IRRIGATION EFFECTS ON GRAIN SUPPLY IN THE BRAZILIAN SOUTHEAST: A SHORT-RUN ANALYSIS

EFEITOS DA ADOÇÃO DE IRRIGAÇÃO SOBRE A OFERTA DE GRÃOS NA REGIÃO SUDESTE DO BRASIL: UMA ANÁLISE DE CURTO PRAZO

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Abstract. The irrigation technology is an important tool capable of mitigating the adverse effects of climate change, ensuring the yields, raising agricultural productivity rates and increasing employment in rural areas, which generates income and raises food security. We aim to analyze the effect of irrigation on grain supply and demand for productive factors in the Southeast region of Brazil. A system of equations was estimated using the restricted quadratic profit function approach. The results point toward a positive effect on the supply of grains and demand for labor. In addition, irrigation contributes to a 2.1% increase (US$ 83.45 million) in the average revenue generated by the grains analyzed. The overall results provide useful information to design public policies that aim to develop irrigated agriculture in Brazil and can assist water-charging policies used for irrigation.
Keywords: Irrigation, farm size, grain supply, return on revenue.

Resumo. A tecnologia de irrigação é uma importante ferramenta capaz de mitigar os efeitos adversos das mudanças climáticas, elevando os índices de produtividade agrícola e aumentando o emprego em áreas rurais, o que gera renda e aumenta a segurança alimentar. Nosso objetivo é analisar o efeito da irrigação na oferta de grãos e na demanda por fatores produtivos na região Sudeste do Brasil. Um sistema de equações foi estimado utilizando a abordagem da função de lucro quadrática restrita. Os resultados apontam para um efeito positivo na oferta de grãos e na demanda por mão de obra. Além disso, a irrigação contribui para um aumento de 2,1% (US$ 83,45 milhões) na receita média gerada pelos grãos analisados. Os resultados gerais fornecem informações úteis para o desenvolvimento de políticas públicas voltadas à agricultura irrigada no Brasil e podem auxiliar na formulação de políticas de tarifação da água utilizada para irrigação.
Palavras-chave: Irrigação, tamanho da propriedade rural, oferta de grãos, retorno sobre o investimento.

1. Introduction

Irrigation projects in Brazil were implemented first in the South region. The use of irrigation systems was driven by private agents to make rice growing feasible, and was extended to coffee plantations in the State of São Paulo in Southeast Region (Ministry of National Integration-MI, 2008). Irrigated areas in Brazil are still considered small compared to the total agricultural area; to the territorial extension; and to the set of favorable physical-climatic factors, including water availability (Cuadra *et al.*, 2019).

On the other hand, annual increases in irrigated area have remained high in recent years, indicating that this potential has been used in areas significantly larger each year, mainly in the Southeast region with grains, sugar-cane and oranges production (ANA, 2016; 2017); and it has presented successive and expressive increments on irrigated land since 1970, which also has greater diversification of irrigation methods among the Brazilian regions.

São Paulo and Minas Gerais States account for 34.0% of the total irrigated land in Brazil and 87.9% of the Southeast, driving the region to respond nowadays to the largest irrigated area, 39.0% of the total (ANA, 2018). The percentage of farmers that adopted irrigation technology in Brazil was around 6.3% in 2006 while the Southeast region presented an adoption rate around 11.8% in the same year (IBGE, 2006).

It should be pointed out that the low adherence of irrigation technology might be due to the irrigation costs; absence of water resources in the properties; difficulties faced in the credit market by the farmers, mainly small farmers; and levels and frequency of precipitation (Cristófidis, 2013). To alleviate water scarcity, irrigation systems are becoming more efficient (Schaible; Aillery, 2012), maximizing water productivity rather than land productivity (Sepaskhan *et al.*, 2006), while irrigation systems adoption can generate higher yields and allow the production of valuable crops and reduce production costs as well (Stubbs, 2016).

Agência Nacional de Águas – ANA (Brazilian Water Agency, in English) highlights that although all the benefits related to irrigation are recognized, there are still difficulties in assessing its importance in the current quantity produced and its role in the food and nutritional security of the Brazilian society due to the unavailability of data or the impossibility of data disaggregation in relation to the agriculture.

The literature about the effects of irrigation on the productive structure of farmers is not so vast. This gap leads to an inconclusive result in relation to the real effect of irrigation mainly on grains supplies and input demands for productive factors and the return in terms of extra revenue achieved by irrigation (Okada *et al.*, 2018). Nonetheless, the knowledge on how irrigation technology and adaptive capacity to climatic variability among farm sizes is a relevant research goal because structural changes in the distribution of farm sizes has implications for rural economies, consumers in both export and local markets, and for new producers entering the industry (Vanschoenwinkel; Van Passel, 2018).

Climatic variations are expected to adversely affect food production in some important regions of the world, generating possibly significant losses, most likely affecting small farmers and poorer populations (Vanderlugt, 2011). Although the growth of irrigated agriculture

generally results in increased water use, several benefits can be observed, such as increase in productivity, reduction of unit costs, mitigation of climatic risks, optimization of inputs and equipment, and mainly to increase food supply and make its stable (Cuadra *et al.*, 2019).

Southeast Region has presented increasingly irrigated areas expansion, mainly with central-pivots in the last two decades (ANA, 2016); and is characterized by the developed stage of mechanization in agriculture, being this region dominated by technically advanced commercial farmers (FAO, 2015). Moreover, irrigation practices in the winter season allow the farmers to crop twice instead of once a year, which may reflect why irrigated land fraction in Southeast is higher than other Brazilian regions and why most of the crop plantations are those more valuables. The region also has the proximity of the main commodities exporting ports in Brazil, Port of Santos and Port of Paranaguá, which leads the region to be in advantage in terms of rural development and agricultural market structure. These interesting aspects caused the Southeast Region to be chosen as our object of analysis in this research.

Thus, we seek in this paper answer the following questions: *How much of grain supply can be achieved through irrigation technology? What is the role of farm heterogeneity in terms of size in response to irrigation expansion? And how much of each grain revenue is due to irrigation and also in total revenue for Southeast region?* To answer those questions, we propose to estimate the irrigation effect on grains supplies, input demands and farmers' revenue using more than 308 thousand farm observations from 2006 Agricultural and Livestock Census.

We aim to estimate the farm marginal effect of irrigated land expansion due its importance to reveals how much of grain supply can be achieved thought irrigation technology and the capacity to increase input demand, allowing measuring the irrigation impact on farmers' revenue. The marginal effect of irrigation is estimated on coffee, rice, soybeans, corn and beans supplies as well as labor and fuel demand, which are obtained using derivative properties from a restricted quadratic normalized profit function. Our estimates also take into account different farms sizes to evaluate how farm heterogeneity responds differently to irrigation and short-run weather effects since these factors might impose production losses (Pereda, 2012).

Our analysis contributes to the literature by providing estimates on how much revenue of each output is due to irrigation and also the change in total revenue of the grain sector. Added revenue due to irrigation measures the opportunity cost of irrigation while comparisons for different commodities allow us to rank commodities according to their revenue efficiency relative to irrigation use (Moolman *et al.*,2006). Thus, policies actions can be driven to those crops mostly valuable in terms of added revenue achieved through irrigation technology and/or

based on the revenue participation of each crop within the total amount of revenue generated for the entire sector.

We found that irrigation expansion affects positively all grains supplies and labor input demand. The change in grain sector revenue due to irrigation is 2.10% (around US$ 83.45 million), where changes in the revenue of coffee, corn and beans represent 97% of the total added revenue. We also found that output supplies and input demands respond differently to heterogeneous farms sizes facing irrigation expansion and short-term weather effects.

This paper is organized in five sections besides this introduction. The following section we present a background of irrigated land and production in the Southeast region. The theoretical framework and empirical model are described in Sections 3 and 4, respectively. Our results are shown in section 5; and our finals conclusions are exposed in Section 6.

2. Background

Throughout the 20th century, a set of institutions focusing on issues of climate, water availability and sanitation were created, being fundamental to the development of irrigation in Brazil. The second phase of government actions related to irrigation expansion came in the late 1960s, while the 1970s is recognized as the starting point for irrigated perimeter projects across the country (Bursztyn, 2008).

In 2002/2003, the Ministério da Agricultura, Pecuária e Abastecimento – MAPA (Ministry of Agriculture, Livestock and Food Supply, in English) created the Irrigated Agriculture Support Program (Proirriga) in order to finance the implementation, renovation or conversion of irrigation systems, including infrastructure buildings, which was managed by the Banco Nacional de Desenvolvimento Econômico e Social – BNDS (National Bank for Economic and Social Development, in English). The program was joined to the Rural Property Storage Program (Proazem), resulting in the Incentive Program for Irrigation and Production in Protected Environment (Moderinfra) (EMBRAPA, 2010). Moderinfra is in force until the present and is the main channel to finance credit to the producers develop and expand irrigated agriculture. Moreover, the More Irrigation Program was launched in 2012 with the purpose to invest in the regional economy, generate employments and income, and ensure the production (BRASIL, 2013).

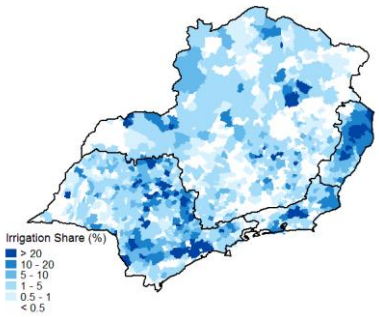
Christofidis (2008; 2013) points out some goals of those policies, such as: expansion of irrigated areas and increasing productivity on an environmentally sustainable basis; reduce the climatic risks; promote local and regional development; increasing the competitiveness of agribusiness for generation of employment and income; supplying outputs for domestic market

and generating surplus exports; training of human resources; and generation and transfer of technologies related to irrigation.

As Brazilian agriculture in general, irrigated agriculture in the Southeast Region is dynamic and diversified, which more than 70 different crops are associated with different irrigation methods. Figures 1a and 1b show the Southeast Region and the fraction of irrigated land, respectively. Despite of irrigation technology adoption in Southeast region be around 12%, we can observe some municipalities facing high irrigation share, for instance, in Espírito Santo and São Paulo States. The percentage of irrigated land in relation to the total land used in agriculture easily surpasses 20% in some municipalities, which imply that those places are mostly based on irrigated production.

Figure 1a – Southeast Region

Figure 1b – Irrigated Land (%)



Source: Author´s elaboration based on 2006 Agricultural Census.

In spite of diversity, it is possible to extract some large-scale patterns between irrigation methods and crops, such as the strong correlation between flooding and rice; dripping and coffee; conventional sprinkler and sugarcane; and central pivots in the grain production, especially, beans, corn and soybeans (ANA, 2018).

Evaluating the percentage of irrigated land by irrigation method in relation to the total irrigated land in the Southeast Region, we can observe larges irrigated areas using sprinkler and central-pivot. These two methods represent more than 78% of irrigated land in São Paulo and 64% in Minas Gerais States. Drip irrigation can be found in Espírito Santo and Minas Gerais States mostly to irrigate coffee and corn, which represents 24.5% of irrigated land to the former and 12.5% to the latter. Rio de Janeiro has 53% of irrigated land by sprinkler mostly to produce corn, bean and fruit growing.

In some places of Southeast region affected by water scarcity in specific periods of the year, some crops and harvests are only feasible with the supplementary application of water in these

periods, although production can be carried out with smaller risk in the rainy season (ANA, 2017). Despite of a larger production observed in the region for those outputs, which represent more than 50% of total production, the percentage of farmers that adopted irrigation technology to produce each output is still low: 14.07% for rice; 7.63% for soybeans; 6.35% for beans; 4.66% for corn; and 3.3% for coffee. Thus, the low percentage of irrigation adoption might imply that most of the amount produced in Southeast region comes from medium and large farms with a high irrigation rate since the region is mostly mechanized and capital intensive.

3. Theoretical Framework

The duality between the production function and the profit function was first investigated in Gorman (1968) and McFadden (1978). The profit function is the mathematical representation to the solution of the economic agent's optimization problems, which is defined as profit maximization (Lau, 1976). Chambers (1988) argues that profit maximization with fixed product implies the same configuration of inputs when implemented by the cost minimization problem. Thus, if the duality between the profit function and the cost function exists then a conjugate relationship between the profit function and the production function can be developed (Chambers, 1988). The profit function approach allows us to retrieve relevant information on the production process, such as product supply relations, factors demand, and own and cross elasticities (Diewert and Morrison, 1989).

Thus, we propose to identify the effect of irrigation on grain production and productive factors using derivative properties of a restricted profit function. It represents that some inputs, such as irrigated land, can be fixed (or quasi fixed), since the possibility of changing the quantities of these inputs are constrained in the short run. Carey and Zilberman (2002) argue that farmers face difficulties when choosing and/or changing production input-output, such as irrigation technology. Therefore, choices related to this technology are long-term decisions and considered as fixed (or quasi-fixed) in the short term. According to Huffman and Evenson (1989), the fixed factors are not under the control of farmers, or they are only partially under their control, or when under control demand some time and cost of adjustment. In the case of irrigation, the preparation of land to be irrigated and the irrigation system implementation demands a certain period, being therefore not feasible in the short term. The existence of these inputs delimits the production possibilities set, leading the problem of profit maximization to a restricted problem.

Lau (1976) and Huffman e Evenson (1989) argue that taking into account a production decision for many outputs and inputs (multi input-output), the farmers make choices on $n +$

$m+1$ products y_i, which they supply $n+1$ outputs, such as $y_i > 0,\ i = 0, \dots, n$ and require m variables inputs, such as $y_i < 0,\ i = n+1, \dots, n+m$. The quasi-fixed factors vector can be represented by z_k, where $z_k \geq 0,\ k = 1, \dots, K$. Since the profit function is normalized, the output at which its price is used to normalize the function can be defined by y_0, i.e., a numeraire output. Thus, p_0 is a numeraire price, which can be set equal the unit, such as $p_i = p_i/p_0,\ i = 1, \dots, n+m$, where p_i is the numeraire price of $y_i,\ i = 1, \dots, n+m$, and $p_i > 0$. This procedure impose homogeneity of degree one in prices $\boldsymbol{p}$. The profit function can be represented by $\pi = f(\boldsymbol{p}, \boldsymbol{z})$, where π is the normalized restrict profit ($\pi = \pi'/p_0$), $\boldsymbol{p}$ is a vector of $n+m$ normalized prices and $\boldsymbol{z}$ is a vector of K quasi-fixed inputs.

The first derivative of the restricted profit function with respect to each output price can be performed using envelope theorem to obtain the correspondent output supply:

$$\frac{\partial \pi}{\partial p_i} = y_i^*(\boldsymbol{p}, \boldsymbol{z}) > 0, \quad i = 1, \dots, m \tag{1}$$

and the input demand is obtained taking the first derivative of restrict profit function in respect to each input price:

$$\frac{\partial \pi}{\partial p_i} = y_i^*(\boldsymbol{p}, \boldsymbol{z}) < 0, \quad i = 1, \dots, n \tag{2}$$

The numeraire output supply or input demand equations also can be represented by Equation (1) or (2) and obtained using homogeneity properties, which depend of the price (input or output) chosen to normalize the restrict profit function. Also from Equation (1)-(2) we can use the second derivative of restricted profit function in respect to price to obtain output/input own and cross elasticities:

$$\frac{\partial^2 \pi}{\partial p_i^2} \frac{p_i}{\partial \pi / \partial p_i} = \frac{\partial y_i^*}{\partial p_i} \frac{p_i}{y_i^*} \qquad i = 0, 1, \dots, n+m \tag{3}$$

where the elasticity predicted by Equation (3) is positive if y_i^* is an output and negative if y_i^* is an input. The former result is due to own price elasticity for output supply and the latter is due to own price elasticity for input demands. To estimate the effect of quasi-fixed input on output supply or a variable input, i.e., input demand, we can obtain the output and input elasticity in respect to the quasi-fixed input:

$$\frac{\partial^2 \pi}{\partial p_i \partial z_k} \frac{z_k}{\partial \pi / \partial p_i} = \frac{\partial y_i^*}{\partial z_k} \frac{z_k}{y_i^*} = \lambda_{z_k}^{y_i} \lesseqgtr 0 \tag{4}$$

where $\partial \pi / \partial p_i = y_i^*$. The theory does not impose any sign on $\lambda_{z_k}^{y_i}$, which a positive sign imply a percentage increase on output supply or input demand due to a percentage increase in the quasi-fixed input, and a percentage decrease otherwise. If $\lambda_{z_k}^{y_i}$ is equal to zero, there are no

effects of quasi-fixed input on output supply or input demand. To measure the irrigation effect on the revenue of each farm output, we multiply the marginal effect of each farm by the output price and the total irrigated land in the farm. Then, if we sum the effect over farmers we obtain the effect of irrigation on revenue of each output for the region:

$$\delta_{i,z_1} = p_i * \frac{\partial y_i^*}{\partial z_k} * \sum_{j=1}^{J} z_{1,j} \quad (5)$$

where $j = 1, \dots, J$ represents each farmer producing the output i; p_i is the output price; $\partial y_i^* / \partial z_k$ is the marginal effect of irrigation on output supply; and $z_{1,j}$ is the irrigated land in hectares. Thus, we can divide each δ_{i,z_1} by the total revenue of each output observed in the market to obtain a relative measure, i.e., the proportion of added revenue of each output due to irrigation in relation to total revenue of that output:

$$\psi_i = \frac{\delta_{i,z_1}}{p_i * Y_i} \quad (6)$$

where $Y_i = \sum_{j=1}^{J} y_{ij}$ represents the quantity produced over all farmers. To obtain a relative measure for the grain sector, we obtain the total revenue gain due to irrigation summed over outputs and farmers and divide by the total revenue observed in the grain sector in the Southeast region.

4. Empirical Application

To obtain a system of supply – for coffee, rice, soybean, corn and beans – and demand equations – for labor and fuel; and then to evaluate the effect of quasi-fixed inputs on production, Diewert et al. (1989) suggest that a flexible functional form is preferable, which have been employed in several studies, such as the translogarithmic function in McKay *et al.* (1983), the normalized quadratic function in Shumway *et al.* (1988), Huffman and Evenson (1989), and Schuring *et al.* (2011), and the generalized Leontief function in Lopez (1984). According to Huffman and Evenson (1989), the normalized quadratic function is preferable due to linear homogeneity in the output and input prices. Lau (1976) and Lopez (1985) argue that the normalized quadratic function has additional implications on production technology, such as weak separability between inputs and outputs, and quasi-homotheticity. In this sense, we assume that our restricted profit function can be represented by a quadratic functional form to obtain the output supply and input demand using derivative properties. Since Equation (1) and (2) are linear on normalized input prices and quasi-fixed inputs, we can obtain

$$\frac{\partial \pi}{\partial p_i} = y_i^* = \alpha_i + \sum_{j=1}^{n+m} \beta_{ij} p_j + \sum_{k=1}^{5} \gamma_{ik} z_k + \sum_{s=1}^{4} \phi_{is} fs_s + \sum_{k=1}^{5} \sum_{s=1}^{4} \varphi_{iks} z_k fs_s + \sum_{f=1}^{4} fu_i + \varepsilon_{yi} \quad (7)$$

where $i = 1, \dots, n+m$ represent outputs/inputs; p_j are the respective output/input prices; z_k are quasi-fixed inputs; fs_s represent dummies of farm size (three out of four); fu_i represent dummies of Federative Units in Southeast region; ε_{yi} represent random shocks for each equation; and α_i, β_{ij}, γ_{ik}, ϕ_{is} and φ_{iks} are parameters to be estimated. Symmetry property is imposed across equations ($\beta_{ij} = \beta_{ji}$) since five outputs supplies and two input demands are considered in this research. The formers are equations for coffee, rice, soybeans, corn and beans; and the latter are labor and fuel; y_i^* is positive if represents an output supply and negative for input demand. Quasi-fixed inputs (z_k) are capital, rain-fed cropland, irrigated land, temperature, precipitation and farm size.

From Equation (2) and parameters estimated in Equation (7) the output supply and input demand own and cross elasticities can be recovered by Equation (8); and cross elasticities related to numeraire and output supplies and input demand by Equation (9):

$$\eta_{y_i p_j} = \frac{\partial y_i^*}{\partial p_i}\frac{p_i}{y_i^*} = \beta_{ij}\frac{p_i}{y_i^*} \tag{8}$$

$$\eta_{y_i p_0} = \frac{\partial y_i^*}{\partial p_0}\frac{p_0}{y_i^*} = -\frac{1}{y_i^*}\sum_{j=1}^{n+m}\beta_{ij}p_j \tag{9}$$

We expect that own price elasticities in Equation (8) are positive for output supplies and negative for input demand. In relation to cross elasticities, the outputs are *complementary* if $\eta_{y_i p_j} > 0$ and *substitutes* if $\eta_{y_i p_j} < 0$. The same relation holds between input price and output supply. On the other hand, the inputs are *complementary* if $\eta_{y_i p_j} < 0$ and *substitutes* if $\eta_{y_i p_j} > 0$. The quasi-fixed input effects ($\lambda_{z_k}^{y_i}$) on output supply and input demand are obtained using Equation (4) and parameters estimated in Equation (7):

$$\lambda_{z_k}^{y_i} = \frac{\partial y_i^*}{\partial z_k}\frac{z_k}{y_i^*} = \left(\gamma_{ik} + \sum_{s=1}^{4}\varphi_{iks}fs_s\right) * \frac{z_k}{y_i} \tag{10}$$

where z_k are the quasi-fixed factors; and the effects of z_k by farm size can be evaluated jointly by the parameters γ_{ik} and φ_{iks}. The effect of irrigation (z_1) on each output revenue and total revenue, i.e., the grain sector revenue for Brazilian Southeast region, we use Equations (5), (6) and the parameters estimated in Equation (7) to obtain

$$\delta_{i,z_1} = \bar{p}_i * \left(\gamma_{ik} + \sum_{s=1}^{4}\varphi_{iks}fs_s\right) * \sum_{j=1}^{J} z_{1,j} \tag{11}$$

where $\bar{p}_i$ is the average output price; $\sum_{j=1}^{J} z_{1,j}$ is the irrigated land in hectares summed over producers; and δ_{i,z_1} is the added revenue in each output due to irrigation. The relative measure is obtained by the ratio $\delta_{i,z_1}/(p_i * Y_i)$, where $Y_i = \sum_{j=1}^{J} y_{ij}$ represents the quantity produced

over all farmers. Agricultural sector revenue gain due to irrigation in Southeast region is obtained by summing up all revenue gains (δ_{i,z_1}) and dividing by the total revenue observed in the production of those outputs in the region.

The jointly estimation of output supplies and input demand described in Equation (7) generate a system of equations, which the error term of one of the equations may be contemporaneously correlated with the error term of the others, leading to a Seemingly Unrelated Regression (SUR) estimation (Zellner, 1962).

4.1. Data Source

In this research we have used a farm level dataset from 2006 Agricultural and Livestock Census for Brazilian Southeast region, which only can be accessed at the Brazilian Institute of Geographic and Statistics headquarter in Rio de Janeiro. We selected only farms that produced at least one of the following outputs: coffee, rice, soybeans, corn and beans. Thus, the final dataset contains more than 308 thousands of farmers. The grains were chosen based on the proportion of farmers that use irrigation to produce them[1] and also based in their relevance on total value of production in Southeast region, which together, represent around 55% of total production value for the region.

We included information on the following quasi-fixed inputs: capital, rain-fed cropland, irrigated land, temperature, precipitation and farm size. *Capital* is the sum of the value of buildings, land (asset) and vehicles; *Rain-fed cropland* represents the land used in crops minus the irrigated cropland; *Irrigated land* is the total of irrigated land (in hectares) used in the production; *Temperature* is the municipality average temperature in degree Celsius for 2006; *Precipitation* is the municipality cumulative average precipitation in millimeters for 2006; and *Farm size* is represented by *dummies* for four different size based on the fiscal module approach. Climatic Dataset was obtained from the Climate Research Unit – CRU/University of East Anglia[2].

Vanschoenwinkel and Van Passel (2018) suggest that farmers are very heterogeneous and different farm types (such as farm size and crop choice) might respond differently to irrigation practices and weather effects. To test their argument, besides the inclusion of *dummies* for four

[1] 2006 Agricultural and Livestock Census did not report the amount of irrigated land used in each output produced. Instead, the survey reports only information on the proportion of farmers that use irrigation to produce each output; and the amount produced when the farmer use irrigation technology.

[2] Available on: http://www.cru.uea.ac.uk/. We are grateful to Laís Rosa de Oliveira from "Natural and Environmental Resource Economics Research Group – PPGEA/UFV/Brazil" to work on the dataset.

farms sizes, these dummies and the quasi-fixed input vector were interacted. Therefore, we are able to evaluate the effect of each quasi-fixed input on output supply and input demand by size.

In relation to construction of output prices, some procedures are required. The sales prices reported by IBGE are a simple average for the crop season in 2006 rather than different inter-annual sales prices. Furthermore, there is lack related to price information for those farmers that not sold or produced the outputs in that crop season. Therefore, we obtained the average price by municipality in Southeast region and replaced the missing prices by these average prices. This procedure assumes that producers face the output price in the market but chose for not producing them, which also imply that farmers have full information about all the six output prices in the market.

Labor and *Fuel* are the two variables inputs considered in this research. Labor price was calculated by the ratio of total wages expenses and the quantity of hired and family labor summed. Following the same procedure, fuel price was calculated by the ratio of fuel expenses and quantities used in the farm, which included ethanol, charcoal, gas, gasoline, grease, lubricant, diesel, kerosene and others. Labor input price was inputted through the procedure described before to farmers that did not report wages expenses in the crop season. As all farmers in Southeast region reported that had used positive quantities of fuel, then its price was used to normalize the restricted profit function.

Descriptive statistics of the variables used in the model (before price normalization) for Southeast region and by farm size pointed that soybean and corn prices increase when farm size increases, which may be correlated to product differentiation through increase in added value by incorporating innovation into the production process. As workforce wages also increase when farm size increases, it may be due to skilled workers employed in large farmers. On the other hand, the remaining output price decreases as the farm size increases, which can be explained by scale efficiency in production[3].

5. Results

Output supply and input demand own and cross elasticities are shown in Table 2, which rows represent the response in quantities due to change in prices (columns). Evaluated at the average of the observations and for those farmers that at least produce one of the selected grains, the supply is monotone, but this is not true at each data point. The percentages of monotonicity

[3] Omitted due to lack of space

violations are 4.8%, 5.86%, 2.9%, 8.95% and 4.11% for coffee, rice, soybean, corn and beans, respectively. For labor, none of the elasticities have presented monotonicity violations.

We found a correct theoretical signal for the output supply and input demand own elasticities, which is highly statistical significant, except for corn. In addition, we found that output supplies are inelastic for all the grains selected. The largest price-effects compared to others outputs are for rice and soybeans, since an increase in 10% on its price would lead to an increase by 5.62% and 3.88% on its supply, respectively. Castro and Teixeira (2012) found rice supply elasticity by 3.2% and Wijetunga (2016) around 6.5%; and Ball (1988) found output supply elasticity around 8.3% for aggregate grains in United States. The most inelastic supply is for coffee, since an increase in 10% on its price would lead an increase on its supply around 1.72%, which is consistent since coffee is the most valuable grain in the region.

Our results suggest that soybeans and corn are substitutes; and coffee is substitute to soybeans and corn production. Pereda (2012) also found similar relation between coffee, soybeans and corn. We found that soybean is complementary to beans production, but it is not statistically significant. Figuereido and Texeira (2002) also found that soybean is complementary to bean, but substitute to corn production. On the other hand, a complementary relation between soybeans and corn were found in Neves *et al.* (2016) and Freitas (2018), which diverges of our findings. This last result implies that crop rotation between soybeans and corn is not usual in the Southeast region.

Table 2 – Average grain supply and input demand own and cross elasticities, Brazilian Southeast.

	Elasticity with respect to the price of						
	Coffee	***Rice***	***Soybeans***	***Corn***	***Beans***	***Labor***	***Fuel***
Coffee	0.172***	-0.0001NS	-0.0001***	-0.034***	-0.001**	0.015***	-0.136***
	(0.0091)	(0.0001)	(0.00003)	(0.0033)	(0.0007)	(0.0013)	(0.0101)
Rice	-0.015NS	0.562***	-0.009***	0.003NS	-0.027NS	-0.007NS	-0.513**
	(0.0195)	(0.1366)	(0.0018)	(0.0514)	(0.0427)	(0.008)	(0.1462)
Soybeans	-0.001***	-0.001***	0.388***	-0.003*	3.00E-06NS	0.033***	-0.382***
	(0.0004)	(0.0002)	(0.0143)	(0.0016)	(0.0002)	(0.0013)	(0.0144)
Corn	-0.043***	0.0001NS	-0.0005*	0.052NS	-0.024***	-0.001NS	0.015NS
	(0.0041)	(0.0016)	(0.0002)	(0.128)	(0.0066)	(0.0012)	(0.1288)
Beans	-0.030**	-0.006NS	5.71E-06NS	-0.137***	0.281***	0.034***	-0.106*
	(0.0136)	(0.0096)	(0.0004)	(0.0383)	(0.0563)	(0.0052)	(0.0558)
Labor	-0.016***	0.0001NS	-0.001***	0.002NS	-0.003***	-0.001***	0.020*
	(0.0014)	(0.0001)	(0.00004)	(0.0014)	(0.00048)	(0.0005)	(1.6789)

Note: Parameters in bold are significant at ***: 1%; **: 5%; and *:10%; NS: Non-Significant; Standard errors in ( ). The elasticities of fuel (numeraire) were obtained by the coefficients of numeraire demand equation. **Source**: Research results.

The own price-effect for labor demand are consistent and suggest that its demand is inelastic in response on changes in the labor wages. Freitas (2018) found similar findings. The author

argues that labor measurement that also includes family labor rather than only hired labor, an inelastic relation is expected because family workers are less volatile to changes in their wages. In general, labor price has a positive effect on output supplies and fuel price has an inverse effect. A higher adverse effect in fuel prices on output supply was expected since Southeast region is capital intensive. Finally, we found that labor and fuel are substitutes.

We estimated the irrigation, rain-fed land and weather effects in terms of semi-elasticity on each grain supply and labor input demand, which represents a short-run effect. Results are reported in Table 3. We found that increases in irrigated land would lead an increase in all grains supplies. The highest effect of irrigation are for beans and rice supply, which an increase in one irrigated hectare would increase, on average, 0.91% and 0.43% its supply, respectively. The lowest effect of irrigation is for soybeans production; this result is consistent since this crop is drought resistant and a small productivity gain between irrigated and rain-fed production is observed in Brazilian agriculture for these crop (EMBRAPA, 2013). Despite the effect of irrigation is not statistically significant to corn production, the effect of rain-fed land expansion is highly significant and shows a positive effect, which an increase in one hectare of non-irrigated land would lead an increase in 0.47% on its supply. Finally, irrigated and rain-fed land expansion would increase labor demand, where the irrigation effect is greater than rain-fed land expansion, which implies that irrigation is a tool of employment generation.

Table 3 – Output and input semi-elasticity with respect to selected fixed factor, Southeast, 2006.

	Coffee	**Rice**	**Soybean**	**Corn**	**Bean**	**Labor**
Irrigation	0.1896***	0.4349**	0.0062*	0.3941^{NS}	0.9144***	0.0287***
	(0.0346)	(0.1781)	(0.0032)	(0.5480)	(0.2261)	(0.0053)
Rain-Fed	0.0552***	0.0243^{NS}	0.0054^{NS}	0.4737*	0.0295^{NS}	0.0059**
	(0.0046)	(0.0617)	(0.0013)	(0.2625)	(0.0251)	(0.0009)
Temperature	-0.1076*	0.3716^{NS}	0.2062^{NS}	-1.044^{NS}	-0.5859^{NS}	-0.0293^{NS}
	(0.0418)	(0.5368)	(0.0222)	(1.8622)	(0.2119)	(0.0081)
Precipitation	0.0577***	0.0547^{NS}	0.0094^{NS}	0.1136^{NS}	-0.0416^{NS}	-0.001***
	(0.0033)	(0.0426)	(0.0019)	(0.1399)	(0.0166)	(0.0006)

Note: Parameters in bold are significant at ***: 1%; **: 5%; and *:10%; NS: Non-Significant; Standard errors in ( ). **Source**: Research results.

Pereda (2012) argues that climate may affect agricultural production in two ways: in the long-run, where is evaluated by the historical observed climate, which might impact land use configuration; and in the short-run, where the weather conditions play an important role of determining crops, livestock failures and productivity losses once the farmers had decided what and how much to produce, which would imply that their production could deviate from an optimal production.

We assume in this research that weather effects on output supply and input demand represents a short-run effect since our climatic dataset is average temperature and precipitation to 2006, i.e., weather events during growing and harvesting seasons, which are not observed by farmers when choosing the output-input mix that optimize their outcomes (Pereda, 2012). As shown in Table 3, a negative effect on coffee supply was found due to increases in temperature; and a positive effect due increases in precipitation. We did not find statistically significant weather effects on the remaining grains production, which may be correlated with Vanderlugt's (2011) argument that farm heterogeneity could respond differently to climate variations.

To test the argument that farm heterogeneity might affect different responses on irrigation expansion (Vanschoenwinkel; Van Passel, 2018) and weather effects (Vanderlugt, 2011) we have estimated the output supply and demand input semi-elasticity in respect to irrigated land by farm size. Results are shown in Table 4.

Table 4 – Average irrigation effect on output supply and input demand, Brazilian Southeast, 2006.

	Coffee	**Rice**	**Soybean**	**Corn**	**Bean**	**Labor**
Very Small	0.259***	0.5107**	0.0054^{NS}	0.4949^{NS}	1.100***	0.0376***
	(0.0542)	(0.2305)	(0.0402)	(0.7910)	(0.3083)	(0.0073)
Small	0.0949***	0.2942***	0.0078^{NS}	0.2949*	0.4958***	0.0129***
	(0.0042)	(0.0542)	(0.0055)	(0.1620)	(0.0260)	(0.0019)
Medium	0.0382***	0.0717***	0.0102***	0.0502***	0.4387***	0.0068***
	(0.0009)	(0.0155)	(0.0003)	(0.0047)	(0.0090)	(0.0004)
Large	0.0005***	0.1279***	0.0006***	0.0024***	0.0252***	0.0009***
	(0.00006)	(0.0006)	(0.00005)	(0.0002)	(0.0003)	(0.00006)

Note: Parameters in bold are significant at ***: 1%; **: 5%; and *:10%; NS: Non-Significant; Standard errors in parentheses. **Source**: Research results.

As expected, we found a positive effect of irrigation on the supply for all selected grains; similar findings were found by Binswanger *et al.* (1987). It is important to highlight that up to a certain point, more irrigation implies more yield, but the increase in yield resulting from a marginal increase in irrigation decreases as more water applied in the crops increases (Frija *et al.*, 2014). In general, we found a negative and linear relation between output supplies response due to irrigation and farm size, which imply that very small and small groups present the highest average response when compared to the others sizes. This result may be in part explained by the fact that very small and small farms in Brazilian agriculture are, in general, more capable to transform inputs in outputs more efficient than medium and large farms; and irrigation has a greater effect on the efficiency gain (Freitas *et al.*, 2019), which reinforce the role of farm heterogeneity on technology adoption.

The findings in Table 4 also allow us to make some inferences: as predicted by Vanschoenwinkel and Van Passel (2018), different farm sizes present different responses in respect to irrigation: the very small and small groups seem to be more capable to achieve yields in terms of produced quantities due to irrigation. Although we are not controlling credit market access, rural extension services adoption, among other factors related to farmers' personal characteristics, as schooling, experience, management skills and technical efficiency, it might be correlated to those aspects.

The semi-elasticities of grains supplies with respect to short-run weather effects by farm size are displayed in Table 5. In general, we found a negative effect of temperature increases on supplies, except for soybeans production. Pereda (2012) found that an increase in 1° Celsius would increase soybeans supply in 0.44%, on average. Our result shows an increase in soybeans supply of 0.43% for medium and 0.33% for large farmers due an increase in 1° Celsius, on average, which is consistent with Pereda´s findings. It is important to highlight that the most suitable temperature to growing soybeans would be around 30° Celsius (EMBRAPA, 2013), while temperatures above this threshold are very harmful[4] (Schlenker and Roberts, 2009). Similar findings in Pereda (2012) were found in coffee production, where increases in temperature would decrease its supply.

Table 5 – Semi-elasticitiicies, average weather effects in grain supply and input demand by farm size, Southeast, 2006.

	Coffee	Rice	Soybeans	Corn	Beans	Labor
Temperature						
Very Small	0.0606*	0.5019^{NS}	-0.0163^{NS}	-1.609^{NS}	-0.2672^{NS}	-0.0047^{NS}
	(0.0379)	(0.4919)	(0.0294)	(2.4911)	(0.2012)	(0.0076)
Small	-0.6003***	-0.1183^{NS}	0.0666**	0.6696**	-1.4973***	-0.0687***
	(0.0629)	(0.7628)	(0.0287)	(0.2857)	(0.2503)	(0.0093)
Medium	-0.5208***	-0.0264^{NS}	0.4381***	-0.3258**	-2.7286***	-0.1502***
	(0.0191)	(0.3675)	(0.0198)	(0.1574)	(0.2774)	(0.0097)
Large	-0.4382***	3.555***	0.3329***	-0.0319^{NS}	-3.4315***	-0.2641***
	(0.0080)	(0.3195)	(0.0053)	(0.0358)	(0.1506)	(0.0105)
Precipitation						
Very Small	0.0456***	0.0588*	-0.0019^{NS}	0.1201^{NS}	-0.0183^{NS}	-0.0019***
	(0.0028)	(0.0367)	(0.0021)	(0.1857)	(0.015)	(0.0005)
Small	0.0948***	0.0387^{NS}	-0.0005^{NS}	0.1245***	-0.0833***	-0.002**
	(0.0056)	(0.0686)	(0.0025)	(0.0257)	(0.0225)	(0.0008)
Medium	0.0865***	0.0506^{NS}	0.0225***	0.0272*	-0.2707***	0.0094***
	(0.0017)	(0.0336)	(0.0018)	(0.0144)	(0.0253)	(0.0008)
Large	0.0494***	0.0933***	0.0196***	0.0192***	-0.4282***	0.0175***
	(0.0007)	(0.0300)	(0.0005)	(0.0033)	(0.0141)	(0.0009)

Note: Parameters in bold are significant at ***: 1%; **: 5%; and *:10%; NS: Non-Significant; Standard errors in ( ). **Source**: Research results.

[4] Average temperature for Southeast region in 2006 was around 22.1° Celsius (Table 1).

Furthermore, beans supply would be negatively affected by increases in precipitation for all farms sizes, and one possible explanation for this effect is due to the larger rainfall averages observed in the summer season. Interesting result is found for beans, which both precipitation and temperature increase would have a negative effect on its supply. Finally, we found that grains supplies and input demand, in general, would be most affected due to changes in temperature rather than changes in precipitation for all farm sizes analyzed, and the size that would be most affected by weather effects would depend of the crops growing type.

We also estimated the effect of rain-fed land on output supplies and input demand in terms of semi-elasticity. Our results suggest that rice supply would be affected negatively by rain-fed land expansion. As rice is mainly produced under flooding irrigation method (Wijetunga, 2016), decreases in rice supply in response to increases in non-irrigated land were expected. All the other grains supplies were positively affected by an increase in non-irrigated land; however, the effect of irrigation expansion is greater than non-irrigated land.

5.1. Effects of irrigation on revenue and policy implication

To evaluate the irrigation effect on the grain market we used the parameters estimated in the system of equations, the average output price, total output supplied and total irrigated land to estimate the market revenue change per output and for the entire sector. Results are displayed in Table 7 and show the observed total revenue, the total added revenue and the change in revenue due to irrigation, and the participation in total revenue in Southeast region for selected grains.

We can observe that beans and rice revenue face an increase of 6.81% and 5.31% due to irrigation. Corn's revenue also presents a great response due to irrigation, around 4.45%. This result implies that these commodities generate more added values due to irrigation adoption. Pereda (2012) found that irrigation in Brazil could increase corn profit share by 3.94% and 4% for coffee. The smallest revenue effect due to irrigation is for soybeans, around 0.17%. Soybeans' growing has presenting some advantages in non-irrigated land due to improvements in seed technology driven by the Empresa Brasileira de Pesquisa Agropecuária – Embrapa (Brazilian Agricultural Research Corporation, in English) among the last four decades, being this crop drought resistant (EMBRAPA, 2013), implying that soybeans production is less efficient in generate revenue relative to irrigation use.

Our findings suggest an increase of 2.1% (US$ 83.45 million) on outputs revenue due to irrigation in Brazilian Southeast region, which coffee's revenue represents 43.65% of this value, followed by corn (43.57%) and beans (9.77%).

Table 7 – Average effect of irrigation on the change in the revenue in Southeast region and selected grains, Brazil, 2006.

	Southeast	Coffee	Rice	Soybean	Corn	Bean
Total Revenue (US$)[1]	3,965.25	2,553.24	33.03	442.35	816.90	119.70
Added Revenue (US$)[1]	83.45	36.43	1.75	0.75	36.36	8.15
Irrigation Effect on Revenue (%)	**2.1**	**1.42**	**5.31**	**0.17**	**4.45**	**6.81**
Participation on Added Revenue (%)	**-**	**43.65**	**2.10**	**0.90**	**43.57**	**9.77**

Note: 1 = Values in US$ millions. Exchange Rate: 2.15 (dec, 2006). **Source**: Research Results

It is important to highlight that those changes in revenue due to irrigation is based on irrigated land, average output price, total output supplied and parameters estimated rather than quantities and price of water used in irrigation. Dinh *et al.* (2018) showed through similar methodology that an arbitrary increase by 30% in irrigation water price would lead a decrease in irrigation water demand, implying a decrease in output supply and then in revenue of dairy (-0.9%), rice (-5.9%) and other outputs as grains (-0.5%), while horticulture was the least responsive to changes in water prices. However, in the case of water dataset availability, we must make the assumption that each farmer pay for the irrigation water, which may be not appropriate for Southeast region agriculture. Despite the lack of information related to water use, our results showed that irrigated land expansion play an important role on grain supply stability and revenue increases.

Although revenue effects due to irrigation is stronger to beans and rice production, our results suggest that policies could be driven to expand irrigated production of coffee and corn since these crops represents 87.2% of the total added revenue due to irrigation, being these outputs more valuable compared to the others. Since we found a positive effect of irrigation on grain supply and also in the revenue for the grain sector of the Southeast region, it is important that governmental policies be driven to expand irrigated agriculture focusing on those products most valued and also to those farmers grouped as very small and small size, since they represent more than 92% of the total farmers in the Southeast region.

Policies at the micro-level could be designed providing credit policies and technical assistance for those farmers producing coffee and soybeans in order to improve the capacity of

irrigation rise their revenue; and at the macro-level by reducing the taxation of coffee, corn and beans in the customs and increasing exports, since those grains represent more the 95% of added value in terms of revenue in grain production in the Southeast region.

Finally, as irrigation seems to be able to increase labor demand, we can conclude that irrigation is an efficient tool in the employment generation and income in rural areas, which implicitly might alleviate poverty and achieve rural development. Policies toward workforce training to operate irrigation systems and the development of irrigation projects in order to absorber unemployed workers are welcome in rural areas, mainly in areas with socioeconomic vulnerability. Another target in the irrigation expansion is the understanding that irrigation technology is a mechanism of mitigation and adaptation to climate anomalies.

6. Conclusions

We aimed to evaluate in this paper the role of irrigation effects on Brazilian Southeast grain sector. We estimated a system of agricultural supplies and input demands using 2006 Agricultural and Livestock Census at the farm level. Output supplies refer to the main grain crops growing in the region: coffee, rice, soybeans, corn and beans; and input demands were estimated for labor and fuel. We used derivative properties of a normalized restricted profit function to estimate own and cross price effects on output supplies, short-run weather effects and changes in revenue due to irrigation. Our findings suggest a positive effect of irrigation on output supplies and labor demand, and capable to change revenue positively for each output and for the entire sector. We also have tested the argument that farm heterogeneity might affect different responses on irrigation expansion and weather.

Our findings also suggest an increase of 2.1% on outputs revenue due to irrigation in Brazilian Southeast region, which coffee revenue represents 43.65% of this value; corn represents 43.57% and beans 9.8%. Beans and rice also faced increases in their revenue due to irrigation, by 6.81% and 5.31%, respectively. The well adapted to rain-fed agriculture, soybeans presented a change in revenue by 0.17% due to irrigation.

Although irrigation present great results when evaluated in an isolated way, this practice is generally implemented in the midst of other improvements in the "technological package" of the rural producer, that is, tends to be accompanied or preceded by improvements in other inputs, services, machinery, implements, climate knowledge and other facilities which together result in a number of benefits.

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