Abstract
Irrigation has resulted in varying levels of depletion of water sources. It is important for policy purposes and economic assessment tools to identify the overall value of this resource in the Brazilian agricultural production and understand how irrigation affects farmer’s yields. Thus, the objective of this research is to fill in this gap in the literature seeking to answer: What is the use value of irrigation water to agricultural producers? Our results show an incremental gross revenue due to irrigation averaged US$668.98/ha. The value of irrigation water was estimated in US$ 7.35 billion, which is based on total additional gross revenue when land is irrigated relative to rain-fed land. This value represents 9.7% of the total agricultural production value in 2006.

Key-words: Water resources; Irrigation response; Production function; Yields

Resumo
A irrigação resulta em níveis variados de esgotamento das fontes de água. Para fins de políticas e ferramentas de avaliação econômica, é importante identificar o valor total desse recurso na produção agrícola brasileira e entender como a irrigação afeta os rendimentos do agricultor. Assim, o objetivo desta pesquisa é preencher essa lacuna na literatura buscando responder: Qual o valor de uso da água de irrigação para os produtores agropecuários? Nossos resultados mostram uma receita bruta incremental média devido à irrigação de US$ 668,98/ha. O valor da água de irrigação foi estimado em US$ 7,35 bilhões, que é baseado no total da receita bruta adicional quando a terra é irrigada em relação à terra não irrigada. Este valor representa 9,7% do valor total da produção agrícola em 2006.

Palavras-chave: Recursos hídricos; Resposta de irrigação; Função de produção; Rendimentos

Classificação JEL: Q10, Q12, Q15

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1. Introduction

Brazil is a major worldwide player in agriculture production. The country produced 6% of the world’s agricultural in 2014 and it is among the ten countries with the largest irrigated area in the world; the leaders are China and India, followed by the United States, Pakistan and Iran (Food and Agriculture Organization – FAO, 2017). Brazil appears in the group of countries with irrigated area between 4 and 7 million hectares, which is closest to Thailand, Mexico, Indonesia, Turkey, Bangladesh, Vietnam, Uzbekistan, Italy and Spain (FAO, 2017).

Despite the leadership in irrigated areas, only a small share of the land used in agriculture in Brazil is irrigated, around 3%, while only 6.3% of the farmers adopt irrigation technology in the country, which is mainly farms with more than 500 hectares (Brazilian Institute of Geography and Statistics – IBGE, 2006). Brazil, whose irrigated land adds up to only 1% of the irrigated area in the world (Ministry of Environment – MDA, 2006), still has a lot of room to increase its use of irrigation which can largely improve the country’s agricultural production.

Several regions in Brazil have observed an increase in droughts and water shortages in the past few years which affect agricultural production and rural income (Cunha et al., 2015). The adoption of irrigation can help counter these negative factors by leading to higher crop yields by sustaining adequate soil moisture in the growing period (Lobell et al., 2009); achieving higher rates of agricultural productivity (Mkanthama et al., 2018); and allowing the impacts of seasonal and inter-annual hydrological variability on agriculture to be smoothed out (Tural et al., 2010).

The use of irrigation might also allow farmers to access domestic and international markets (Schaible; Aillery, 2012); increase farm income and rural employment (Marra et al., 2003); enhance food security (Droogers, 2004); alleviate poverty (Lipton et al., 2003; Hussain; Hanjra, 2004); and help mitigate the effects of climate change by maintaining agricultural productivity in scenarios with lower rainfall rates (Vanschoenwinkel; Van Passel, 2018), mainly in regions with semi-arid climate and socio-economic vulnerability (Zougmore et al., 2010; Njuki; Bravo-Ureta, 2016).

Agência Nacional de Águas (Brazilian Water Agency, in English) points out that around 70% of freshwater in the country is used in irrigated agriculture, while water is an increasingly scarce resource. Despite its scarcity, the demand for irrigation is expected to increase in all regions (Cunha et al., 2015). However, irrigation of agricultural crops affects the dynamics of water and soil properties such as salinity, being these effects slow to revert in the short-term (Suárez, 2013).

Water management for agriculture is becoming increasingly complex since its management requires several factors as technical knowledge, infrastructure, and factors related to social and economic issues (Rosenzweig et al., 2004). Thus, irrigation water use must be supplied facing a context of diminishing availability, due environmental awareness, population growth, economic development and others factors (Iglesias; Garrote, 2015), which lead the adoption of more technically efficient irrigation systems to maintain water consumption with reduced applications as a drought response (Schuck et al., 2005). The knowledge needed mostly has been provided by extension services, which help farmers to adapt and implement viable solutions, thus gaining more benefits from irrigation technology (Levidow et al., 2014).

What are less clear in the role of irrigated agriculture are the contribution of the yield increase due to irrigation adoption (Ozdogan, 2011) as well as yield response to different water management practices, and thus current on-farm water-efficiency levels (Levidow et al., 2014). The value of water used in production is another complex task due the difficulty to quantify its value because different agents conceptualize and describe their values differently, i.e., the private sector tends to use finance concepts, while governmental sector often employ economics and civil society concepts (e.g. environmental issues; property rights based or social-goods concepts) for valuing this water (Morgan; Orr, 2015). It is also important to highlight that different approaches tend to find different water values (Young, 2005).
Only a small fraction of farmers that access water coming from resources under government control are charged for both surface and groundwater pumped for irrigation in Brazilian agriculture (ANA, 2018). The remaining farmers pay capital, maintenance, and operation costs of water withdrawal. Under this arrangement, water resources face overexploitation (Nikouei et al., 2013), while rational management of water requires the knowledge of the value of the resource (Mesa-Jurado et al., 2010; 2012). Without regulations of water use, the farmer could implement irrigation and so the potential value of irrigation may be capitalized into the price of both currently irrigated land and dryland (Brozovic; Islam, 2010).

The main source of irrigation water in Brazil comes from the surface rather than groundwater (ANA, 2017; 2018) while much of the water used in irrigation comes from private sources and are not traded among economic agents (Ferrarini et al., 2016). Because of the well-known common property problems of shared surface and groundwater sources, the Brazilian Water Agency is responsible for granting the water use to the farms across the twelve hydrologic basins spread among the country when this resource belongs to government.

Given that irrigation has resulted in varying levels of depletion of water sources and also the lack of studies on irrigation water value in Brazil, it is important for policy purposes and economic assessment tools to identify the overall value of this resource in the Brazilian agricultural production and understand how irrigation affects farmer’s yields. Thus, the objective of this research is to fill in this gap in the literature seeking to answer the following questions: What is the elasticity of yield when a hectare is converted into irrigation? How much of total gross yield per hectare could be achieved through irrigation? What is the use value of irrigation water to agricultural producers?

We estimate the total gross value added by irrigation to agricultural production value in the 5,538 municipalities in Brazil, based on production value and irrigated hectares through production function approach. The extra production value attributable to irrigation at the municipality level allows us to evaluate and obtain estimates of the additional revenue flow attributable to irrigation, giving a sense of how much is the use value of irrigation water in agriculture.

Our results shows an incremental gross revenue due to irrigation averaged US$668.98/ha. The value of irrigation water was estimated in US$ 7.35 billion, which is based on total additional gross revenue when land is irrigated relative to rain-fed land. This value represents 9.7% of total agricultural production value in 2006, 2.35% of agricultural sector Gross National Product (GNP) and 0.56% of Brazilian GNP, which is considered low.

In the following section we highlight different approaches to access the value of irrigation water. Section 3 and 4 we describe the theoretical framework and the empirical model, respectively. Results are shown in Section 5 and our finals conclusions in Section 6.

2. Accessing the value of irrigation water

There are several ways to measure the agriculture water value. In the case where water markets exist, the researcher is able to use approaches that will derive the water demand and supplying curves and thereby determining the optimal allocation and its price, which allow optimize the amount of water applied to crops based on the marginal productivity of that water (Johansson, 2005), where up to a certain point, more water implies more yield, but the increase in yield resulting from a marginal increase in water decreases as the total water input increases; this is known as a positive and diminishing marginal productivity of water (Frija et al., 2014).

A review of the approaches to estimate the economic value of water can be found in Gibbons (1986), Johansson et al. (2002; 2005), Tsur et al. (2004) and Young (2005). A simple approach to measuring the value of irrigation is to compare sales values of irrigated land versus non-irrigated land, or to compare sales values of land over an aquifer versus land not over an aquifer (Brozovic; Islam, 2010; Hornbeck; Keskin, 2014). Relevant to our analysis are those approaches based on
production function, which are a deductive method that involves the derivation of shadow prices where water or irrigated land is an input into production systems (Suárez et al., 2018).

Alternatives approaches are the Contingent Valuation (Adamowicz et al., 1999; Carson et al., 2001), Residual Method (Mesa-Jurado et al., 2008; Ziolkowska, 2015), Hedonic Water Pricing (Faux and Perry, 1999; Latinopoulos et al., 2004; Berbel and Mesa, 2007), or Choice Experiments (Gómez-Limón et al., 2002; Rigby et al., 2010). Recently the policymakers are interested in the implicit impacts of macroeconomic policies on the irrigated agricultural sector, especially as related to agricultural trade reform (Johansson, 2005). General Equilibrium Model (CGE) has been applied as alternative model to access water demand in a inter-regional perspective (Ferrarini et al., 2016); and also a combination of approaches implementing a multi-sector growth model through CGE and Residual Methods to estimate the stock value of irrigation water has been accessed (Santos; Spolador, 2018).

Crop-Water Functions can be used when the farmer is producing a single crop; and Profit Maximization when farmers seek to maximize profits, given market prices of water and output, allowing those farmers to choose water inputs optimally (Mesa-Jurado et al., 2012). The Generalized Solutions can be accessed when the primal approach is generalized to multiple producers and multiple crops; and Constrained Profit Maximization when the provided water is free of charge, but constrained to some volume, which allow to indentify the willingness to pay (WTP) to relax the water constraints per unit of water (Johansson, 2005). Supply curves of water also can be estimated, which reflects the increasing available supply with increasing costs (Hussain et al., 2007). When water supply is constrained and the producer is unable to acquire sufficient water to exhaust its marginal returns to production, the derived demand can be determined in terms of the shadow value for water (Tsur et al., 2004).

3. Theoretical Framework

The approach to evaluate the value of irrigation in Brazilian agriculture is to estimate increased production value due to irrigation by means of a municipality-level yield function, which has as one of its arguments the fraction of irrigated land with crop and pastures (aggregated). The increased production value is obtained by differentiation of this function with respect to fraction irrigated.

Estimation of production functions can be improved by simultaneously estimating share equations that reflect producers’ evaluation of marginal product of inputs. In this case, we are assuming profit maximization and first order conditions allow estimation of a system of equations that includes production function and derived demand for inputs (or factor shares) allowing a more robust estimation (Mundlak, 2001). The profit maximizing decisions of price-taking producers can be represented as:

$$\max_x \pi = py - w^\top x; \quad y = f(x,z); \quad p > 0, w > 0$$

where $py$ is the production value (revenue); $x$ is a vector of variables inputs, $w$ is a vector of input price, and $z$ is a vector of environmental characteristics (e.g. weather). The input requirement set of the production function $y = f(x,z)$ must be closed and bounded, and this function is assumed to be monotone and quasi-concave (Varian, 1992). Under rational economic behavior, the first order conditions are given by differentiation of the profit by each of the inputs:

$$\frac{\partial \pi}{\partial x_k} = p \cdot \frac{\partial f(x,z)}{\partial x_k} - w_k = 0 \quad k = 1,\ldots,K$$
Given profit maximization and perfect competition, expressing equations (1) and (2) in logarithms we obtain production elasticities $\varepsilon_k$ that also reflect the share of factor payments in output value, $s_k$, as:

$$\varepsilon_k(x, z) \equiv \frac{\partial \ln f(x, z)}{\partial \ln x_k} = \frac{\partial f(x, z)}{\partial x_k} \cdot \frac{x_k}{f(x, z)} = \frac{w_k}{p} \cdot \frac{x_k}{y} = s_k \quad k = 1, \ldots, K \quad (3)$$

where $s_k$ is the share of the input $k$ in the total cost of production. The derivative of the log of the production function with respect to the log of the input $k$ (i.e. the production elasticity of $k$, $\varepsilon_k$) is equal to the cost share of that input in the total cost, and $\partial y/\partial x_i > 0$ due to monotonicity. These elasticities indicate the percentage change in production value per one percent change in each of inputs.

As the irrigated land is measured in level, rather than logarithms of levels, the derivative of $y$ with respect to $x$ represents the semi-elasticity of response, which is interpreted as the percentage change in the production value per unit change in $x$. Multiplying the semi-elasticity of response by the output value we obtain the incremental gross value of production due to irrigation, and multiplying the incremental gross value by the irrigated land we obtain the average total gross value of irrigation water.

4. **Empirical Model**

For the empirical application the production function is assumed to follow transcendental logarithmic functional form (Christensen et al., 1973). Assuming a Translog specification allows for more flexibility since it does not impose a priori restrictions on the structure of the technology (it allows for a non-linear relationship between the dependent variable and the factors of production) and provides a local second order approximation to any production frontier. The following Translog production function is estimated:

$$y_h = \alpha_0 + \sum_{i=1}^{K} \beta_i x_{ih} + \frac{1}{2} \sum_{i=1}^{K} \sum_{j=1}^{K} \beta_{ij} x_{ih} x_{jh} + \sum_{t=1}^{T} \gamma_t z_{th} + \frac{1}{2} \sum_{t=1}^{T} \sum_{t=1}^{T} \gamma_{tt} z_{th} z_{th}$$

$$+ \sum_{i=1}^{K} \sum_{t=1}^{T} \phi_{it} x_{ih} z_{th} + \epsilon_i \quad (4)$$

where $y_h$ represents the logarithm of the output for $h=1, \ldots, 5538$ municipalities, $x$ is the logarithm of the input $i, j = 1, \ldots, K$, $z$ is the logarithm of climatic variables $t=1, \ldots, T$, and $\alpha_0, \beta_i, \beta_{ij}, \gamma_t, \phi_{it}$ are parameters to be estimated. Our measure for output is the value of agricultural production. For inputs, we consider land, labor, expenses (purchased inputs), capital and the fraction of irrigated land. Under constant returns to scale, the output and all the inputs have been scaled down by the land factor. Climatic variables are precipitation and temperature for different seasons. We also include dummies of Federative Units (States) to capture heterogeneity across country.

We have included labor, expenses and irrigated land share equations since they have observable prices and are part of the variable cost of the farmer. Given the Translog specification defined in equation (4) and the assumptions of profit maximization and perfect competition, the factor shares equations are:

$$S_i = \beta_i + \sum_{j=1}^{K} \beta_{ij} x_j + \sum_{t=1}^{T} \phi_{it} z_{th} + \epsilon_i \quad (5)$$
The labor cost is measured as total expenses in wages with the workforce in agriculture; and purchased inputs are measured as the total expenses related to several inputs. We do not have information about irrigated land sales/rent. Thus, to measure the price of irrigated land we evaluate the average land value to those municipalities that use irrigation (at least one irrigator), then we multiply by 0.05 to obtain the irrigated land service price, which expresses the opportunity cost for owned land or approximate cash rental rate for leased land, which is normally around 2–6% of the land value (Ziółkowska, 2015).

To estimate the increase in gross value of production per hectare, \( V_h \), due to irrigation, we use the semi-elasticity with respect to irrigation, \( \varepsilon_h \), and multiply by the yield, \( y_h \), as described below:

\[
V_h = \varepsilon_h y_h
\]

where \( V_h \) is interpreted as the gross value of irrigation per hectare in municipality \( h \). Suaréz, Fulginiti and Perrin (2018) argue that the value of irrigation is thus reflected in the higher production if producers are producing more valuable crops on the irrigated hectare. Multiplying the incremental gross values by the number of irrigated hectares provides an estimate of the average total gross value of irrigation water for all Brazilian municipalities in 2006, i.e., the irrigation value.

The procedure to estimates our model fits a system of nonlinear equations by IFGNLS (Iterative Feasible Generalized Non Linear Last Squares). It can be viewed as a nonlinear variant of Zellner’s seemingly unrelated regression model (Zellner 1962; Zellner and Huang 1962; Zellner 1963) and is therefore commonly called nonlinear SUR or nonlinear SURE. Moreover, fitting the equations jointly allows us to impose cross-equation restrictions on the parameters and obtain more efficient estimates as well. Iterative FGNLS estimation is equivalent to maximum likelihood estimation with multivariate normal disturbances.

Mundlak et al. (2008) pointed out that farmers face multiple technologies so the decision of how to produce is jointly made with input choice. Then, the simultaneity of the decision process can result in an error term fully transmitted to inputs or that the expected value of the error term is not independent of the exogenous variables. To our analysis, this assumption implies that, for instance, irrigation could be a source of endogeneity.

For robustness in estimation with the SUR, we also include instrumental variables which Three-Stage Least Square (3SLS) estimation is required. Typically, the endogenous explanatory variables are dependent variables from other equations in the system. The 3SLS estimation procedure consists of \( y = \mathbf{ZB} + \varepsilon \) with \( E(\varepsilon \varepsilon') = \Sigma \). Endogenous variables are instrumented allowing for a generalized least squares estimator in first stage and the matrix \( \Sigma \) is estimated from the second stage residuals. Then, the matrix \( \mathbf{B} \) is estimated in third stage (Zellner and Theil, 1962).

In our estimation, we specify that irrigated land, and its square and interactions, are endogenous, while climatic variables (and also its squares and interactions) are exogenous. Thus, the exogenous variables are taken to be instruments for the endogenous variables. Production elasticities are calculated at each data point (one for each municipality) since we are using a Translog specification. Then we take the mean to evaluate the overall elasticity, and Delta method is used to calculate standard errors.

### 4.1. Data Source
We consider in this study 5,538 municipalities in Brazil using a cross-sectional data from the 2006 Agricultural Census provided by Brazilian Institute of Geographic and Statistics (IBGE)\(^5\). The **Output** represents the sum of total production value of crops and animals. **Land** is the sum of land used in crops and pastures (hectares); **Labor** is the sum of familiar and hired workers in agriculture; **Purchased Inputs** represents the sum of expenses on fertilizers, correctives, agrochemicals, energy, animal medicines, transports, packages, seeds and animal feeds; and **Capital** is the sum of the value of buildings, land and vehicles. **Irrigation** represents the ratio of total land irrigated and total land used in both crops and pastures. The aggregation of the production value across crops is driven mainly the fact that we do not have municipality-level data on the hectares irrigated by crops, while we do have data on total hectares irrigated for all crops. Climatic variables are represented by precipitation (millimeters) and temperature (Celsius degree) averaged by municipality for 2006. These were segregated by season – summer and winter. Data was obtained from the Terrestrial Hydrology Research Group (Princeton University).

5. **Results**

Before presenting our estimates, it is worth to observe some characteristics of the variables used in our analysis and also interesting aspects of the irrigated agriculture and climate conditions in the heterogeneous Brazilian regions. Figure 1 illustrates the irrigated land as a fraction of planted land in crops and pastures in Brazilian municipalities.

**Figure 1 – Irrigated land as a fraction of planted land (2006)**

![Irrigated land as a fraction of planted land](image)

There is an important variability of irrigated land across states with higher values in Southeast and Southern region; isolated irrigated spaces in Northeast region and low values in the Midwest and North region. Table 1 shows the descriptive statistics of the variables averaged by region and for Brazil as well.

The Midwest Region presents the highest average of agricultural production value. Agriculture in this region presents an advanced stage of mechanization, being known as the agricultural frontier in

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\(^5\) In 2006, there were 5548 municipalities with farmers in Brazil. However, 10 municipalities presented non-positive production value for both crops and pastures. We excluded those municipalities of the sample.
the production of grains in Brazil. In addition, this region is more intensive on land, expenses and capital when compared to the other Brazilian regions (Table 1). In the east part, irrigation is required during a six-month dry season while is free of winter temperature constraints. Most of the Midwest Region is cerrado which is potentially productive when soil is corrected. Farmers are able to take advantage of perennial rivers to complement their rain-fed cereal, soybean, bean and cotton production with dry-season irrigated cropping (FAO, 2015).

The Southeast Region has the largest fraction of irrigated land, where 4.6% of land used in crops and pastures are irrigated (Table 1). This region is dominated by technically advanced commercial farmers, mainly in the extreme south. Winter irrigation allows the farmers to crop twice instead of once a year, rotating winter plantings of wheat, peas or beans with rain-fed summer crops, which include corn, cotton and sugarcane (FAO, 2015). Mostly of the perennial crops are coffee and oranges production.

South Region is specialized in irrigated rice production with flooding on summer which supplementary irrigation in this season can help farmers from crop failures in a dry year; on average it gives only a small increase over the rain-fed yields of the typical summer crops of the South: maize, beans and soybean. It has a highly developed, commercially-oriented agriculture (FAO, 2015).

The North Region presented the highest average levels of precipitation in summer season, while irrigation is needed in the winter season and is limited to a small area of lowland rice. When we analyze the land use separately for crops and pastures, the North Region presents the second highest average value in lands used in pastures (Table 1) as a result of the extensive livestock production observed in the region, mainly in Pará and Tocantins States.

Northeast Region is known for low quality of soils and several periods of drought with the lowest average rainfall value and the highest average temperature in the summer season (Table 1); this region is highly dependent of irrigation. We can observe that Northeast Region is more labor intensive when compared to the others (Table 1), which indicates the backwardness of mechanized agriculture. Water resources in most of the Northeast are a severe constraint to agriculture. One major river, the San Francisco River, requires that its water be extracted by pumping, due to its topography. Although mostly of semi-arid region in Brazil is in Northeast Region (covering 1,133 municipalities in 2006), there are a great number of irrigated projects being developed to ensure production levels, mainly in fruit growing, horticulture and seed production (Moraes et al., 2018). Some lowland areas are suitable for flooded rice, mainly in the humid coastal strip. Where water constraints can be overcome, the warm climate favors maize, beans, cotton and sugarcane (FAO, 2015).
Table 1 – Summary Statistics, 5,538 municipalities, Brazil and Regions, 2006[^6]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Midwest</th>
<th>North</th>
<th>Northeast</th>
<th>South</th>
<th>Southeast</th>
<th>Total</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of Production (US$[^1])</td>
<td>28,604.75</td>
<td>9,234.85</td>
<td>7,504.27</td>
<td>17,181.36</td>
<td>14,894.04</td>
<td>13,689.58</td>
<td>2.79</td>
<td>422088.37</td>
<td>51119.37</td>
</tr>
<tr>
<td>Land (ha)</td>
<td>153,621.1</td>
<td>69,333.05</td>
<td>25,584.58</td>
<td>26,035.21</td>
<td>25,085.73</td>
<td>39,861.44</td>
<td>3</td>
<td>3699296</td>
<td>86088.93</td>
</tr>
<tr>
<td>Crops Land (ha)</td>
<td>26,934.61</td>
<td>9,438.47</td>
<td>8,488.65</td>
<td>12,809.55</td>
<td>8,160.08</td>
<td>10,946.96</td>
<td>1</td>
<td>500981</td>
<td>22009.06</td>
</tr>
<tr>
<td>Pastures Land (ha)</td>
<td>126,686.5</td>
<td>59,894.57</td>
<td>17,095.93</td>
<td>13,225.66</td>
<td>16,925.65</td>
<td>28,914.48</td>
<td>0</td>
<td>3695165</td>
<td>79578.11</td>
</tr>
<tr>
<td>Irrigation (fraction)</td>
<td>0.0122</td>
<td>0.0060</td>
<td>0.0292</td>
<td>0.0329</td>
<td>0.0406</td>
<td>0.03</td>
<td>0</td>
<td>1.156424</td>
<td>0.076242</td>
</tr>
<tr>
<td>Labor (workers)</td>
<td>3,005.64</td>
<td>4,522.16</td>
<td>5,423.93</td>
<td>2,798.73</td>
<td>2,651.45</td>
<td>3,761.19</td>
<td>13</td>
<td>74407</td>
<td>4264.122</td>
</tr>
<tr>
<td>Purchases (US$[^*])</td>
<td>9,963.89</td>
<td>743.68</td>
<td>1,399.60</td>
<td>5,580.43</td>
<td>2,908.71</td>
<td>2,983.28</td>
<td>0</td>
<td>604,988.83</td>
<td>41584.07</td>
</tr>
<tr>
<td>Capital (US$[^*])</td>
<td>265,093.34</td>
<td>74,776.65</td>
<td>28,772.41</td>
<td>114,560.41</td>
<td>92,823.90</td>
<td>89,807.06</td>
<td>17.20</td>
<td>1,710,329.3</td>
<td>296954.8</td>
</tr>
<tr>
<td>Precipitation_Summer (mm)</td>
<td>8.45</td>
<td>8.50</td>
<td>2.25</td>
<td>5.11</td>
<td>6.76</td>
<td>5.23</td>
<td>0.704</td>
<td>13.45</td>
<td>2.8343</td>
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<tr>
<td>Temperature_Summer (°C)</td>
<td>25.84</td>
<td>26.69</td>
<td>26.85</td>
<td>23.85</td>
<td>24.59</td>
<td>25.44</td>
<td>21.06</td>
<td>28.75</td>
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<tr>
<td>Precipitation_Winter (mm)</td>
<td>0.397</td>
<td>2.39</td>
<td>1.72</td>
<td>2.35</td>
<td>0.62</td>
<td>1.47</td>
<td>0.003</td>
<td>19.83</td>
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<tr>
<td>Temperature_Winter (°C)</td>
<td>23.88</td>
<td>26.76</td>
<td>24.43</td>
<td>16.52</td>
<td>19.94</td>
<td>21.54</td>
<td>13.29</td>
<td>28.01</td>
<td>3.7503</td>
</tr>
</tbody>
</table>

Note: *: Values in thousands of 2006 U.S. dollars (Exchange rate = 2.15); Source: Author’s elaboration based on 2006 Agricultural Census.

[^6]: One municipality presents a fraction of irrigated land larger than the unit. This municipality, Itamarandiba, located in Minas Gerais State, presents increasing vegetal extraction and forestry activities, which implies deforestation in order to produce charcoal from native and planted forests. As our land measure does not account for forest areas, this result leads us to conclude there is a fraction of forest areas being irrigated for agricultural activities. In addition, this municipality ranked 1st in the Deforestation Ranking of the Atlantic Forest in Minas Gerais State until 2005. Source: [http://www.inep.gov.br/](http://www.inep.gov.br/).
5.1. Elasticities and Water Value Estimation

Following Trindade (2015) and Suaréz, Fulginiti and Perrin (2018), after adding error terms and imposing symmetry in the second order parameters, the production function (Eq. 4) and the share equations (Eq. 5) for labor, expenses and irrigated land were simultaneously estimated using two alternative econometric models: seemingly unrelated regression (SUR) and three stage last squares (3SLS). These two models allow us to explore implications of potential endogeneity and cross sectional variations not captured by the variables included in our analysis. Since the translog specification allows the estimation of the elasticities for each data point, we only show average elasticities for land, labor, expenses and capital, and semi-elasticity (percentage change in output value per unit change of variable) for irrigation. The standard errors and p-values are at their means. Results are shown in Table 2.

The irrigation semi-elasticity for the SUR model is 2.95, which seems too high and inconsistent. This result might imply that SUR model are influenced by some source of endogeneity, while irrigation semi-elasticity for 3SLS model is 1.69. We found that SUR model had the lowest Akaike Information Criteria (AIC), while presents monotonicity violation properties higher than 3SLS model (in percentage), which is inconsistent with decisions driven by profit maximizing behavior. Thus, due balancing statistical fit leads to the choice of 3SLS model to use in further analysis. The Pseudo R-square for the 3SLS model is 0.7188.

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>SUR</th>
<th>3SLS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land</strong></td>
<td>0.090**</td>
<td>0.061**</td>
</tr>
<tr>
<td></td>
<td>(0.0370)</td>
<td>(0.0354)</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>0.243***</td>
<td>0.240***</td>
</tr>
<tr>
<td></td>
<td>(0.0246)</td>
<td>(0.0241)</td>
</tr>
<tr>
<td><strong>Expenses</strong></td>
<td>0.380***</td>
<td>0.393***</td>
</tr>
<tr>
<td></td>
<td>(0.0226)</td>
<td>(0.0221)</td>
</tr>
<tr>
<td><strong>Capital</strong></td>
<td>0.285***</td>
<td>0.276***</td>
</tr>
<tr>
<td></td>
<td>(0.0420)</td>
<td>(0.0415)</td>
</tr>
<tr>
<td><strong>Irrigation</strong></td>
<td>2.95*</td>
<td>1.69**</td>
</tr>
<tr>
<td></td>
<td>(0.3858)</td>
<td>(0.5631)</td>
</tr>
<tr>
<td><strong>AIC</strong></td>
<td>84941.39</td>
<td>153785.3</td>
</tr>
</tbody>
</table>

Note: *, **, *** significant at 10%, 5%, and 1%, respectively; ns: non-significant; #Semi-Elasticity: dlny/dx

Source: Research results

Test of endogeneity was performed in each equation of the system separately via instrumental variables regression, which leads us to conclude that irrigation is endogenous. Then, Sargin's and Basmann's tests of overidentifying restrictions for a regression estimated via instrumental variables for an overidentified equation (number of instruments exceeds the number of regressors) were performed, which the joint null hypothesis that the excluded instruments are valid instruments, i.e., uncorrelated with the error term and correctly excluded from the estimated equation. Tests are shown in Table 5 in Appendix A.

---

7 Endogeneity test was based on Wu-Hausman and Durbin-Wu-Hausman tests via ivendog command.
Evaluated at the average of the observations, the technology is monotone for all the inputs, but this is not true at each data point. The percentages of monotonicity violations are 0.36% for labor, 1.62% for expenses, 0.63% for capital and 0.46% for irrigation. Monotonicity violations for land go up to 5.63%, but the coefficient is not statistically significant.

The irrigation semi-elasticity indicates that changing a hectare from dryland to irrigated increases production value by 169%. If we only account for municipalities that have any irrigation the average elasticity diminishes to 1.39; the exclusion of 715 municipalities that do not use irrigation shifts our estimated elasticity⁷. Our estimate of the production semi-elasticity of irrigation (1.69) is higher than Trindade et al. (2015) estimates (0.23) and Suaréz et al. (2018) estimates (0.511) for a semi-arid region in the United States.

The negative coefficient for irrigation square implies that the yield boost from irrigation declines as the fraction of irrigated land increases within a municipality. A simple difference in percentage of output value between municipalities that use irrigation (at least one irrigator) and municipalities that do not use any irrigation averaged by Brazilian region might guide us to understand whether our irrigation semi-elasticity estimates make sense or not. Table 3 shows the results.

### Table 3 – Averaged gross value of production (GVP) between rain-fed and irrigated municipalities and percentage change in GVP, by Brazilian regions, 2006.

<table>
<thead>
<tr>
<th>Region</th>
<th>Non-Irrigators</th>
<th>Irrigators</th>
<th>Irrigation Share</th>
<th>Change in GVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>4.06</td>
<td>11.23</td>
<td>0.60%</td>
<td>176%</td>
</tr>
<tr>
<td>Northeast</td>
<td>2.51</td>
<td>8.12</td>
<td>2.92%</td>
<td>223%</td>
</tr>
<tr>
<td>Southeast</td>
<td>3.83</td>
<td>15.82</td>
<td>4.06%</td>
<td>313%</td>
</tr>
<tr>
<td>South</td>
<td>9.50</td>
<td>18.61</td>
<td>3.29%</td>
<td>96%</td>
</tr>
<tr>
<td>Midwest</td>
<td>18.54</td>
<td>30.15</td>
<td>1.22%</td>
<td>61%</td>
</tr>
<tr>
<td>Brazil</td>
<td>6.32</td>
<td>14.75</td>
<td>3.00%</td>
<td>133%</td>
</tr>
</tbody>
</table>

Source: Research results

The average percentage change in production value for Brazil between irrigators and rain-fed municipalities is 133%, on average, reaching 313% in the Southeast Region and 223% in the Northeast Region. The North Region is well known for great precipitation levels in summer season, despite of that, the percentage change in production value is 176% while the fraction of irrigated land is only 0.6%. Mostly of the crops planted in the Midwest Region presents a better response to droughts due seeds genetical enhancement mainly driven by the Brazilian Agricultural Research Corporation (Embrapa), which explain in part the low change in production value.

Although the simple percentage difference in the GVP (on average) between irrigators and rain-fed municipalities do not tell us the irrigation response estimates, it gives a sense of irrigation benefits and the capacity to shift the average gross value of production. Figure 2 depicts the kernel density of the rain-fed and irrigated gross value of production using farm level data.

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⁷ If we predict the irrigation elasticity rather than semi-elasticity for the entire sample, its value is 0.03 (significance at 5%), where the interpretation would be a percentage change in production value due a percentage change in the fraction of irrigated land, which is not useful to our analysis.
Our estimates of the value of annual increment in gross production value per hectare due to irrigation (Equation 6) are summarized by state and region in column 4 of Table 4. The incremental values in Brazil averaged US$668.98/ha. The lowest average is US$144.12/ha for Roraima State and the highest average for São Paulo, US$1,323.38/ha. The Southeast and South Regions are those that more use irrigation, incremental values averaged US$881.85 and US$752.05 per hectare, which is higher than the overall average.

The North and Northeast regions show the highest irrigation semi-elasticities, reflecting the small fraction of irrigated land. Specifically to North region, the great irrigation response might be explained by the fact that, on average, irrigation adoption has been slower in this Region. Multiplying the incremental gross value of production by the number of irrigated hectares provides an estimate of the average total gross value of irrigation water for all Brazilian municipalities in 2006. This result can be observed in column 7 of Table 4.

The average value of irrigation in Brazilian agriculture (summed to all municipalities) is approximately US$7.35 billion in 2006. We found the highest value of irrigation water is for Southeast region (US$3.38 billion) driven by irrigation value in São Paulo and Minas Gerais States, where is observed large areas irrigated on coffee, oranges, corn and sugarcane production. Northeast region presents the irrigation water value around US$2.23 billion which highest values is found for Bahia, Alagoas and Pernambuco States, where the former is driven by irrigated micro-regions in the western part and the two later driven mainly by sugarcane production and fruit growing in São Francisco Basin.

Rio Grande do Sul State in South Region (US$1.06 billion) presents the highest irrigation water value, around US$906 million, presumably by irrigated rice production, while irrigation value for Goiás State (US$398 million) in Midwest region is driven by irrigated pastures and sugarcane. As expected, irrigation water value for Mato Grosso and Mato Grosso do Sul States is low compared to the Midwest Region as a result of a low irrigated areas and the good response to droughts, mostly with soybeans production. The lowest irrigation water value is estimated for Acre State (US$0.95 million) in the North Region (US$61.9 million), while Pará and Tocantins States present the highest irrigation value in this region mainly due to irrigated pastures as a result of extensive cattle ranching.

It is important to highlight that our estimates are based on extra revenue per hectare ($/ha). Studies that use quantity of water applied in production functions to measure the value of irrigation water usually obtain returns in terms of $/m³ which is not strictly comparable to our estimates. Furthermore, we emphasize that we do not have data sources to estimate the additional costs of

Figure 2 – Kernel density estimate of irrigated and rain-fed Gross Value of Production (GVP)

Source: Research results
irrigated production versus non-irrigated production to be deductible from the values we estimate to obtain net value of irrigation, while we have estimates on total additional gross revenue when land is irrigated relative to unirrigated land. The total cost of water would be measured by energy, operation, and maintenance costs for diversion and pumping at agricultural nodes (Cuadra et al., 2019).

Table 4 – Estimated Annual Average Irrigation Water Value by State, Brazil, 2006

<table>
<thead>
<tr>
<th>State</th>
<th>Observed Production Value (US$/ha)</th>
<th>IR Semi-Elast.</th>
<th>Av. Gross Value per Hectare Irrigated (US$/ha)</th>
<th>Hectares Irrigated (Thousands hectares)</th>
<th>Irrig. Share (%)</th>
<th>Total Gross Value of Irrigation Water (Million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rondônia</td>
<td>122.28</td>
<td>2.22</td>
<td>267.72</td>
<td>14.12</td>
<td>0.24</td>
<td>6.16</td>
</tr>
<tr>
<td>Acre</td>
<td>216.61</td>
<td>2.40</td>
<td>355.95</td>
<td>1.45</td>
<td>0.09</td>
<td>0.95</td>
</tr>
<tr>
<td>Amazonas</td>
<td>264.29</td>
<td>2.50</td>
<td>443.97</td>
<td>6.12</td>
<td>0.40</td>
<td>5.48</td>
</tr>
<tr>
<td>Roraima</td>
<td>110.65</td>
<td>2.45</td>
<td>144.12</td>
<td>12.72</td>
<td>3.22</td>
<td>2.74</td>
</tr>
<tr>
<td>Pará</td>
<td>404.23</td>
<td>2.53</td>
<td>451.17</td>
<td>29.20</td>
<td>0.90</td>
<td>25.10</td>
</tr>
<tr>
<td>Amapá</td>
<td>257.57</td>
<td>2.62</td>
<td>355.91</td>
<td>2.28</td>
<td>0.68</td>
<td>3.15</td>
</tr>
<tr>
<td>Tocantins</td>
<td>95.78</td>
<td>2.33</td>
<td>164.83</td>
<td>37.58</td>
<td>0.30</td>
<td>18.28</td>
</tr>
<tr>
<td><strong>North</strong></td>
<td><strong>232.54</strong></td>
<td><strong>2.42</strong></td>
<td><strong>321.97</strong></td>
<td><strong>103.47</strong></td>
<td><strong>0.60</strong></td>
<td><strong>61.86</strong></td>
</tr>
<tr>
<td>Maranhão</td>
<td>295.18</td>
<td>2.43</td>
<td>415.33</td>
<td>63.26</td>
<td>1.63</td>
<td>82.96</td>
</tr>
<tr>
<td>Piauí</td>
<td>185.08</td>
<td>2.22</td>
<td>317.60</td>
<td>30.90</td>
<td>1.19</td>
<td>19.77</td>
</tr>
<tr>
<td>Ceará</td>
<td>738.99</td>
<td>2.11</td>
<td>779.41</td>
<td>117.38</td>
<td>3.90</td>
<td>159.11</td>
</tr>
<tr>
<td>Rio G. do Norte</td>
<td>1,640.16</td>
<td>2.10</td>
<td>528.21</td>
<td>53.83</td>
<td>3.12</td>
<td>64.96</td>
</tr>
<tr>
<td>Paraíba</td>
<td>433.38</td>
<td>1.99</td>
<td>582.06</td>
<td>58.54</td>
<td>2.54</td>
<td>71.37</td>
</tr>
<tr>
<td>Pernambuco</td>
<td>896.67</td>
<td>1.86</td>
<td>979.39</td>
<td>152.89</td>
<td>5.45</td>
<td>401.67</td>
</tr>
<tr>
<td>Alagoas</td>
<td>838.42</td>
<td>1.76</td>
<td>1,070.54</td>
<td>195.71</td>
<td>8.88</td>
<td>545.00</td>
</tr>
<tr>
<td>Sergipe</td>
<td>495.28</td>
<td>2.02</td>
<td>736.31</td>
<td>20.40</td>
<td>3.59</td>
<td>21.20</td>
</tr>
<tr>
<td>Bahia</td>
<td>309.78</td>
<td>1.87</td>
<td>413.50</td>
<td>312.29</td>
<td>1.50</td>
<td>862.29</td>
</tr>
<tr>
<td><strong>Northeast</strong></td>
<td><strong>573.63</strong></td>
<td><strong>2.04</strong></td>
<td><strong>580.13</strong></td>
<td><strong>1,005.20</strong></td>
<td><strong>2.92</strong></td>
<td><strong>2,228.33</strong></td>
</tr>
<tr>
<td>Minas Gerais</td>
<td>520.49</td>
<td>1.60</td>
<td>612.80</td>
<td>524.65</td>
<td>2.22</td>
<td>1,362.76</td>
</tr>
<tr>
<td>Espírito Santo</td>
<td>709.36</td>
<td>1.46</td>
<td>747.01</td>
<td>209.84</td>
<td>9.29</td>
<td>279.28</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>499.35</td>
<td>1.49</td>
<td>469.77</td>
<td>81.74</td>
<td>4.38</td>
<td>215.93</td>
</tr>
<tr>
<td>São Paulo</td>
<td>1,345.47</td>
<td>1.49</td>
<td>1,323.38</td>
<td>773.73</td>
<td>5.81</td>
<td>1,522.92</td>
</tr>
<tr>
<td><strong>Southeast</strong></td>
<td><strong>839.89</strong></td>
<td><strong>1.55</strong></td>
<td><strong>881.85</strong></td>
<td><strong>1,589.96</strong></td>
<td><strong>4.04</strong></td>
<td><strong>3,380.89</strong></td>
</tr>
<tr>
<td>Paraná</td>
<td>809.30</td>
<td>1.29</td>
<td>862.63</td>
<td>103.97</td>
<td>1.08</td>
<td>127.94</td>
</tr>
<tr>
<td>Santa Catarina</td>
<td>1,716.56</td>
<td>0.94</td>
<td>1,119.10</td>
<td>136.02</td>
<td>5.73</td>
<td>28.90</td>
</tr>
<tr>
<td>Rio G. do Sul</td>
<td>1,169.85</td>
<td>0.83</td>
<td>446.39</td>
<td>996.12</td>
<td>3.62</td>
<td>906.45</td>
</tr>
<tr>
<td><strong>South</strong></td>
<td><strong>1,181.16</strong></td>
<td><strong>1.01</strong></td>
<td><strong>752.05</strong></td>
<td><strong>1,236.10</strong></td>
<td><strong>3.29</strong></td>
<td><strong>1,063.28</strong></td>
</tr>
<tr>
<td>Mato G. do Sul</td>
<td>204.52</td>
<td>1.91</td>
<td>255.09</td>
<td>119.34</td>
<td>0.70</td>
<td>52.64</td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>201.13</td>
<td>2.10</td>
<td>396.85</td>
<td>144.49</td>
<td>0.50</td>
<td>162.33</td>
</tr>
<tr>
<td>Goiás</td>
<td>234.75</td>
<td>2.00</td>
<td>411.40</td>
<td>302.25</td>
<td>1.80</td>
<td>397.93</td>
</tr>
<tr>
<td><strong>Mid-West</strong></td>
<td><strong>219.52</strong></td>
<td><strong>2.02</strong></td>
<td><strong>380.84</strong></td>
<td><strong>566.08</strong></td>
<td><strong>1.22</strong></td>
<td><strong>612.89</strong></td>
</tr>
<tr>
<td>Brazil</td>
<td>726.80</td>
<td>1.70</td>
<td>668.98</td>
<td>4,500.81</td>
<td>3.00</td>
<td>7,347.26</td>
</tr>
</tbody>
</table>

Note: IR Semi-Elasticity is weighted by the land planted with crops and pastures in each municipality relative to total land in the respective State.

Source: Research results.
Are our irrigation water values estimates plausible, given results of other studies? Santos and Spolador (2018) combined General Equilibrium with Residual Method in a multi-sector growth model to estimate the stock value of irrigation water in Brazil to the year of 2007 and found a value of US$9.6 billion, which is slightly higher than our estimates, US$7.35 billion. Production function was used in Carramaschi et al. (2000) to estimate the net irrigation value of horticulture and fruit growing in the Midwest Region and found a net income of US$1,779/ha; our gross estimates is so much lower, US$668.98/ha for Brazil and US$380.84/ha for that region. Yield function in response to water application using linear programming model estimated in Frizzone et al. (1997) to an irrigated district settled in São Francisco River Basin (Pernambuco State) averaged a shadow price of irrigated land in US$1,115.20/ha which is closer to our estimates of that State, US$979.39/ha.

Nikouei et al. (2013) estimated the water value in Iran and found a value of US$689.7 million/year in total revenue which is closest to our estimates to Midwest Region, US$612.9 million. They also estimated a total net income of US$379.4 million/year where the average net income US$2.3 thousand/ha/year. The value of irrigation water estimated in Suaréz et al. (2018) to High Plans Aquifer in US is around US$3.34 billion in 2007 which extra gross revenue per acre averaged US$125.2. The total net benefit in irrigated production in England and Wales was estimated in Rey et al. (2016) around US$854 million assuming no constraints in resource availability and optimal irrigation practices. The annual incremental benefit from irrigation was averaged US$226.96/ha in Viswanathan and Kumar (2016) for India. These previous results for different countries are lower than our estimates for Brazilian agriculture.

The Brazilian Gross National Product (GNP) in 2006 was US$ 1.31 trillion, and the agricultural sector GNP was US$312.68 billion, which represents 24% of total GNP (IBGE, 2006). Taking into account the total production value given by our data, this value is around US$75.81 billion. Thus, our estimates of water irrigation value represents 9.7% of total agricultural production value in 2006, 2.35% of agricultural sector GNP and 0.56% of Brazilian GNP, which is reasonable to consider. Santos and Spolador (2018) found that stock value of water used in irrigation would correspond to only 0.22% of the value of the stock of physical capital for the entire Brazilian economy. However, as pointed out by the authors and also Resende Filho et al. (2015), from an economic point of view the value of water used in irrigation can be considered low in Brazil. Figure 5 depicts the value of irrigation water estimates.

**Figure 3 – Irrigation water value, Brazil (2006)**

Source: Research results.
We can observe based on Figure 3 that the highest values of irrigation water are for those municipalities that present high values of irrigated land (in %) as can be noted if we compare Figure 3 and Figure 1. Thus, we can conclude that irrigation water is more valuable in regions where irrigated agriculture is well developed.

5.2. Post estimation analysis

As highlighted by Young (2005), Frija et al. (2014) and Suárez et al. (2018), diminishing marginal elasticity of irrigation response is expected as irrigation increases. This relationship is unclear when we observe our irrigation semi-elasticity estimates and the fraction of irrigated land in Table 4. For instance, we can observe that irrigation response rise when irrigated land increase, as in Tocantins State with a response of 2.33 with 0.3% of irrigated land, while Maranhão State presents an irrigation response of 2.43 while irrigated land is 1.63%; the same relationship can be observed to Santa Catarina State with an irrigation response of 0.94 with 5.73% of irrigated land. When compared to the highest fraction of irrigated land, that is, Espírito Santo State (9.29%), the irrigation response shift up to 1.46, which seems not corroborate to diminishing marginal productivity of irrigation.

To evaluate this relationship accurately a scatterplot of the irrigation response and irrigated land is needed with the whole data collection due there might be municipalities characteristics, such as soil characteristics, that are not captured by the model specification used. Figure 4 depicts a scatterplot of this relationship.

Figure 4 – Semi-elasticity of irrigation response estimated by 3SLS

Our estimation does support this intuition and shows a lower irrigation response as the irrigated land ratio increases. A prediction of the irrigation elasticity rather than semi-elasticity shows a yield increase when the irrigated fraction increase, but it becomes reverse when more irrigation is applied, which implies that our results are consistent with diminishing marginal productivity of irrigation at the extensive margin within municipalities. Figure 5 depicts a scatterplot of the yield response to irrigation elasticity.
Figure 5 – Elasticity of irrigation response estimated by 3SLS

Source: Research results.

6. Conclusion

Brazil has shown significant incorporation of irrigated areas for several decades, where productivity gains can be explained in part by the implementation of efficient irrigation systems. However, the role of irrigated agriculture in the contribution of the yield increase and the value of water used in irrigation has not been much analyzed in Brazilian agriculture.

This research aimed to estimates the average increases in gross value of production due to irrigation and also measure how much is the value of irrigation water in Brazil using production function approach to 5,538 municipalities. Dataset was obtained from 2006 Agricultural Census and a system of equations was performed to estimate a production function and labor, expenses and irrigated land share equations.

A yield response due to irrigation averaged 1.69 was found and incremental gross revenue due to irrigation averaged US$668.98/ha. The value of irrigation water estimates is US$ 7.35 billion, which is based on total additional gross revenue when land is irrigated relative to rain-fed land. To obtain the net value the costs of irrigated production is required. Our estimates are consistent with diminishing marginal productivity of irrigation at the extensive margin within municipalities.

We found that irrigation water is more valuable in regions where irrigated agriculture is well developed as in Rio Grande do Sul State with irrigated rice production (located in the Uruguai and Antlântico Sul Basins); São Paulo State (settled in Paraná Basin) with oranges, sugarcane and cotton production; and Espírito Santo and Minas Gerais States with coffee, corn and beans production; both settled in São Francisco and Atlântico Leste Basins, respectively.

In the Midwest region (sharing Paraguai, Paraná, Araguaia/Tocantins and Amazônica Basins) we can observe high values for those municipalities producing soybean, corn and sugarcane; and Northeast Region in areas settled by the São Francisco Basin mainly in horticulture and fruit growing, and also in areas settled in western part of Bahia, where soybean and grains in general has been harvested in the last years as a response of the development of MATOPIBA region (known as the new agriculture frontier in Brazil in the States of Maranhão, Tocantins, Piauí and Bahia).

Municipalities located in Pernambuco and Alagoas States presented high values of irrigation water due irrigated sugarcane, and also in Ceará State (those located on Atlântico Nordeste Oriental Basin) where several irrigated projects has been developed in the last two decades. Finally, we can observe isolated municipalities in North region that presented high irrigation values, mainly settled in...
Tocantins and Pará States (Tocantins/Araguáia Basin) with graze plantation; and flooded rice in Roraira, Amazonas and Rondônia States.

Public policies on irrigation expansion could be driven in three ways: (i) in regions where irrigation response presented high values, but more use of water could be associated to a smaller production vis-à-vis another area with the same characteristics; (ii) or where the extra revenue per hectare due to irrigation is the highest compared to others regions; (iii) and also based where irrigation water is more valuable. Our estimates also allow obtaining some interesting results to support water price policy for irrigation among the twelve hydrological basins in Brazil, which the water price policy to pump water to irrigate must reflect the availability and the quality of the resource.

References


BEBEL, J.; MESA, P. Valoración del agua de Riego por el método de precios quasi-hedónicos: aplicación al Guadalquivir. Econ Agrar Recurs Nat 7, 127-144. [In Spanish]. 2007.


TERRESTRIAL HYDROLOGY RESEARCH GROUP – Civil and Environmental Engineering Department of Princeton University. Available on: http://www.hydrology.princeton.edu/data/pgf/1.0deg/monthly/


**APPENDIX A**

<table>
<thead>
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<th>Table 5 – Tests of endogeneity and instruments validation tests</th>
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<tr>
<td><strong>Endogeneity Test</strong></td>
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| **Instruments Validation** | **Sargan Test** | **Basmann Test** |
| --- |
| Production Function | 6.58157NS | 6.51682NS |
| Labor Share Equation | 0.13578NS | 0.13535NS |
| Expenses Share Equation | 1.83833NS | 1.83296NS |
| Irrigation Share Equation | 2.03232NS | 2.02646NS |

**Notes:** Null hypothesis of Wu-Hausman and Durbin-Wu-Hausman tests are that endogenous regressors’ effects on the estimates are not meaningful, and instrumental variables techniques are not required; Null hypothesis of Sargan and Basmann tests are that excluded instruments are valid instruments.

Endogenous: lx5, lx5lx5, lx2lx5, lx3lx5, lx4lx5, lx5t1, lx5t2, lx5p1, lx5p2.

Exogenous: t1, t2, p1, p2, tl1, t22, p11, p22, tl1t2, tl1p1, tl1p2, tl2p1, t2p2, p1p2.

Labels: lx5=irrigation; lx2=labor; lx3=expenses; lx4=capital; p1,p2=precipitation; and t1,t2=temperature