A Stochastic Frontier Estimator of Oligopsony Power in the Brazilian Citrus Industry

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Abstract

The objective of this study was to develop a model to estimate oligopsony power with only input price data using the Stochastic Frontier (SF) approach. Using the duality theory and through the envelop theorem we show that elasticities of a primal and a dual function are the same. Thus, it is possible to estimate the market power with quantity or price data. The use of SF model to measure market power although recent it stands out by its robustness and has been wildly applied. The model developed in this study was applied to the Brazilian Citrus Industry that beyond the biggest in the world stands for to be highly concentrated. It was measured the oligopsony power in the purchase of oranges by the producers of orange juice from 1997 to 2018. The results show that the price received by the orange producers is 5.9% lower than the net value of the marginal product of orange juice.

Keywords: Oligopsony Power; Stochastic Frontier Approach; Duality Theory; Orange Juice.

Resumo

O objetivo deste estudo foi desenvolver um modelo para estimar poder de oligopsônio apenas com dados sobre preço de insumos utilizando a abordagem de Fronteira Estocástica. Utilizando a teoria da dualidade e através do teorema do envelope nós mostramos que as elasticidades da função primal e dual são as mesmas. Então, é possível estimar poder de mercado com dados de quantidade ou preços de insumos. O uso de modelos de Fronteira Estocástica para medir poder de mercado, embora recente, destaca-se pela robustez e tem sido amplamente aplicado. O modelo desenvolvido neste trabalho foi aplicado a Indústria Brasileira de Citros que além de ser a maior do mundo se destaca por ser altamente concentrada. Foi medido o poder de oligopsônio na compra de laranja pelos produtores de suco de laranja de 1997 a 2018. Os resultados mostram que o preço recebido pelos produtores de laranja é 5,9% inferior ao valor líquido do produto marginal de suco de laranja.

Palavras-chave: Poder de Oligopsônio; Fronteira Estocástica; Teoria da Dualidade; Suco de Laranja.

JEL CODES: L11; L66; D22; D43.

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1 Introduction

In this work we will develop a new model to estimate market power in oligopsony framework using only input price data instead input quantity. The model is based on Stochastic Frontier Approach and starts from Panagiotou and Stavrakoudis (2017). The idea is the same by Muth and Wohlgenant (1999) to estimate an oligopsony power in the absence of input quantity.

This model will be applied to Brazilian Citrus Industry who is the biggest worldwide producer of orange juice in the word, biggest exporter, has the biggest company and a highly concentrated market. This market also stands out for having the longest case of investigation in Brazil's antitrust authority for cartel formation among the orange juice producing firms. The lawsuit lasted 17 years and was only terminated because firms signed an accord pleading guilty to the cartel formation and paying about USD 90 million in fines. To the best of our knowledge no analysis has been done to measure the degree of market power in the market of purchase of orange by citrus industry.

The market power is a central issue in Industrial Organization (IO) and, since Lerner (1934) researchers has been creating alternatives to deal with the absence of data and estimate a measure that represent the market power of many industries or firms. In the field of New Empirical Industrial Organization (NEIO), different authors developed alternative methods to estimate the market power in oligopolized structures, but to oligopsony, i.e., to measure buyer power, the works still are scarce[1].

Scalco, Lopez, and He (2017) pointed out that for every paper that investigates oligopsony power has around 15 in oligopoly power. We can highlight how as seminal works the articles of Schroeter (1988), A. M. Azzam and Pagoulatos (1990), A. M. Azzam (1997) and Muth and Wohlgenant (1999), but most recently Panagiotou and Stavrakoudis (2017) has developed a model to estimate oligopsony power and measure the mark-down exerted in the beef packing industry on purchase of living cattle in USA. This model is based in a new class of models proposed by the seminal work of Kumbhakar, Baardsen, and Lien (2012) and use Stochastic Frontier (SF) approach to estimate market power.

The SF model have several advantages when compared to the traditional NEIO models, such as flexibility and low data requirements. In the case of PS model, for example, the market power is estimated only with data about total revenue, total cost of specific input and inputs quantities. In addition the method allows estimate market power with or without constant returns to scale and provides an estimate of the degree of market power in the same style as the Lerner index.

However, even with all these advantages, there are some industries where we do not have data on the quantity of all inputs, and the model proposed by PS cannot be used. Muth and Wohlgenant (1999) points out that for some industries we have quantity only for specific input and for other inputs just their price. In this context the flexibility property of SF models become important because Kumbhakar, Baardsen, and Lien (2012) show that we can use alternative ways to estimate oligopoly power using data about input quantity or input price through the application of envelope theorem.

The SF models to measured market power although recent has been applied to a variety of markets. Kumbhakar, Baardsen, and Lien (2012) study the oligopsony power in the Norwegian sawmilling, with the primal and dual approaches. Bairagi and A. Azzam (2014), Coccorese (2014), and Das and Kumbhakar (2016) study the oligopsony power in the bank industry. And Scalco, Lopez, and He (2017) and Lopez, He, and A. Azzam (2018) study whether market power is exerted in the buyer or retailer side and oligopoly power of the food industry respectively.

Panagiotou and Stavrakoudis (2017) are pioneers in the use of the Stochastic Frontier

[1]See Bresnahan (1989)

approach to estimate the oligopsony power. They measured the oligopsony power exerted by the beef packing Industry in the USA. It was estimated an Output Distance Function (ODF) which the requirement of data is quantity of inputs.

In our results, using price input, we have found evidences of oligopsony power. The degree of market suggested that, on the average, the price received by farmers is 5,9% lower than the net value of the marginal product of orange. The Lerner index was, on average, 6.3% over the period analyzed and with a maximum of 14.7% in 2000 which is the period of the Industry pledge guilty in the investigation of cartel formation (1999-2006).

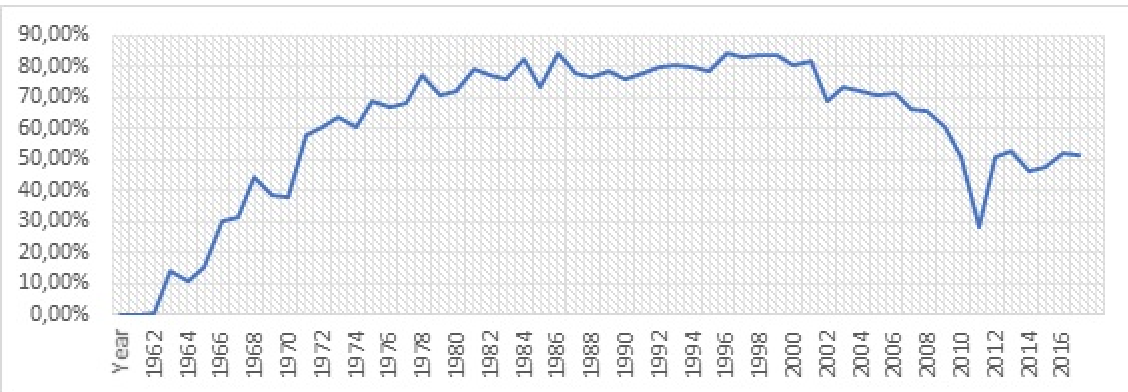
This article is organized in six sections, including this introduction. The second section presents an overview of Brazilian citrus industry. The empirical model is developed into the third section and in the fourth section we describe the data. The fifth contains results of empirical models used and in the last section contains the final remarks.

2 The Brazilian Citrus Industry

The production of citrus industry includes the varieties of grapefruit, tangerines, lemons and limes, and mainly, oranges. Among these derivatives stands out the production of orange juice, with the most quantity and the most value produce by the sector. The production of orange juice represents more than 80% of citrus fruit processing. Of all the orange produced worldwide, only 20% of the total is sold as the fruit in nature and the remainder is used in the industrial processing to make juice (FAOSTAT 2019).

Brazil has the largest production of orange worldwide and, consequently the biggest production of orange juice. In addition is the biggest exporter of the orange juice and it is destined mostly to Europe, United States and Japan, respectively. Brazil accounted on average for 70% of the orange juice exported to the world between 1960 and 2017 (Figure 1) and the product almost certainly comes from São Paulo state (COMEX 2019).

Figure 1: Percentage of orange juice exports from Brazil



Source: FAOSTAT

The production of orange is concentrated mainly in the state of São Paulo which accounted for almost 80% of the total Brazilian production in 2019 (IBGE 2018) and between the period of 1997 and 2019 the citrus industry located into the state accounted for almost 98% of all Brazilian exports of orange juice (COMEX 2019). This make the state of São Paulo one of the most important market in Brazil and in the world.

The Brazilian citrus industry was born in São Paulo in the 1960's and has always been characterized by a concentrated structure. Between 1970's and the end of 2000's the CR4

Table 1: Market Share of industries producers of orange juice in São Paulo state (%) from 1970 to 2004

Companies	**1970**	**1980**	**1990**	**1995**	**2002**	**2004**	**2008**	**2010**
Citrosuco	39.47	24.00	33.40	27.07	20.90	24.12	28.46	48.34
Cutrale	23.68	35.00	28.13	23.44	21.70	29.33	32.36	36.30
Cargill	15.79	15.62	14.69	12.76	13.00	*	*	*
Coinbra	7.89	14.06	10.53	16.29	13.00	11.75	10.53	10.53
Citrovita	**	**	**	n/d	14.00	19.68	23.82	***
Outros	13.17	10.30	13.25	20.44	17.40	15.12	4.83	4.83
Total	100	100	100	100	100	100	100	100
2 biggest companies	63.15	59.00	61.53	50.51	42.60	53.45	60.82	84.64
4 biggest companies	86.83	88.68	86.75	79.56	69.60	84.88	95.17	97.88
Herfindahl Index[3]	0.251	0.175	0.253	0.245	0.164	0.233	0.254	0.390

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*In 2004, Cargill was bought by Cutrale and Citrosuco

** The company start their operations in 1991

*** Fusion between Citrosuco and Citrovita

were around 80% and HHI between 0,164 and 0,2542 and throughout this period there were also many mergers and acquisitions mainly between top four companies such as Cargil (3rd biggest) which sold their units to the biggest ones Cutrale (2nd biggest) and Citrosuco (the biggest one) in 2004 and Citrovita bought the Sucorrico, in 2005 becoming the fourth largest company in the industry (Paulillo and Almeida 2010).

In 2010, there was also another important announcement the fusion of Citrosuco and Citrovita, two of the four biggest processors of orange juice, which would become not only the largest orange juice industry of Brazil but in the world, with capacity to process between 40% and 50% of the Brazilian orange production and considering available data in 2009 the merger may have increased CR4 upward 95%.

Beyond the highly concentrated market, the citrus industry was also characterized by their involvement in the longest CADE in cade history, lasting 17 years, over the accusation of cartel formation and imposition on the orange prices by the associations of processors[2]. Since the early 90's was imposed by CADE some penalties and sanctions over the association of the citrus industry anticompetitive actions. But only in 1999, the CADE go throught with the accusation of cartel formation. In 2016, the investigated firms had to sign a Termination Agreement to finish the lawsuit, pleading guilty of cartel formation between 1999 and 2006 and pay a fine of around USD 90 million (Gonçalves and Vicente 2010; Ito and Zylbersztajn 2016).

3 Theoretical Framework

We are proposing a stochastic frontier model which allow estimate oligopsony power using input prices rather than input quantities. Our model starts with the Panagiotou and Stavrakoudis (2017) model and we use the duality theory and the envelope theorem in the same way as Kumbhakar, Baardsen, and Lien (2012) to switch from primal to dual form. Specifically, we show that output elasticity is equal to cost elasticity and therefore we can replace an input

[2]Administrative Proceedings 08012.008372/1999-14, 08012.001255/2006-66 and 08012.010505/2007-30

distance function (IDF) for cost function in the model which use input prices instead input quantity.

3.1 Individual Firm

Such as Panagiotou and Stavrakoudis (2017) we start assuming that profit function for a firm can be represent by $\Pi^j = P \cdot f^j(x_1, \mathbf{x_z}) - W_1 \cdot x_1^j - \mathbf{W_z} \cdot \mathbf{x_z^j}, \quad j = 1, \dots J$, where Π^j is the profit of the firm j, P is the deflated price of the output (at the wholesale level) and this are market prices and they are given, $f(.)$ is the production function, x_1 is the specialized input quantity on the firm level, $\mathbf{x_z}$ is the vector of other inputs (e.g. labor, energy, capital) used by the firm to produce the output q^j, W_1 is the deflated price of the specialized input and $\mathbf{W_z}$ is the vector of the deflated prices of other inputs, this are market prices, that is, given prices. We assume the industry is an oligopsony, then $W_1 = W_1(X_1)$ is the inverse supply curve for that product.

Assuming the firm maximizes profit, the demand for the specific input will be given by the first-order condition (FOC):

$$W_1(1 + \frac{\phi^j}{\varepsilon}) = P \cdot \frac{\partial f^j(.)}{\partial x_1^j} = P \cdot \frac{\partial q^j}{\partial x_1^j} = MVP_x^j \tag{1}$$

Let $\varepsilon = (\frac{W_1 \cdot \partial X_1}{X_1 \cdot \partial W_1})$ be the price elasticity of the demand and $\phi^j = (\frac{x_1^j \cdot \partial X_1}{X_1 \cdot \partial x_1^j})$ the weighted share of the individual demand with respect to the total demand, conjectural elasticity and MVP_x^j is the marginal value of product of the firm j. Since ϕ^j varies from 0 to 1 and (ϕ^j/ε) is negative but grater then -1, which is an interior solution, we get the following inequation from (1):

$$W_1 \leq MVP_x^j = P \cdot MP_x^j \tag{2}$$

where $MP_x^j = \frac{\partial q^j}{\partial x_1^j}$ is the marginal product of the firm j. If we multiply both sides of inequation (2) by $(\frac{1 \cdot x_1^j}{P \cdot q^j})$ we get:

$$\frac{W_1 \cdot x_1^j}{P \cdot q^j} \leq \frac{\partial \, ln \, q^j}{\partial \, ln \, x_1^j} \tag{3}$$

Like Kumbhakar, Baardsen, and Lien (2012), Germeshausen, Panke, and Wetzel (2014), Das and Kumbhakar (2016) and Panagiotou and Stavrakoudis (2017) we can transform the inequality in (3) into an equality by adding a non-negative, one-sided term u, that represents the mark-down exerted by an oligopsonistic firm:

$$\frac{W_1 \cdot x_1^j}{P \cdot q^j} + u^j = \frac{\partial \, ln \, q^j}{\partial \, ln \, x_1^j} \Rightarrow \frac{W_1 \cdot x_1^j}{P \cdot q^j} = \frac{\partial \, ln \, q^j}{\partial \, ln \, x_1^j} - u^j \tag{4}$$

The term u^j in the stochastic frontier literature represents the technical inefficiency of a production function of the firm (Kumbhakar and Lovell, 2003). In this work, we are not dealing with the production problem, but the market power problem, so it is clear that the term u^j represents the technical inefficiency of the firm, in an oligopsonistic structure the market power exerted on the supply offers, the mark-down, which captures the ratio of imperfect market in comparison with the perfectly market on the purchase of specific input by the firm.

3.2 Aggregate industry

So far the model developed by Panagiotou and Stavrakoudis (2017) allow us to estimate the mark-down at the firm level which it is not our case. Here we deal with the problem on an aggregate level, the industry level. Appelbaum (1982) assumed that in equilibrium the conjectural variation elasticities do not vary across firms, which will be used in this work, this means that $\phi^j = \Phi$ for every citrus industry. Following Azzam and Pagoulatos (1990), the invariance of the conjectural variation across firms enables us to drop the subscript j on the marginal product, where the weight of each firm is the share in whole market.

Multiplying through (1) by (x_1^j/X_1) and summing across the J firms of the industry we obtain the aggregate supply relation:

$$\sum_{j=1}^{J} \frac{x_1^j}{X_1} \cdot W_1 + \sum_{j=1}^{J} \frac{x_1^j}{X_1} \cdot W_1 \cdot \frac{\phi^j}{\varepsilon} = \sum_{j=1}^{J} P \cdot \frac{x_1^j}{X_1} MP_x^j \tag{5}$$

Rearranging the constant terms:

$$W_1 \cdot \sum_{j=1}^{J} \frac{x_1^j}{X_1} + W_1 \cdot \frac{\Phi}{\varepsilon} \sum_{j=1}^{J} \frac{x_1^j}{X_1} = P \cdot \sum_{j=1}^{J} \frac{x_1^j}{X_1} MP_x^j \tag{6}$$

And since $\sum_{j=1}^{J} \frac{x_1^j}{X_1} = 1$, from (6) we get:

$$W_1 + W_1 \cdot \frac{\Phi}{\varepsilon} = P \cdot MP_x \tag{7}$$

Where $MP_x = \sum_{j=1}^{J} \frac{x_1^j}{X_1} MP_x^j$ is the weighted marginal product of individual firms, according Azzam and Pagoulatos (1990). Hence, the industry is analogue to the firm (1):

$$W_1 \cdot (1 + \frac{\Phi}{\varepsilon}) = P \cdot MP_x \quad or \quad W_1 \cdot (1 + \frac{\Phi}{\varepsilon}) = MVP_x \tag{8}$$

In the same way of equation the firm the equality of (1) can be written as inequality as $W_1 \leq MVP_x$.If we multiply both sides of this inequality by $(\frac{1 \cdot X_1}{P \cdot Q})$, where X_1 and Q is the specific input and the output quantity at at industry level. This inequaility has the same direction as inequality of the firm (3):

$$\frac{W_1 \cdot X_1}{P \cdot Q} \leq \frac{\partial \, ln \, Q}{\partial \, ln \, X_1} \tag{9}$$

In equation (9) the term $(\partial \, lnQ/\partial \, lnX_1)$ is the elasticity of an Output Distance Function (ODF) also represented by ε_{QX_1}.

Adding a term u, mark-down of the industry, in equation (9) in order to transform the inequality in equality, but at the industry level:

$$\frac{W_1 \cdot X_1}{P \cdot Q} + u = \frac{\partial \, ln \, Q}{\partial \, ln \, X_1} \Rightarrow \frac{W_1 \cdot X_1}{P \cdot Q} = \frac{\partial \, ln \, Q}{\partial \, ln \, X_1} - u \tag{10}$$

Thus far, the model developed here (10) is the same as Panagiotou and Stavrakoudis (2017). The term $(\partial \, ln \, Q/\partial \, ln \, X_1)$ is the partial derivate of an Output Distance Function (ODF) with respect to the quantity of inputs or the elasticity of an ODF and requires data on quantity of input which is not available to all markets.

The Cost function requirement of data is price of input and according to duality theory of Shepard (1970) the cost function is dual to the Input Distance Function (IDF), so we start from an ODF to get an IDF, then through envelope theorem it is possible to estimate the function we data on input price.

Equation (9) may be rewritten as:

$$\frac{P \cdot Q}{W_1 \cdot X_1} \geq \frac{\partial \, ln \, X_1}{\partial \, ln \, Q} \tag{11}$$

Where $(\partial \, ln X_1 / \partial \, ln Q)$ is the elasticity of an Input Distance Function (IDF) also represented by $\varepsilon_{X_1 Q}$.

The Output Distance Function (ODF) became the Input Distance Function (IDF), which is the dual function of the cost function. Solving the inequality:

$$\frac{P \cdot Q}{W_1 \cdot X_1} = \frac{\partial \, ln \, X_1}{\partial \, ln \, Q} + u \tag{12}$$

Now we proceed through the duality theory from an IDF function to obtain a Cost function, which data requirement are prices of inputs.

3.3 Dual approach

Following Kumbhakar, Baardsen, and Lien (2012) and Das and Kumbhakar (2016) and according to duality theory, all characteristics of the production technology, implied by the production function $\mathbf{Q} = f(\mathbf{X}, T)$, can be uniquely represented by a minimum total cost function $C(\mathbf{W}, \mathbf{Q}, T)$ where C is the minimum total cost, T is a technological trend and $\mathbf{W}$ is the vector of price of the inputs, composed by W_1, the price of the specialized input, and W_z, the vector of other inputs prices. This function is positive and non-decreasing in Q and W, and homogeneous, concave and continuous in W.

Since we have a structure of multiple inputs and outputs ($X_i, Q_m; i = 1, 2, ..., I$, and $m = 1, 2, ..., M$). We start from a transformation function and express the efficient production technology as $h(Q, \mathbf{X}, T) = 1$. This primal approach allows us to obtain the production function, the output and input distance functions, simply by using normalizations of the transformation function as demonstrated by Kumbhakar (2011). As shown below it also enables us to estimate mark-downs either using price or quantity information. This approach has shown very useful to deal with the absence of data.

Here we assume the transformation function, $h(.)$, is a translog function associated with IDF and can be written as:

$X_1 = h(Q, \tilde{\mathbf{X}}, T) \Rightarrow \; ln \; X_1 = h(\; ln \; Q, \; ln \; \tilde{\mathbf{X}}, T)$, when $\tilde{\mathbf{X}} = (\frac{X_i}{X_1}), \quad i = 2, 3, ..., I.$

And we also assume the above IDF uses the normalization that $h(Q, \mathbf{X}, T)$ is homogeneous of degree -1 in $\mathbf{X}$ which means:

$$\sum_{i=1}^{I} \frac{\partial \, ln \, h}{\partial \, ln \, X_i} = -1 \tag{13}$$

To apply the duality theory, we start from the Lagrangian for cost minimization using the transformation function: $L = \mathbf{W'X} + \lambda(h(Q, \mathbf{X}, T) - 1)$. The First order conditions to the optimization problem is:

$$\frac{\partial L}{\partial X_j} = 0 \Rightarrow W_j + \lambda \cdot \frac{\partial h(.)}{\partial X_j} = 0 \Rightarrow W_j = -\lambda \cdot \frac{\partial h(.)}{\partial X_j} \tag{14}$$

Multiplying (13) by X_j in both sides and by $(h(.)/h(.))$ the right side and summing across the inputs:

$$W_j \cdot X_j = -\lambda \cdot h(.) \cdot \frac{\partial h(.) \cdot X_j}{\partial X_j \cdot h(.)} \Rightarrow W_j \cdot X_j = -\lambda \cdot h(.) \cdot \frac{\partial \, ln \, h}{\partial \, ln \, X_j}$$

$$C = -\lambda \cdot h(.) \sum_j \frac{\partial\, ln\, h}{\partial\, ln\, X_j} \Rightarrow -\lambda = \frac{C}{h(.)} \cdot \frac{1}{\sum_j \frac{\partial\, ln\, h}{\partial\, ln\, X_j}}$$

Since $h(.)$ is homogeneous of degree -1 in $\mathbf{X}$, equation (13):

$$\lambda = \frac{C}{h(.)} \tag{15}$$

From the Envelope Theorem, the marginal cost (MC) for output Q is:

$$\frac{\partial L}{\partial Q} = MC = \frac{\partial C}{\partial Q} = \lambda \cdot \frac{\partial h(.)}{\partial Q} \tag{16}$$

Substituting (15) into (16):

$$\frac{\partial L}{\partial Q} = MC = \frac{\partial C}{\partial Q} = \frac{C}{h(.)} \cdot \frac{\partial h(.)}{\partial Q} \tag{17}$$

If we multiply both sides of (16) by (Q/C) we get:

$$\varepsilon_{CQ} = \frac{\partial\, ln\, C}{\partial\, ln\, Q} = \frac{\partial C}{\partial Q} \cdot \frac{Q}{C} = \frac{C}{h(.)} \cdot \frac{\partial h(.)}{\partial Q} \cdot \frac{Q}{C} = \frac{\partial\, ln\, h(.)}{\partial\, ln\, Q} = \varepsilon_{hQ} \tag{18}$$

ε_{hQ} can be computed using estimated parameters of the IDF transformation function ($X_1 = h(Q, \mathbf{X}, T)\ \forall\ X_j = 2, 3, ...J$). That is, the cost elasticity of output (ε_{CQ}) can be estimated from a IDF and there is no need to estimate the use of quantity of inputs. Then equation (12) can be written as:

$$\frac{P \cdot Q}{W_1 \cdot X_1} = \frac{\partial\, ln\, X_1}{\partial\, ln\, Q} + u = \frac{\partial\, ln\, C}{\partial\, ln\, Q} + u \tag{19}$$

The elasticity of the production function ($\varepsilon_{X_1 Q}$) is equal to the cost elasticity of output (ε_{C_Q}) as was shown though a transformation function. Econometrically the Cost function shown the same elasticity of an Input Distance function. Hence, allow us to use an cost function instead a production function to estimate the market power in the industry where only proxies of input prices are available.

Adding a the stochastic term we get:

$$\frac{P \cdot Q}{W_1 \cdot X_1} = \frac{\partial\, ln\, C}{\partial\, ln\, Q} + u + v \tag{20}$$

We can observe that the models (20) follows the SF literature applied to the estimation of market power (KBS, 2012; Das e Kumbhakar, 2016; Scalco et al, 2017; e PS, 2017) and the composed error term $(u + v)$ is the same of the SF models, hence can be estimated (20) using the maximum likelihood method. Following the literature, we assume u has a normal distribution truncated at zero from below, i.e. $u \sim N^+(0, \sigma_u^2)$, and v is the usual two-sided normal noise term, i.e. $v \sim N(0, \sigma_v^2)$.

As already mentioned, to estimate (20) we assume that cost function takes a form of a translog which can be written as:

$$ln\, C = \beta_0 + \sum_{i=1}^{I-1} \beta_i\, ln\, \tilde{W}_i + \frac{1}{2} \sum_{i=1}^{I-1} \sum_{k=1}^{I-1} \beta_{ik}\, ln\, \tilde{W}_i \cdot\ ln\, \tilde{W}_k + \beta_Q\, ln\, Q + \frac{1}{2} \beta_{QQ} (\, ln\, Q)^2 +$$
$$+ \sum_{i=1}^{I-1} \beta_{iQ}\, ln\, \tilde{W}_i \cdot\ ln\, Q + \beta_T\, T + \frac{1}{2} \beta_{TT}\, T^2 + \sum_{i=1}^{I-1} \beta_{jT}\, ln\, \tilde{W}_j \cdot T + \beta_{QT}\, ln\, Q \cdot T$$

Where the index I refers to the inputs, i.e. specific input, labor, energy and capital,... and $\tilde{W}_i = \frac{W_i}{W_I}$, $\forall\ i = 1, 2, ..., I-1$. In addition we assume the assumptions about symmetry $\beta_{ik} = \beta_{ki}$ and homgeneity $\sum_{i=1}^{I-1} \beta_{iQ} = 0$.

From (20) the cost elasticity (ε_{CQ}):

$$\frac{\partial\ ln\ C}{\partial\ ln\ Q} = \beta_Q + \beta_{QQ}\ ln\ Q + \sum_{i=1}^{I-1} \beta_{jQ}\ ln\ \tilde{W}_i + \beta_{QT}\ T \tag{21}$$

Finnaly, substituting (21) into (20) we get:

$$\frac{P \cdot Q}{W_1 \cdot X_1} = \beta_Q + \beta_{QQ}\ ln\ Q + \sum_{j=1}^{J} \beta_{jQ}\ ln\ \tilde{W}_j + \beta_{QT}\ T + u + v \tag{22}$$

The model (22) is the model that will be estimated in this work.

According to Panagiotou and Stavrakoudis (2017), to measure the degree of market power (θ) we use:

$$\theta = \frac{MVP_X - W_1}{MVP_X} \tag{23}$$

To show that θ can be estimated from $\theta = u/(\frac{\partial lnQ}{\partial lnX_1})$ where u is the mark-down estimated and $\partial lnQ/\partial lnX_1$ is the output elasticity calculated from ODF. We use the result from (18) and the fact that input elasticity from IDF is the inverse of output elasticity to rewrite this expression as follow:

$$\theta = \frac{u}{(\frac{\partial lnQ}{\partial lnX_1})} \Rightarrow \theta = \frac{u}{\frac{1}{(\frac{\partial lnQ}{\partial lnX_1})}} \Rightarrow \theta = u \cdot \frac{\partial lnX_1}{\partial lnQ} \Rightarrow \theta = u \cdot \frac{\partial lnC}{\partial lnQ} \tag{24}$$

In that way, after estimate (22) we use the estimated values of cost elasticity (ε_{CQ}) and of mark-down ($\hat{u}$) to estimate $\hat{\theta}$ as follow:

$$\hat{\theta} = \hat{u} \cdot (\hat{\beta}_Q + \hat{\beta}_{QQ}\ ln\ Q + \sum_{j=1}^{J} \hat{\beta}_j Q\ ln\ \tilde{W}_j + \hat{\beta}_{QT}\ T) \tag{25}$$

With some algebraic manipulation it is possible to represent the measure market power like a Lerner index. First we rewrite (23) as follow:

$$\theta = \frac{MVP_X - W_1}{MVP_X} \Rightarrow \theta = 1 - \frac{W_1}{MVP_X} \Rightarrow (1-\theta) = \frac{W_1}{MVP_X} \tag{26}$$

Hence, after estimating θ with the help of equation (25) the Lerner index of oligopsony power for the industry can be estimated as:

$$L = \frac{MVP_x - W_1}{W_1} = \frac{(\frac{MVP_x}{MVP_x}) - (\frac{W_1}{MVP_x})}{(\frac{W_1}{MVP_x})} = \frac{1-(1-\theta)}{(1-\theta)} \Rightarrow L = \frac{\theta}{1-\theta} \tag{27}$$

Therefore, after estimating θ by (25) the Lerner index can be calculated using estimated values in (27).

Finally, we can show that $\varepsilon_{CQ} = \partial lnC/\partial lnQ = (\partial C/\partial Q)(Q/C) = MC/AC$, where AC is the average cost. This means that the return to scale is inversely related to cost elasticity, i.e. $RTS = 1/\varepsilon_{CQ}$. Therefore, we can calculate RTS from estimated values in (22) as follow:

$$RTS = 1/(\hat{\beta}_Q + \hat{\beta}_{QQ}\ ln\ Q + \sum_{j=1}^{J} \hat{\beta}_j Q\ ln\ \tilde{W}_j + \hat{\beta}_{QT}\ T) \tag{28}$$

If $\varepsilon_{CQ} = 1$ we have constant returns to scale, if $\varepsilon_{CQ} < 1$ we have increasing returns (economy of scale) and if $\varepsilon_{CQ} > 1$ we have decreasing returns (diseconomies of scale).

4 Data

The data set used to empirical analysis are annual aggregate time series from orange juice industry in the São Paulo state. As describe in Section 2 orange juice production represents more than 80% of citrus fruit processing. São Paulo concentrate 80% of the Brazilian production and 98% of this production is exported. Then, the exports orange juice in São Paulo represents an relevant buyer and therefore represents the Brazilian orange juice industry who has the ability to potential exert oligopsony power.

The time series cover period between 1997 and 2018. The data were obtained from different sources, from Brazilian Foreign Trade Statistics (Comex Stat), Agricultural Economics Institute (IEA), Annual Report on Social Information (RAIS) and Institute of Applied Economic Research (IPEA DATA). The period was mainly dictated by the data availability but it cover the time where orange juice industry was over investigation in Brazil's antitrust office for cartel formation. The monetary variables were deflated with the General Price Index – Internal Availability (IGP-DI) and all values correspond to the base prices of 2018. The table 2 presents the descriptive statistics of the sample.

Table 2: Variable definition and descriptive statistics*

Variable	**Description**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Source**
$P \cdot Q$	Revenue value of Exportation Orange juice (billion R$)	6.489	1.324	4.822	9.650	Comex Stat
$W_1 \cdot X_1$	Cost of Orange in nature (billion R$)	4.089	1.221	1.673	6.404	IEA
Q	Orange Juice (billion kg)	1.724	0.364	1.139	2.303	Comex Stat
W_1	Price orange in nature (R$/ kg)	0.393	0.120	0.164	0.620	IEA
W_2	Proxy on price of labor (salaries thousand R$/ annual)	40.24	3.278	36.00	48.33	RAIS
W_3	Proxy on price of Energy (price of Diesel fuel R$/ lt)	2.882	0.295	2.443	3.504	ANP
W_4	Proxy on price of cost of capital (Long term interest rate - TJLP - %)	8.105	2.429	5.000	13.22	IPEA DATA
T	Time trend (1=1997, 22=2018)	11.50	6.494	1	22	-

Source: Author elaboration; * The values are deflated with the inflation rate of the period to current values of 2018.

The dependent variable in (22) is the ratio between the revenue of exportation of orange juice and the cost of the orange in nature that goes to industry in the São Paulo state $(PQ)/(W_1X_1)$. The other side, the independent variables are: the quantity of orange juice exported from São Paulo in kilograms (Q), price of orange in nature in kilograms (W_1), the average annual salaries in the orange juice industry is used as proxy of price of labor (W_2), annual average price of diesel in the São Paulo state is the proxy to energy price (W_3) and annual average Brazilian long term interest is the proxy to cost of capital (W_4), and still, a time trend (T) to account the technological improvement on the period.

5 Results

The results of parameters estimated in equation (22) are presented in Table 3. The estimates of price of orange and labor were statistically significant at the level of 1% and 5% of significance respectively.

Table 3: Stochastic Frontier Results

Parameters	Estim. Coef.	Std. Err.	p-Value
$\hat{\beta}_{QQ}$	0.834	1.223	0.495
$\hat{\beta}_{Q1}$	-2.012	0.297	0.000
$\hat{\beta}_{Q2}$	1.766	0.815	0.030
$\hat{\beta}_{Q3}$	-1.157	0.858	0.177
$\hat{\beta}_{QT}$	0.0180	0.033	0.583
$\hat{\beta}_{Q}$	-32.10	29.35	0.274
σ_u^2	0.0430	2.202	0.984
σ_v^2	0.346	0.112	0.002
λ	0.124	2.301	0.957

Source: Author elaboration

Table 4 present the estimates and standard deviations of the relevant parameters of the model. The mark-down term u, such as expressed in (22), was 0.03 and its mean that the ratio between total revenue and cost of orange in the citrus industry is around 1.03 times higher than would be in a market with perfect competition. The estimate of the market power , as defined in (24) was on average 0.059, suggesting that the price received by the orange farms is 5.90% lower than the net value of the marginal product of orange.The Lerner index indicates the industry's ability to lower the price of a specific input below its marginal value of production (Love and Shumway 1994). Our estimates of Lerner Index was on average 0.063, indicating that orange's net marginal value product is 1.063 times above the orange price. Lastly, the estimate of return to scale (0.651) indicates that orange juice industry operates with decreasing returns, which makes sense since not all orange is use to produce orange juice, orange pomace and seeds are not used by the industry.

Table 4: Estimates of Degree of market power, Lerner Index, Mark-down and Return to Scale

Variable	Description	Mean	Std. Dev.	Min	Max
$\hat{\theta}$	Degree of Market Power	0.059	0.021	0.034	0.128
$\hat{L}$	Lerner Index	0.063	0.025	0.035	0.147
u	Mark-down	0.966	0.001	0.963	0.969
RTS	Return to Scale	0.651	0.209	0.289	1.049

Source: Author elaboration

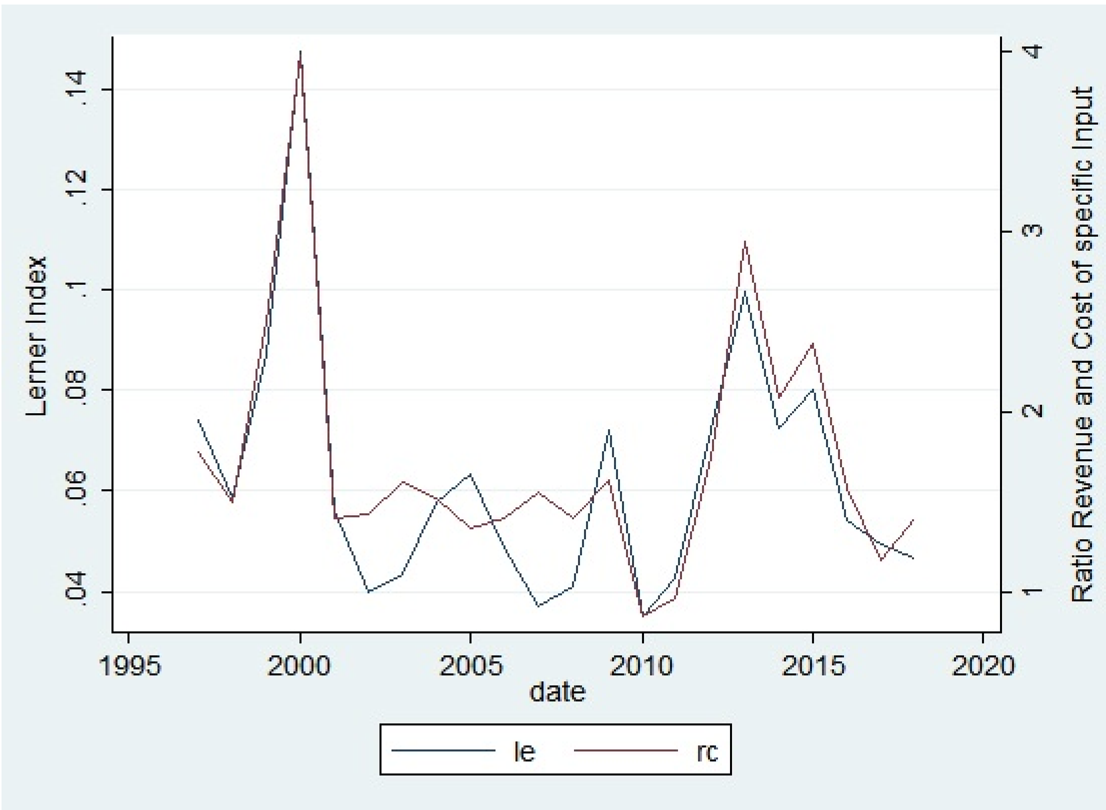
The Lerner Index it is very useful to explain the movements of the market during the period investigated, 1997-2018, and how they impacts on the competitive behavior. In figure 2 it interesting to show the Lerner index follow the behavior of the ratio of revenue and the cost of orange.

The behavior of Lerner index can also be explained to the events that impacted the market of orange juice. In 1997 the Lerner index was 0.075. The litigious on CADE, Brazil antitrust authority, between the producers of orange and the processors starts in 1999 with the accusation of cartel formation by citrus industry and this match the moment of the raise and highest Lerner index during the whole period analyzed, with almost 0.15 in 2000.

The fall of Brazilian exports from 2001 and increase of production in Florida, US, one of mainly destination of Brazilian exports led to the decrease of ratio revenue and cost of specific input. Also in 2006 the Brazilian orange juice cartel was dismantled, which hurts the ability of the industry to exert oligopsony power in the bought of orange. In response to that movements, the Lerner index was the smaller in the period till 2010 varying from 0.037 to 0.75. The market power of the industry was not high if with analyze the highly concentrated marked, where biggest four industries holds 90% of the production.

In 2010 occurs a interesting movement in the market. The international prices of orange increases more than 40% since the previous year due to a small crop in consequence of unfavorable weather conditions. Consequently, the Lerner index reached its lowest level with 0.035 and lowest ratio revenue and cost of specific input too. However, 2010 was the year of the fusion between Citrovita and Citrosuco forming the biggest processor of orange juice not only in São Paulo but in the world.

Figure 2: Lerner Index and Ratio of Revenue and Cost of specific input



Source: Author elaboration

In the following years the international prices of orange began to retreat due to big stock on orange in the market. Consequently the ratio revenue and cost of specific input began to increase and the Lerner index as well. The maturation of the fusion of the processors might have a influence on the market behavior once in 2013, three years after the fusion, the Lerner index was 0,10. It is important to see how the international prices of orange reflects in the São Paulo market and then in the market power exerted.

The empirical results of this work suggest that orange in nature price was 5,9%, on average, lower than their net marginal value product, indicating evidence of oligopsony power exerted in the Brazilian Citrus Industry. The highly concentrated market can be a explanation of this outcome. The relation between the ratio revenue and cost of specific input and Lerner index evidencing the market power exerted by industry was mostly on the orange producers.

6 Final Remarks

The aim of this work was to develop a model to estimate market power in an oligopsony framework with price data using SF approach. Here, like Muth and Wohlgenant (1999) we start from a model that the data requirement is input quantity which is not always available to all markets to obtain a model that allow us to estimate oligopsony power with only input price requirement.

The model developed was applied to measure oligopsony power in the Brazilian Citrus Industry. Our empirical results suggest that, on average over 1997 to 2018, the net value of the marginal product of orange is 5.90% higher than the price of the orange. Hence, based on the empirical outcome of this study, one can conclude that there is significant evidence that the producers of orange receive lower prices because the Brazilian Citrus Industry might be on imperfect competition.

Other evidence found is Lerner Index of degree of oligopsony power that, on average, was 6.3% and with reach their highest in 2000 with almost 15% which correspond the time the industry pledge guilty in the investigation of cartel formation (1999-2006) by Brazilian Antitrust authority (CADE).

Finally, the model developed here can be applied to any market. It stands out due to his flexibility of data requirement. Oligopsony power can be estimated either with quantity or price data. Hence, the stochastic frontier approach shows its robustness to measure market power in a single equation and the possibility to obtain directly the Lerner index and measure of degree of market power.

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