make our estimate, and assume, as the previous papers did, that the price elasticity of demand is unitary and constant in time. Therefore, the model to be estimated is:

$$\ln(HHI)_{\mathrm{it}} = \beta_1 \ln(IP)_{it} + \beta_2 \ln(IP) * D_{ogm} + \alpha_i + \varepsilon_{it} \quad (20)$$

In which *HHI* stands for the concentration index; IP is the research intensity; D_{ogm} is the dummy representing the GMO introduction; α_i represents the fixed effects; and ε_{it} is the error term. There is no consensus in the sign of the explanatory variable. We inserted a multiplicative dummy aiming to investigate if the GMO introduction affect the relationship, i.e., D_{ogm} has a value equal to 1 for the years after the first year of registration of GMO at RNC. Such information is relevant because this situation occurred in 2008 for the corn seed market and in 2003 for the soybean seed market.

We apply Two-Stage Least Squares (2SLS) and Generalized Method of Moments (GMM) to this equation. Both methods use instrumental variables for the estimation of only one equation with the purpose of correcting the endogeneity problem. We estimate the two-step GMM because it is more efficient (Johnston and Dinardo, 1997).

The endogeneity and validity of instruments are performed for both methods. The former is numerically similar to *Hausman Test* and the latter is either a Sargan Test or a Hansen Test, depending of which error matrix is used.

ii) Intensity research equation

The equation that measures the relationship between the intensity of research and technological opportunity and appropriability faces four problems: (i) fixed effect panel data, (ii) endogeneity, (iii) non-negative dependent and countable variable, and (iv) non-linearities in the parameters. Therefore, the procedures of Cameron and Trivedi (2005) are utilized, wherein a nonlinear function of least squares is taken into account. We corrected endogeneity using the two-step procedure proposed by Cameron and Trivedi (2005) for data in a cross-section format. According to Levin and Reiss (1989), the functional form to be estimated is found from (16):

$$ip_{it} = \left(\beta_1 \alpha_y + \frac{\beta_2 \gamma_y}{1 - H}\left[\frac{1}{1 + \beta_3 \omega_y * (N - 1)} - HHI\right]\right) + \varepsilon_{it} \quad (22)$$

in which ip_{it} refers to the intensity of research, and subscripts *i* and *t* represents, respectively, the identification of the firms and the year; β_1 represents the technological opportunity (α_y), which is described by the number of registrations of public firms in the RNC or by dummy variables with values equal to 1 when the firm is public and when it presents a link between research and seed production. β_2 represents the appropriability productivity (γ_y), which is described by the number of species surveyed by a given firm; and β_3 represents the appropriability extension (ω_y), which is described by the number of registrations of private firms in the RNC. The estimates of equation (22) are corrected for heteroskedasticity and autocorrelation by the method of Newey-West (HAC).

It is expected that β_1 exhibits a positive sign since the technological opportunity represented by public research aims to increase the intensity of market research. For β_2, a negative sign is expected since the increase in productivity in rival firms R&D—represented

by the number of species identified in the RNC—decreases the investment made by firm i. And for β_3, a negative sign is also expected since greater extension or a more effective mechanism of appropriateness leads to smaller spillover impact—i.e., a smaller possibility for a firm to grasp the knowledge produced by the rest of the industry.

We perform several estimations aimed at testing the robustness of model (22), which only considers non-linearity and endogeneity. In the Appendix (Table 4) we show these robustness results, which considered panel data by using the differentiation of the variables (aiming to remove the unobserved heterogeneity) and countable data (taking out the observations with zeros in the dependent variable).

3.3 Data

The concentration index Herfindahl-Hirschman Index (HHI) is obtained by estimating the production of cultivars. These data are constructed from the SMAPA and use 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. Most of the data from these databases are confidential.

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. The ratio of the number of registrations to the estimated production of each firm stands in for the research (innovation) intensity, 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 appropriateness and extent of spillovers is represented by the number of registrations of private firms, as demonstrated in Schimmelpfennig, Pray and Brennan (2004). Productivity spillovers can be represented by the number of species registered and obtained in RNC (2011) due to the existence of a complementarity between surveys of different species on the seed market. The public research measure as a technological opportunity is represented by the number of registrations of cultivars filed by public institutions. Table 1 summarizes the variables as well as reports and indicates the source.

Table 1 - Variables, description, and source of data

Variables	Description	Source
HHI	Concentration Ratio of Herfindahl for estimated production	SMAPA[b]
IP	Intensity of Research—ratio between the number of registrations in RNC and the amount produced	RNC[a]/SMAPA[b]
	Technological Opportunity	
PR-RNC	Public Research—number of registrations of public companies in RNC	
PUBLIC FIRMS	Public Companies—*dummy* with value equal to one when the firm is a public company	RNC[a]
PRODUCTION & DEVELOPMENT	Link between Research and Development and Seed Production—*dummy* with value one when the firm holds this link	
	Productivity of Appropriability	
MARKETS	Differentiation in Research and Development—number of species registered in RNC	RNC[a]
	Extension of Appropriability	
RNC-PRIVATES	Patents of private companies—number of registrations of private companies in RNC	RNC[a]

Note: [a] RNC— National Records of Cultivar; [b] SMAPA—Superintendents of the Ministries of Agriculture, Livestock and Supplies.

Source: Prepared by the author.

4. Results and discussion

First, we will carry out a descriptive analysis of the data. Then, we will estimate the two equations for concentration and research intensity using econometric models. The results for the regression and the fit tests are present in the next two sub-sections.

With regards to the descriptive analysis, we find higher average values for innovative intensity for the corn seed market than those found for soybean seed. The market for corn seeds can be distinguished from others markets by two essential characteristics: the industrial-secret and the natural appropriateness of its products characterized in the hybrid seeds. These features provide the highest returns of innovation and hence demonstrate greater research intensity among private companies. As a result, private firms hold greater values of market share in corn than in the soybean seed market. It is worth noting the decreased participation of public enterprises, mainly EMBRAPA, in both markets, suggesting that the market shares of private firms were higher than desirable by the national authorities.

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.

The number of innovation registrations of public companies 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. The state attenuated in the late 2000s with the introduction of GMOs, which led to a decreasing market share for public firms in their innovating activity.

4.1 Concentration Equation

We estimate Equation (20) using 2SLS and GMM methodology, and both results are present in Table 2. For both methods, the tests of endogeneity and validity of instruments are carried out, and, under the null hypothesis that the endogenous regressor can be treated as exogenous, the result of the endogeneity test (shown in Table 2) indicates that there is endogeneity for the two markets. The test of validity of the instruments for the two markets reveals that the instruments used here are valid. We use lag of dependent and independent variable and variables of intensity research as instrumental variables. The estimated models have been corrected for heteroscedasticity and autocorrelation using standard errors, according to the Newey-West procedure.

We find statistical significance for the explanatory variable, which means there is a relationship between market concentration and research intensity. Both estimated explanatory variables are statistically significant. The variables that measure the intensity of research, **L(*IP*),** and intensity of research after the introduction of GMOs, $\mathbf{L(\mathit{IP})*\mathit{D}_{ogm}}$, had a significant effect and in a distinct manner on the corn and soybean seed markets. These results support the assertion that there is no consensus on how the relationship between innovation and market concentration behaves. Hence, neither and—at the same time—both of Schumpeter's and Arrow's ideas are corroborated by the analysis performed here.

For the corn seed market, we note a modification in the relationship after 2008 due to the introduction of the research on GMO seeds in the NRC. In the period up to 2008, we find a direct relationship, but after the GMOs introduction, it becomes inverse. This outcome might be due to the growth of private firms that hold the GMO technology, which resulted in an increased market concentration.

The industrial-secret and lack of cooperation among firms led firms with the GMO technology to increase their market share. Therefore, this could be one of the reasons for unnecessary intensification of investments in research and development, thus clarifying the inverse relationship. In addition, the loss of relative share of EMBRAPA and in the R&D corroborates this result.

Table 2 - Relationship between concentration and research intensity for corn and soybeans

L(*HHI*)	**Corn**		**Soybean**	
	MQ2E	**GMM**	**MQ2E**	**GMM**
L(*IP*)	0,066**	0.070**	-0,069**	-0,076***
	(0.03)	(0.03)	(0.02)	(0.03)
L(*IP*)*D_{ogm}	-0.080***	-0.081***	0.118***	0.129***
	(0.01)	(0.01)	(0.01)	(0.01)
Observations (#)	106		75	
Wu-Hausman Test	9.636***		7.519**	
Hansen J. Test	4.339*		4.233*	

Note: Standard error appears between parentheses; and, *, **, and *** are 10%, 5% and 1% of statistical significance, respectively

Source: Research results.

The results found for the period after 2008 corroborate what Schimmelpfennig, Pray, and Brennan (2004) found for the same market in the United States, indicating an inverted relationship between research and market structure. Hence, policies that enhance the research and development activity would have a double effect on society welfare: increase the number of innovations and decrease the market concentration.

In the soybean seed market, there is also an alteration in the relationship between concentration and research intensity. In the first period (1999-2005), there is an inverse relationship, while in the second period (after 2005), the relationship becomes direct. 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. 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.

The participation of domestic, public, and private firms in the research into 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. This result differs from that found by Schimmelpfennig, Pray, and Brennan (2004) for the same market in the United States. However, they evaluate this relationship using a different theoretical framework as well as 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 the 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.

In terms of theory, the results found in this study support the ideas of both Schumpeter and Arrow. The differences between the markets were important to determine the unequal determination of the relationship. The importance of the industrial-secret for the corn seed market and of the licensing agreements and technology transfers for the soybean seed market might explain the differences in the results. This result will unfold with the interpretation of Table 3, which suggests the importance of agreements and the industrial secret as determinants of R&D. Despite the fact that the relationship between market concentration and research is not uniform within and across markets, it is important to highlight the role of antitrust institutions in investigating the impact of market concentration on R&D with the goal of not allowing firms to penalize society twice—with market concentration and lower research intensity.

4.2 Research Intensity Equation

We estimate Equation (22) in different ways but only present the pooled method here because the results corroborate the theory and are quite similar to the results present in the Appendix. The result takes into account the presence of heteroskedasticity and autocorrelation, and therefore HAC estimators corrected it. We present the results for the model—which took into account the panel data and the countable data—in the Appendix to demonstrate the robustness of the model. In short, the results hold true in relation to those portrayed in Table 3.

Model (1) uses the number of registrations of public firms to measure the public poll while Model (2) surveys the technological opportunity from two dummy variables. The results stress the relevance of public firms for the development of new cultivars. The public poll shows the positive and expected sign for the markets. Despite the stronger presence of the private sector in the corn seed market, the R&D conducted by public enterprises proves more effective in promoting the intensity of research in this market. This result possibly arises from the significant change in the number of registrations of public firms in the corn seed market as compared to the soybean seed market.

Table 3 – Research in the corn and soybean seed markets

	Corn		**Soybean**	
	(1)	**(2)**	**(1)**	**(2)**
PR-RNC	**0.001066*** (0.00005)	-	**$6.27e^{-0.6}$***** ($1e^{-0.6}$)	-
PUBLIC FIRMS	-	**0.066219*** (0.0379)	-	**0.003191** (0.00199)
PRODUCTION & DESENVELPMENT	-	**0.015228***** (0.0057)	-	**0.000965***** (0.0001)
MARKETS	**-0.000050*** (0.00002)	**-0.000819** (0.000510)	**-0.000027***** ($6e^{-0.6}$)	**-0.000065*** (0.00003)
RNC-PRIVATES	**-0.000021***** ($3e^{-0.6}$)	**$-6.5e^{-0.6}$**** ($2e^{-0.6}$)	**-0.000051***** ($7e^{-0.6}$)	**0.0000446**** (0.00001)

Observations (#)	190	190	126	126

Note: Standard error between brackets; *, ** and *** denote 10%, 5%, and 1% of statistical significance, respectively; and PPRNC marks the number of registrations of public firms in RNC.

Source: Results of research.

Fuck and Bonacelli (2006) 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 noteworthy that this action is reflected in the geographical size of the country. The link between production and R&D of seeds is also positive and consistent with what we expected for each crop. In the corn seed market, the impact was greater due to the bigger importance of private firms on the market and due to the intensity of research.

Appropriateness affected the intensity of research and, in general, showed the same result. The complementarity in the research represented by the number of species investigated shows the expected negative sign. In other words, an increase in the productivity of rival firms negatively impacts the intensity of research in firm *i*. We find greater impact in the corn seed market due to a bigger share of private firms and probably due to the industrial-secret. These results highlight what was discussed before, namely the importance of the appropriation mechanisms to enhance R&D efforts.

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 of an 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 Bonacelli and Fuck (2006), 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.

Our results also find that the extent of appropriability is consistent with the theoretical model proposed by Levin and Reiss (1989) in most of the estimated models. Initially, it can be inferred that the RNC has reached its goal in acting as a mechanism for protecting appropriability and innovation. The negative impact shows that the appropriateness mechanism inhibits spillovers and hence decreases the intensity of research. In general, our results indicate: a positive association between the research conducted by public firms and research intensity; a negative relationship between the R&D of rival firms and the research intensity of firm *i*; and a negative impact in the extent of the appropriateness of the research intensity, indicating that the National Registry of Cultivars inhibited spillovers.

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 smaller effects in the extent of appropriability. Alternatively, in the soybeans seed market, the licensing agreements and technology transfers were important to determining the extent of appropriability results.

In regards to the intensity research equation, we can conclude that an increase in public research investments leads to an intensive market in R&D. Additionally, enhancing the efforts to deal with agreements in these markets enables other firms to have accesses to technologies that only a few firms have. Hence, these results suggest that the government (who is responsible for EMBRAPA) should intensify the research and development actions of public institutions such as EMBRAPA.

5. Final remarks and policy implications

The results found in this paper show no consensus on how the relationship between the intensity of research and market concentration should behave since we found distinct relationships between them over the period surveyed for each market due to changes in the way that research is carried out in the industry. Therefore, the empirical evidence makes it possible to say that Schumpeter’s and Arrow’s ideas apply to the markets under this study, but not uniformly. In other words, it follows that perhaps there is a complementarity between these theories and that they actually vary according to the specific characteristics of each market.

The relationship between concentration and intensity of research for the corn seed market was direct over the period of 1999 to 2008 and inverse over the period after the introduction of GMOs. However, for the soybean seed market, we found the behavior to be opposite—first, the relationship was inverse, and then with the introduction of GMOs, it became direct. Hence, it follows from the literature review and our results 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. About this, it is worth noting some points:

i. Public research and the link between production and R&D have positively affected the intensity of research, specifically in the corn seed market;

ii. Increasing the productivity of R&D of rival firms in the industry causes a decrease in the intensity of research in firm *i*;

iii. The registration of cultivars functions as an instrument of protection for the innovations; however, this effect was less significant in the corn seed market due to the existence of an industrial-secret.

In spite of the estimated model being static, the results represent a starting point for such research topics and serve to support government antitrust policies and R&D analysis. The following aspects are suggested for the public agencies responsible for such policies:

i. Depending on the market's characteristics, market concentration may have a negative impact on the development of research;

ii. Public research proves essential to some markets; thus, the government should stimulate public research—mainly EMBRAPA;

iii. Licensing and transfer agreements proved to be influential in spreading technology to areas where only a few firms, such as EMBRAPA, act; and

iv. These agreements possibly were responsible for altering the relationship between concentration and intensity of research for the soybean seed market and allowed the existence of spillovers.

This paper has some limitations, especially in the database and econometric model. The absence of continuous data in time, of expenditure per firm in R&D, and the non-utilization of a method that jointly took into account the non-linearity, endogeneity, panel-data, and the countable dependent variable may have caused some limitations to the inferences made in this paper. Therefore, it is suggested that future research should solve these limitations and consider the dynamic aspects of innovation to the analytical model.

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APPENDIX

Table 4 – Research equation for the corn and soybean markets taking into account the panel data and countable data problems

	Corn				Soybean			
	W/o zeros		W/o zero and Dif.	Dif.	Without zeros		W/o zero and Dif.	Dif.
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
PR-RNC	0.00019*		0.0001**	0.00038	0.00001***	-	-0.00001	0.000055**
	(0.0001)		(0.00005)	(0.003)	(0.00)		(0.00)	(0.00002
PÚBLIC FIRMS	-	0.17***	-	-	-	0.008*	-	-
		(0.08)				(0.004)		
PRODUCTION & DESENVELPMENT	-	0.040**	-	-	-	0.0016***	-	-
		(0.01)				(0.0)		
MARKETS	-0.00016	-0.002*	-0.00011	-0.00023	-0.00004***	-0.0001*	0.00002	-0.000043*
	(0.0001)	(0.001)	(0.00007)	(0.0002)	(0.00)	(0.00)	(0.00)	(0.00002)
RNC-PRIVATES	-0.00001***	$3e^{-0.6}$	0.0011***	0.00117***	-0.00004***	0.00005***	-0.019***	-0.02102***
	(0.0)	$2e^{-0.6}$	(0.0001)	(0.0001)	(0.0)	(0.0)	(0.005)	(0.00024)
OBS.	107	107	46	112	75	75	35	78

NOTES: Standard errors between brackets. *. ** and *** for 10%, 5% and 1% of statistical significance. The models in this order: without zeros in the dependent variable; distinguished, at level and without zeros, and, in differences without zeros.

Source: Results of the research.