Cost-benefit analyses of the adoption of irrigation on oranges in São Paulo, Brazil

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ABSTRACT

Brazil contributes 55% and 60% of the world’s production of fresh oranges and orange juice, respectively. In recent years, increasing production costs and low orange prices reduced the citrus producers’ profitability. In this paper we investigate the potential for irrigation to improve the profitability of orange production, using data from a sample of 98 citrus producers in the state of São Paulo, 34 of whom had adopted irrigation. Based on a translog production function, we use 3SLS to estimate a system of equations comprising the production function and the inverse derived demands for inputs, to obtain the impact of irrigation adoption on productivity. Results show that adopting irrigation increases citrus production by 19%. We estimate production elasticities of capital (.16), labor (.21), land (.26) and fertilizers (.20). We found that by considering yield increases versus both fixed and variable costs of implementation, farmers could expect to break even by the fifth year of irrigation use.

Key words: Orange production, Irrigation adoption, Production economic theory.

JEL: D22, D24, Q16.

1. Introduction

Brazil produces 55% and 60% of the world’s production of fresh oranges and orange juice, respectively. The citrus sector is also important to the Brazilian economy (Brazilian Association of Citrus Exporters – CITRUSBR, 2015). The Brazilian citrus production is clustered mainly in the north-central São Paulo state and southwest Minas Gerais state (Triângulo mineiro), an area known as the citrus belt, which is responsible for more than 80% of the production of both products in the country (Neves et al., 2010).

In 2014, Brazil produced more than 11 million tons of fresh oranges and about 1.0 million tons of orange juice (Agricultural Economics Institute – IEA, 2014; United States Department of Agriculture – USDA, 2014). About 70% of the fresh oranges produced are destined to juice processors and more than 90% of juice produced is exported, mainly to the European Union (EU) and the United States (US). The remaining 30% of fresh orange production is sold mostly on the domestic fresh orange market (CITRUSBR, 2015).
Over the past decades the increase in production costs and the low prices paid per box of oranges has led to a reduction in the farmer’s profitability, resulting in the abandonment of the activity by more than 70% of the producers\(^1\) (Survey of Agricultural Production Units – LUPA, 2008; National Supply Company – CONAB, 2013). An increase on productivity due to irrigation may reduce the unit production costs and increase the farmer’s profitability, which may lead to a decrease on farmers’ exit of the market.

Barreto et al. (1976), Zanini et al. (1998) and Silva et al. (2009) have shown an increase in productivity of Brazilian orchards by the use of localized (drip or micro sprinkler) and/or traveling sprinkler. They evaluated the importance of irrigation using field experiments with irrigated and non-irrigated treatments. Barreto et al. (1976) identified an increase of 56% in the number of fruits per 'Natal' orange tree. Zanini et al. (1998) identified an increase of more than 40% in the number of boxes (40.8 Kg) of 'Natal', 'Valencia' and 'Pêra' produced per tree, while Silva et al (2009) identified an increase of 32% in the total production of 'Valencia' oranges. Irrigation also induced improvement in orange size, weight and juice content and increase in dry matter of the roots and nutrients in the leaves (Barreda et al., 1984; Silva et al., 1999; Villas-Bôas et al., 2002; Prado et al., 2007).

In 2014, 24.6% of the orange production area in the citrus belt was using irrigation systems (Brazil’s Citrus Defense Fund – FUNDECITRUS, 2015). This low rate of implementation may be associated with high cost of adoption, which may offset the impact of increasing yields (Foundi and Erdlenbruch, 2011).

This paper investigates the on-farm costs and benefits of irrigation in orange production in the state of Sao Paulo-Brazil. We model farm production assuming that farmers maximize profits constrained by a production technology represented by a translog production function. A Three Stage Least Squares (3SLS) procedure was used to estimate the function, from which we obtain the impact of irrigation on productivity. Based on these results, we calculated alternative investment criteria – Net Present Value (NPV), Payback period, and Internal Rate of Return (IRR) – to evaluate the benefits of irrigation adoption. We are not aware of any other paper that uses farm-level data to analyze the payoff from irrigation for orange production in the Brazilian citrus belt.

\(^1\) In 1995/1996 there were 35,883 orange farmers in the belt decreasing to 10,100 in 2014 (LUPA, 2008; CONAB, 2013).
Other things equal, we estimate the average impact of irrigation on yields to be 19%, slightly lower than the 22% simple difference reported by adopters versus non adopters in the survey, but considerably lower than the 32-56% estimates reported by the above researchers. The investment analysis showed on average a positive NPV and an IRR greater than the discount rate considered, and 91% paid the irrigation system project in less than 15 years but for about 50%, payback was five years or less.

The reminder of this study will be organized as follow. Section 2 will present a description of the theoretical model used to find the impact of irrigation on orange productivity, and of the investment analysis tools. Section 3 presents the data and the empirical specification. Section 4 discusses the results, and, section 5 presents the conclusion of the study.

2. Methodology

2.1. The model

We use a primal approach (production function) to examine the role of irrigation in the production structure. We assume constant returns to scale\(^2\) and perfect competition (value of marginal product of inputs are set equal to market prices).

A profit (\(\pi\)) maximization problem considering a production possibility set \(T\) represented by the constant returns to scale production function \(y = f(x)\), can be represented by

\[
\max_x \pi = py - wx; \ y = f(x) \epsilon T; \quad p, w \gg 0
\]

where \(p\) is output price, \(w\) is a vector of input prices, respectively; \(y\) is output and \(x\) is a vector of input quantities, all divided by land to impose homogeneity. First order conditions for solving Equation 1 set the marginal products of inputs equal to their prices divided by output price. Converted to logarithms, for input \(i\) the stochastic version of this condition can be rewritten as\(^3\)

\[\text{\footnotesize(1)}\]

\(^2\) Constant returns to scale was imposed by dividing all inputs by one of the inputs – land.
\(^3\) The production function is monotone in inputs (Chambers, 1988). The matrix of second order derivatives is symmetric \((d^2y/dx_idx_j = d^2y/dx_jdx_i)\).
\[
\frac{\partial \log(y)}{\partial \log(x_i)} = \frac{\partial f(x_i)}{\partial x_i} \frac{x_i}{f(x_i)} = \frac{w_i x_i}{p y} = S_i = \varepsilon_i
\]  

where \( S_i \) is the share of input \( i \) in output value and \( \varepsilon_i \) represents the production elasticity. The monotonicity property requires this and all input production elasticities to be equal or greater than zero.\(^4\) We estimate equation (2) for each input simultaneously with the production function \((y = f(x))\) with cross-equations restrictions on the estimates of common parameters to achieve more efficient estimation and theoretical consistency.

The main goal of the paper is to measure the impact of irrigation adoption on yield. This is obtained as

\[
\lambda_{irr} = \frac{\partial \log(y)}{\partial \text{irr}}
\]  

because \( \partial \log(y) = \partial y / y \), it is interpreted as the percentage change in \( y \), where output \( y \) is divided by land. Because \( \text{irr}_i \) is a zero-one indicator variable, a one-unit change represents the difference between no irrigation and irrigation. Therefore, equation (3) can be interpreted as the percentage increase in unirrigated yield due to irrigation. This information will be used in investment analysis tools, described in the next section.

2.2. Investment analysis: NPV, IRR and Payback Period

Investment analyses are used to evaluate the profitability and risks in implementing projects. The Net Present Value (NPV) brings the stream of income and expenses through time to equivalent values at the present. A project must show a NPV greater than zero to be considered economically feasible (Wesseler, 1992)\(^5\). The NPV is calculated using the following formula:

\[
\begin{align*}
\varepsilon_{\text{land}} &= 1 - \sum_{i=1}^{N-1} \frac{\partial \log(y)}{\partial \log(x_i)} = 1 - \sum_{i=1}^{N-1} \frac{\partial f(x)}{\partial x_i} \frac{x_i}{f(x)} \\
&= 1 - \sum_{i=1}^{N-1} \frac{\partial f(x)}{\partial x_i} \frac{x_i}{f(x)}
\end{align*}
\]  

\(^4\) Due to the imposition of constant returns to scale the land production elasticity is calculated from

\[
\varepsilon_{\text{land}} = 1 - \sum_{i=1}^{N-1} \frac{\partial \log(y)}{\partial \log(x_i)} = 1 - \sum_{i=1}^{N-1} \frac{\partial f(x)}{\partial x_i} \frac{x_i}{f(x)}
\]  

\(^5\) The NPV and IRR were estimated considering an irrigation project length of 15 years and a discount rate of 12% (Morris et al., 2008).
\[ NPV = -C_0 + \sum_{t=0}^{n} \frac{NB_t}{(1 - i)^t} \]  \hspace{1cm} (5)

where \( C_0 \) is the initial investment (implementation cost of the irrigation project), \( NB_t \) is the cash flow (extra revenue from irrigation minus extra fixed and variable costs during year \( t \)), \( t \) represents time \( (t = 1, 2, \ldots, 15) \), and \( i \) is the discount rate. The cash flow for year \( t \) is calculated as

\[ NB_t = R_i - (CF_i + CV_i) \]
\[ = p_t(q_t \ast \lambda_{irr,i}) - (\tilde{c}_{f} + \tilde{c}_{v}) \]  \hspace{1cm} (6)

where the subscript \( t \) is omitted for simplicity and \( i \) represents an individual farm. The first equality considers cash flow as the extra revenue obtained from irrigation \( (R_i) \) minus the sum of fixed \( (CF_i) \) and variable \( (CV_i) \) cost with irrigation. The second equality considers the revenue \( (R_i) \) as the multiplication of farm’s orange price \( (p_t) \), obtained from Souza Filho et al. (2013), times the increase in yield from irrigation \( (q_t \ast \lambda_{irr,i}) \), where \( \lambda_{irr,i} \) is obtained from equation (3), minus estimated costs obtained in Rezende et al. (1999).\footnote{Fixed variable cost per hectare ranges from US$ 125 to US$ 156.50 and the variable cost per hectare ranges from US$ 219.40 to US$ 335.74 depending of the type of irrigation system used (Rezende et al., 1999).} We do not have future prices and costs (prediction) in the model, which makes \( NB_{i,t} = NB_{i,t+1} \).

The Internal Rate of Return (IRR) is the discount rate that equates the NPV of the project to zero, which is the rate of return earned on the investment over the lifetime of the irrigation system. The project will be profitable if the IRR is higher than the cost of capital, or discount rate \( (i) \), considered (Gitman, 1979). We estimated the IRR using the following formula

\[ r \ such \ that \ 0 = -C_0 + \sum_{t=0}^{n} \frac{NB_t}{(1 - r)^t} \]  \hspace{1cm} (7)

where \( NB_t \) was previously defined. For both of the investment criteria the cost of capital is chosen as 12\%, and the time horizon of the project \( t \) was chosen as 15 years, based on the literature, i.e. Morris et al. (2008). The payback period identifies the number of years necessary
to repay the capital invested, with no discounting. This criterion can be used as a primary decision mechanism, however is uncommon to make investment decisions based only on the payback period. Complementary criteria, such as NPV and IRR are required (Damodaran, 1999). We estimated the future fixed and variables costs and benefits as described above.

3. The application

3.1. Dataset

The dataset was obtained from a survey conducted by the Department of Production Engineering located at the Federal University of Sao Carlos\(^7\) in 2014 of a sample of 98 citrus farmers located in the state of Sao Paulo, which included 34 irrigation adopters and 64 non-adopters. The survey aimed to obtain information on economic aspects of orange production system for the 2013/14 crop season\(^8\). It is a representative sample of São Paulo and Brazilian orange production. The sample covers the main orange production regions within the state (Figure 1). For detailed description of the survey see Souza Filho et al. (2013).

\[\text{Figure 1}\]

Figure 2 displays irrigation adoption by farm size. Farm size was measured as the number of orange trees in the property. Small farms have between 0 to 20,000 trees, medium farms have 20,001 to 100,000 and large farms are more than 100,001 trees. Small (44.89\%) and medium (43.87\%) farmers compose most of our sample, which represent the most prevalent categories found in the citrus activity in the state. The large producers are 11.24\% of the sample.

\[\text{Figure 2}\]

Figure 3 displays the average production per tree (boxes of orange/tree) for each size category of producers. Productivity for adopters, in all categories, is higher than for non-adopters. Average productivity for the small, medium, and large adopters are 1.72 box/tree, 2.72 box/tree,

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\(^7\) This project was coordinated by the professor Dr. Hildo Meirelles de Souza Filho. The outcome of the project is confidential since it contains strategic and private information.

\(^8\) The survey also obtained additional information such as farmers and farm characteristics.
and 1.86 box/tree, respectively, while for non-adopter are 1.46 box/tree, 2.70 box/tree, and 1.59 box/tree, respectively.

[Figure 3]

Figure 4 displays the average orange production per hectare (box/hectare) for each size category of producers. On average, irrigators reported 22% higher yields than non-irrigators.

[Figure 4]

Based on data availability and inputs relevant to orange production, we consider one output (orange production) and five inputs used on orange production (capital, labor, fertilizer, land and irrigation). Table 1 displays the descriptive statistics by choice of irrigation adoption.

[Table 1]

Labor (hours and expenses), capital (machine – hours and expenses) and fertilizer (quantity and expenses) are higher for irrigation adopters than for non-adopters. Total orange production and revenue are higher for the adopters than for non-adopters. Figure 5 reports descriptive statistics for inputs by size and irrigation adoption.

[Figure 5]

Irrigation adopters, on average, use 127.11 hectares for orange production, which represents 62.30% of their property, while non-adopters, on average, use 79.93 hectares (61.16%). Additionally, irrigation adopters have higher dependency on the orange activities. On average, 60% of their total income comes from oranges sales, while for non-adopters, less than half of their income (44%) comes from orange sales (Rossi et al., 2015).

9 In the empirical model labor and capital was in hours while fertilizer was in kilograms. Table 2 will present the descriptive statistics for the variables used in the model.
Irrigation adoption may increase yields, but it also requires higher labor, capital, and fertilizer, as shown in Table 1. Thus, it is relevant to investigate the impact of irrigation adoption on productivity and its economic costs versus benefits.

### 3.2. Empirical specification

We estimate a system of equations consisting of the production function and the inverse demand equations for labor, capital, and fertilizer, assuming perfectly competitive profit maximizing producers under constant return to scale. Production technology is represented by a translog production function, which is a second order Taylor expansion in logarithms. We consider one output (y – citrus production per hectare) and three inputs per hectare (x_i, i = labor per hectare, capital per hectare, fertilizer per hectare), and irrigation (which is a dummy variable that assumes value equal 1 for irrigation adopters, and 0 otherwise), where land is used as the numeraire to impose constant returns to scale:

\[
\log(y) = a_0 + \sum_i^3 a_i \log(x_i) + \beta_1 \text{irr} + \frac{1}{2} \sum_i^3 \sum_j^3 a_{ij} \log(x_i) \log(x_j) + \sum_{i=1}^3 \beta_{1i} \log(x_i) \text{irr} + u, \\
\]

and

\[
S_i = a_i + \sum_j^3 a_{ij} \log(x_j) + \beta_{1i} \text{irr} + u_s, \quad k = 1, \ldots, 5
\]

where \(u\) and \(u_s\) represent random errors with normal distributions; \(S_i = w_i x_i / py\) represents the input share for input i; and \(\text{irr}\) represents the dummy variable for irrigation. The system estimated has four equations: the production function, and the share equations for labor, capital and fertilizer. Table 2 displays descriptive statistics of the variables used in the model.

The system of equation was estimated using a 3SLS approach (Zellner and Theil, 1962). We considered irrigation adoption as endogenous. The instruments aim at correcting a potential endogeneity issue are: number of orange varieties (used on production), orange production

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10 See Chambers (1988) and Christensen, Jorgenson, and Lawrence (1973) for more details of it.
11 We did not have price of irrigation. Thus, we did not estimate its share equation.
destination (industry, for example) and whether the farm pays for technical assistance. We tested the specification chosen against a Cobb-Douglas functional form\(^\text{12}\).

The impact of irrigation on yield per hectare will be evaluated for each firm by using the parameters estimated from Equation (8) on Equation (3)

\[
\lambda_I = \frac{\partial \log(y)}{\partial \text{irr}} = \beta_1 + \sum_{i=1}^{3} \beta_{1i} \log(x_i) \tag{9}
\]

which gives the percentage increase on yields (oranges/area) due to irrigation adoption. Equation (9) will be used to evaluate the increase on revenue due to irrigation adoption on investment tool described in Section 2.2.

4. Results

The system of equations (8) was estimated using a 3SLS\(^\text{13}\), imposing constant returns to scale and equality and symmetry across equations. We estimated four equations simultaneously – the production function and the share equations for labor, capital and fertilizer. Table 2 reports the estimated parameters. Overall, eight parameters out of fourteen were statistically significant. A Hasen-Sargan test for overidentification of instruments suggests that we are using valid instruments at 1%. A Breusch-Pagan LM diagonal covariance matrix test was performed indicating that equations should not be estimated separately using Ordinary Least Square (OLS), but with 3SLS. A Wald test favored the translog specification over the Cobb-Douglas. Average production elasticities displayed the expected sign\(^\text{14}\) (Table 3), suggesting that an increase in inputs will lead to an increase in yields.

[Table 3]

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\(^{12}\) Using a Wald test for all quadratic terms of the translog function.

\(^{13}\) Stata 14 was used to estimate (the codes used were reg3, Imcovreg3 and overid)

\(^{14}\) Monotonicity was satisfied in 96 out 98 observations. Second order derivatives were evaluated to test diminishing marginal productivity. For irrigation, all observations (100%) satisfied this hypothesis while for fertilizer (92%), labor (97%), and capital (56%) some observations did not satisfy the hypothesis. Quasi-concavity is only satisfied locally.
Production elasticities are displayed in Table 4. All production elasticities are statistically significant for the full sample (second column) and for irrigation adopters (third column). For adopters, land has a smaller effect on yields, reflecting a decrease in the contribution of land with the increase in the contribution of irrigation. Other elasticities are comparable for irrigators and non-irrigators. A ten percent increase in capital (hours of machine) leads to an increase of 1.5% on yields. Labor and fertilizers have a higher impact on yields. Labor has a 17% higher impact for irrigation adopters than non-adopters. A ten percent increase in hours of labor leads to an increase of 2.1% on yields. Fertilizer has a smaller effect.

[Table 4]

Irrigation increases yields by 19%, on average. This result is consistent with the raw data that indicates higher production in irrigated farms. We also estimated the irrigation impact for non-adopters to measure a hypothetical change in yield if they adopted irrigation. As expected, the impact is higher for adopters than for non-adopters (and both are statistically significant at 5%). For adopters, the impact is, on average, 0.192 and for non-adopters is 0.188, which means that irrigation adoption increases productivity by 19%, on average for the full sample. These values were used in the investment, presented next.

4.1. Investment analysis: NPV, IRR and Payback Period

We calculated annual change in cash flow from irrigation for each farmer as a 19% change in reported revenue, minus the extra variable and fixed (insurance, etc) costs. This annual cash flow is projected out 15 years, discounted at the rate of 12%. From that, the irrigation investment cost is subtracted to obtain NPV. Figure 6 and Table 7 summarize the results. Gitman (1979) indicates that a project is accept if NPV is equal or greater than zero, which means that the rate of return the farmer will obtain on his investment will exceed the 12% cost

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15 The prices paid per orange box used to estimate the three investments methods (NPV, IRR and payback) analyzed in this paper were based on the prices received by the producers on the crop season of 2013/2014. Thus, the number of producers with negative NPVs, IRRs and greater Payback periods can be overestimated because the orange sector was experiencing a crisis which affected negatively the prices. Also, in order to estimate these methods, besides the estimation done for the irrigation elasticity, an irrigated area, an implementation cost and the fixed and variable costs from the irrigation project was estimated based on a farmer adopter with the same orange area in the property.
capital. Among adopters, estimated NPV was positive for 70.58% of farms, averaging US$ 182,493.71\textsuperscript{16}. Only 46.75% of estimated NPVs were positive for non-adopters, averaging US$ 64,808.95. While we calculated NPV over a 15-year project life, we also calculated it for shorter project lives, from 1 to 15. Figure 6 shows how these NPVs increase as the project increases to an expected life of 15 years.

[Figure 6]
[Table 5]

The IRR estimates are complementary to results obtained with the NPV analysis. As shown in Figure 7 and Table 6, among adopters the average IRR was 102.60%, and 70.58% of the producers had an IRR greater than the discount rate (12%). This implies that irrigation has had higher returns than the cost of capital. Among non-adopters the IRR average estimated was lower, 48%, and 45.31% of the farmers exceeded the cost of capital, 12%.

[Figure 7]
[Table 6]

We also estimated the payback period, displayed in Table 7. For adopters, the average of years to pay back the investment was five years and by the 15\textsuperscript{th} year, 91.18% of the producers had completed payback. For non-adopters, we estimate that the payback would average 5 years, but only 73.44% would complete payback by the 15\textsuperscript{th} year.

[Table 7]

Although most of the irrigation adopters presented a positive NPV (70.58%) and IRR higher than the cost of capital (70.58%), others did not. We performed three extra analyses on NPV aiming to identify the reasoning behind the negative NPV obtained by some farmers. First, we evaluated the NPV at lower discount rates. We did not find a significant change when decreasing

\textsuperscript{16} An exchange rate of December 2014 was used – US$ 1 equals to R$ 2.639.
the discount rate. For a rate of 0.05 (5%), the number of farmers with a positive NPV increased only 2.95% (one farmer).

Second, as suggested previously, low orange prices of 2013/14 might have negatively affected the outcome of this analysis. At a 12% discount rate and using the average orange price for irrigation adopters with a positive NPV (US$ 3.90 per box) instead of the price reported by the farmer, the number of farmers with a positive NPV increased 5.9% (two farmers). With both average price and a lower discount rate (5%), still only two more farmers would have a positive NPV. At the maximum orange price obtained by the farmers (US$ 8.81 per box) and a discount rate of 12% all farmers but one would present a positive NPV.

Third, we analyzed these results by the farm size. At a discount of 12% and observed orange prices, positive NPVs were obtained for 100% of large, 66% of medium and 60% of small farms. Reducing the discount rate to 5% affects only one small farm, while changing the average price affects both one small and one medium sized farm.

Based on the outcome of these tests, we conclude that orange price has a much higher impact on the viability of the project than the discount rate, and that the payoff for small and medium farms is noticeably lower than for large farms.

Overall, we found profitability on irrigation implementation. We can observe that for the adopters the investment on irrigation was more profitable than for non-adopters, suggesting that farmer awareness of these circumstances has influenced their decision in adopting this technology.

5. Conclusions

This paper evaluates the costs and benefits of irrigation in orange production in the state of Sao Paulo obtained by estimating the production technology of these orange producers. We simultaneously estimated system of equations including a translog production function and the corresponding shares of labor, capital and fertilizer. The results show a 19% increase in per hectare yields under irrigation.

17 Small farms have between 0 to 20,000 trees, medium farms have 20,001 to 100,000 and large farms are more than 100,001 trees.

18 In our application of NPV the orange price did not vary, it was constant over the fifteen years. It is important to have this information in mind when interpreting the results. A changing price (future prices) would affect the NPV calculation.
We simulated adopters’ investment returns, assuming a 19% increase in reported yield, with prices and input quantities reported by the respondent, projected the cash flow annually for 15 years, at a discount rate of 12%. More than seventy percent of the 34 NPVs exceeded zero, and the overall average NPV was R$1,435.71/ha; 70.58% of the IRRs exceeded 12%, with an average IRR of 102.60%; and the average payback period was 5 years. Thus we conclude that the irrigation investment has been a profitable one for most Sao Paulo orange producers. However, we also estimated that it would have been profitable for many non-adopters, as well. Using the same 19% yield improvement and estimated investment, fixed and variable costs of the adopters, we estimate that 46.75 % would obtain a positive NPV from adoption.

References


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Figure 1 – Surveyed region (red circles) in the state of São Paulo, Brazil. 
Note: Darker yellow represents higher orange production areas within the state of Sao Paulo. 
Source: Souza Filho et al. (2013).

Figure 2 - Stratification of the sample by size of the adopters and non-adopters of irrigation, orange producers, Sao Paulo-Brazil 
Source: Souza Filho et al. (2013).
Figure 3 – Average productivity (boxes of oranges/tree) of each category of orange producers, Sao Paulo-Brazil
Source: Souza Filho et al. (2013).

Figure 4 – Average productivity (boxes of oranges/hectare) of each category of orange producers, Sao Paulo-Brazil
Source: Souza Filho et al. (2013).
<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-Irrigation Adopter ($N = 64$)</th>
<th>Irrigation Adopter ($N = 34$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Labor (1000 hours)</td>
<td>5.57</td>
<td>8.59</td>
</tr>
<tr>
<td>Labor expenses (R$ 1000)</td>
<td>44.90</td>
<td>63.62</td>
</tr>
<tr>
<td>Capital (machines – 1000 hours)</td>
<td>2.09</td>
<td>2.15</td>
</tr>
<tr>
<td>Capital expenses (R$1000)</td>
<td>37.09</td>
<td>40.78</td>
</tr>
<tr>
<td>Fertilizer (NPK - ton)</td>
<td>46.18</td>
<td>61.367</td>
</tr>
<tr>
<td>Fertilizer expenses (R$ 1000)</td>
<td>52.57</td>
<td>69.70</td>
</tr>
<tr>
<td>Area of orange production (hectares)</td>
<td>79.93</td>
<td>107.56</td>
</tr>
<tr>
<td>Orange (1000 boxes)</td>
<td>46.78</td>
<td>64.84</td>
</tr>
<tr>
<td>Orange revenue (R$ 1000)</td>
<td>444.99</td>
<td>763.25</td>
</tr>
</tbody>
</table>

*Source: Souza Filho et al. (2013)*
Table 2 – Descriptive statistics of variables used in Equation (5), orange producers in Sao Paulo, Brazil

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall Mean (N=98)</th>
<th>Non-Irrigation Adopter (N = 64)</th>
<th>Irrigation Adopter (N = 34)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>$\log (\text{Labor/area})$</td>
<td>4.322677</td>
<td>4.286124</td>
<td>0.615744</td>
</tr>
<tr>
<td>Share of labor</td>
<td>0.196499</td>
<td>0.194637</td>
<td>0.185081</td>
</tr>
<tr>
<td>$\log (\text{Capital/area})$</td>
<td>3.416246</td>
<td>3.449069</td>
<td>0.545072</td>
</tr>
<tr>
<td>Share of Capital</td>
<td>0.172074</td>
<td>0.197646</td>
<td>0.275398</td>
</tr>
<tr>
<td>$\log (\text{Fertilizer/area})$</td>
<td>6.332954</td>
<td>6.319816</td>
<td>0.544036</td>
</tr>
<tr>
<td>Share of Fertilizer</td>
<td>0.204914</td>
<td>0.223001</td>
<td>0.291007</td>
</tr>
<tr>
<td>$\log (\text{Orange/area})$</td>
<td>6.288331</td>
<td>6.203311</td>
<td>0.463196</td>
</tr>
</tbody>
</table>

Note: Irrigation is a dummy variable which assumes value equal for irrigation adopters – its overall average is 0.34.
Source: Souza Filho et al. (2013)
**Figure 5** – Total expenditure for labor, capital and fertilizer, and revenues from sales by size and irrigation adoption, orange producers in Sao Paulo-Brazil

**Source:** Souza Filho et al. (2013)
Table 3 – Parameters estimates for the system of equations for 98 orange producers in Sao Paulo, Brazil, 2014.

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production function</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>0.6383</td>
<td>0.2446</td>
</tr>
<tr>
<td>Labor</td>
<td>0.7683</td>
<td>0.2302</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.0887</td>
<td>0.5823</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>0.3944</td>
<td>0.2879</td>
</tr>
<tr>
<td>Labor(^2)</td>
<td>0.0682</td>
<td>0.0241</td>
</tr>
<tr>
<td>Capital(^2)</td>
<td>0.1220</td>
<td>0.0276</td>
</tr>
<tr>
<td>Fertilizer(^2)</td>
<td>0.0753</td>
<td>0.0311</td>
</tr>
<tr>
<td>Capital x Labor</td>
<td>-0.0909</td>
<td>0.0211</td>
</tr>
<tr>
<td>Capital x Irrigation</td>
<td>0.00109</td>
<td>0.0423</td>
</tr>
<tr>
<td>Capital x Fertilizer</td>
<td>-0.0793</td>
<td>0.0229</td>
</tr>
<tr>
<td>Labor x Fertilizer</td>
<td>-0.0921</td>
<td>0.0215</td>
</tr>
<tr>
<td>Labor x Irrigation</td>
<td>0.0346</td>
<td>0.0401</td>
</tr>
<tr>
<td>Fertilizer x Irrigation</td>
<td>-0.0083</td>
<td>0.0466</td>
</tr>
<tr>
<td>Constant</td>
<td>0.9364</td>
<td>1.6832</td>
</tr>
<tr>
<td><strong>Share equation: Capital</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>0.1220</td>
<td>0.0276</td>
</tr>
<tr>
<td>Labor</td>
<td>-0.0909</td>
<td>0.0211</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>-0.0793</td>
<td>0.0229</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.0010</td>
<td>0.0423</td>
</tr>
<tr>
<td>Constant</td>
<td>0.6383</td>
<td>0.2446</td>
</tr>
<tr>
<td><strong>Share equation: Labor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>-0.0909</td>
<td>0.0211</td>
</tr>
<tr>
<td>Labor</td>
<td>0.0682</td>
<td>0.0241</td>
</tr>
<tr>
<td>Fertilizer</td>
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<td>0.0215</td>
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<tr>
<td>Irrigation</td>
<td>0.0346</td>
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</tr>
<tr>
<td>Constant</td>
<td>0.7683</td>
<td>0.2302</td>
</tr>
<tr>
<td><strong>Share equation: Fertilizer</strong></td>
<td></td>
<td></td>
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<td>0.0229</td>
</tr>
<tr>
<td>Labor</td>
<td>-0.0921</td>
<td>0.0215</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>0.0753</td>
<td>0.03116</td>
</tr>
<tr>
<td>Irrigation</td>
<td>-0.0083</td>
<td>0.04669</td>
</tr>
<tr>
<td>Constant</td>
<td>0.3944</td>
<td>0.28793</td>
</tr>
</tbody>
</table>

Source: Own elaboration.
Table 4 – Production elasticities for orange producers in Sao Pablo, Brazil, 2014

<table>
<thead>
<tr>
<th>Production Elasticity</th>
<th>Average and (s.e.) (N = 98)</th>
<th>Average and (s.e.) for adopter (N = 34)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital</strong></td>
<td>0.1597*** (0.0362)</td>
<td>0.1446*** (0.0406)</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>0.1814*** (0.0341)</td>
<td>0.2121*** (0.0385)</td>
</tr>
<tr>
<td><strong>Fertilizer</strong></td>
<td>0.1995*** (0.0397)</td>
<td>0.1945*** (0.0446)</td>
</tr>
<tr>
<td><strong>Irrigation</strong>a</td>
<td>0.1918** (0.088)</td>
<td>0.1918** (0.088)</td>
</tr>
<tr>
<td><strong>Land</strong></td>
<td>0.3927*** (0.0996)</td>
<td>0.2567* (0.1234)</td>
</tr>
</tbody>
</table>

Note: a Irrigation production elasticity is for farmers that own an irrigation system (34 observations)
Source: Own elaboration.

Figure 6 – Share of farmers with positive NPV, by number of years the project continues, for orange producers in Sao Paulo-Brazil
Source: Own elaboration.
Table 5 - Net Present Value (NPV) estimations for adopters and non-adopters of irrigation, orange producers in Sao Paulo, Brazil

<table>
<thead>
<tr>
<th>Investment analysis method</th>
<th>Non-Irrigation Adopter (N = 64)</th>
<th>Irrigation Adopter (N = 34)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of producers with NPV &gt; 0</td>
<td>46.75</td>
<td>70.58</td>
</tr>
<tr>
<td>Average NPV</td>
<td>64,808.95</td>
<td>182,493.71</td>
</tr>
</tbody>
</table>

Source: Own elaboration.

Figure 7 – Share of farmers categorized by the level of Internal Rate of Return for orange producers in Sao Paulo-Brazil

Source: Own elaboration.
Table 6 - Estimates of Internal rate of return (IRR) over 15 years, for adopters and non-adopters of irrigation, orange producers in Sao Paulo, Brazil

<table>
<thead>
<tr>
<th>Investment analysis method</th>
<th>Non-Irrigation Adopter ((N = 64))</th>
<th>Irrigation Adopter ((N = 34))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of producers with IRR &gt; 0%</td>
<td>51.56</td>
<td>79.41</td>
</tr>
<tr>
<td>Percentage of producers with IRR &gt; 12%</td>
<td>45.31</td>
<td>70.58</td>
</tr>
<tr>
<td>Average IRR (%)</td>
<td>48.00</td>
<td>102.60</td>
</tr>
</tbody>
</table>

Source: Own elaboration

Table 7 - Estimates of payback period for adopters and non-adopters of irrigation, orange producers in Sao Paulo, Brazil

<table>
<thead>
<tr>
<th>Investment analysis method</th>
<th>Non-Irrigation Adopter ((N = 64))</th>
<th>Irrigation Adopter ((N = 34))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of producers with payback by the 15(^{th}) year</td>
<td>73.44</td>
<td>91.18</td>
</tr>
<tr>
<td>Average number of years to pay back the project*</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: * We considered a payback period of 20 years for producers whose payback period was negative in all 15 years of the project.

Source: Own elaboration.