Agriculture and Climate: Short and Long-term Implications from Brazilian Municipalities

Prof. M. Sc. Paula Carvalho Pereda (paulapereda@gmail.com)
Phd Candidate/Temporary Professor at School of Economics, University of São Paulo
Av. Prof. Luciano Gualberto, 908, FEA I / Room 123-c
05508-900 – Cidade Universitária, São Paulo, SP – BRAZIL

Prof. Dr. Denisard Alves, *(dcoalves@usp.br)*
Full Professor at School of Economics, University of São Paulo
Av. Prof. Luciano Gualberto, 908, FEA I
05508-900 – Cidade Universitária, São Paulo, SP – BRAZIL

Resumo: Este estudo analisou os efeitos das mudanças climáticas e da variação do clima nos lucros agrícolas dos municípios brasileiros. Os objetivos foram avaliar as potenciais medidas de adaptação para efeitos de mudança de longo prazo do clima e o tamanho de ineficiência causada por eventos climáticos extremos. As contribuições são tanto com relação à medição de tais efeitos do clima quanto na incorporação de instrumentos de política na análise empírica de fronteira estocástica na função lucro. De acordo com as estimativas, o uso de instrumentos tecnológicos, tais como sementes GTO, gado confinado e plantio direto podem ser importantes de medidas de adaptação às mudanças climáticas que serão observadas. Quando se trata de efeitos de curto prazo no clima, a vulnerabilidade climática pode ser reduzida a partir do uso de técnicas como a irrigação. Há fortes evidências de que a associação de cooperativas também traz benefícios técnicos de curto prazo para os agricultores.

Abstract: This study analyzed the effects of climate change and climate variation on agricultural outputs. The objectives were to measure the potential adaptation measures for climate change effects on agriculture and the size of inefficiency caused by climate extreme events. The contributions are both the measurement of climate effects on agricultural profits and incorporation of policy instruments on the empirical analysis derived from a profit frontier approach. The main result derives from the estimated effects of long-run changes in climate on agriculture. According to the estimates, use of technological instruments such as GTO seeds, confined cattle and tillage might be important adaptation measures to climate changes that will be generated. When it comes to the short-term climate effects most of this vulnerability might be reduced from the use of techniques such as irrigation. The association to cooperatives also brings technical benefits for the farmers.

Palavras-chave: variabilidade climática, adaptação a mudanças climáticas, modelos de fronteira de lucro, eficiência técnica.

Key words: climate variability, climate change adaptation, profit frontier model, technical efficiency

Área ANPEC: Área 10 - Economia Agrícola e do Meio Ambiente

Classificação JEL: Q51, Q54, Q55, D24

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Abstract

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1 Introduction

According to the United Nations, the world population might reach approximately 10.6 billion people by 2050. Two main problems arise from the expected population growth: I) Aggravations of environmental problems as the carbon emissions increase proportionally with population growth; and II) Expected pressure on basic resources: water; land; energy; and food. When it comes to food demand problem, for example, given the pessimist assumption for population growth by 2050, the farmers of the globe would have to increase from 70 to 100% the food production in order to attend the global latent demand for food[1]. The agricultural sector will be challenged to ensure the food security of an increasing global population.

Simultaneously, many researchers believe that average global crop production may not change dramatically till 2050 and some regions may even observe reductions in production due to increased climate variability and extreme weather shocks [IPCC 2001 and 2007; Rosenzweig and Tubiello 2006][2].

The agriculture is one of the most climate vulnerable sectors in the world. It is widely known that the climate alterations are accelerated by the anthropogenic factors[3]. Thus, it is essential to be aware of the implications of climate in order to plan the measures to adapt to the new climate conditions and, at the same time, ensure the food supply for the

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[1] Calculations based on FAO (www.fao.org/docrep/014/am947e/am947e00.pdf); and USDA (www.usda.gov/oce/weather/Private/Murcia Proceedings-FINALwCovers.pdf). Accessed on May, 2012.

[2] The Fourth (Fifth) Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicated that the world has been suffering more from droughts during the past decades and climate projections suggest that this trend will become more frequent in the near future.

[3] The emission of (GHG) of the industries, as the most common example, is considered as a negative externality, causing important inefficiencies not accounted by the markets. Negative externalities increse the social costs of the markets and should be accounted when the production decision is made. The microeconomic theory points out that the new production equilibrium is reduced by the presence of negative externalities [Pindyck and Rubinfeld, 2002].

increasing global population. Within this context, an important question to be addressed by this study is:

How can agriculture adapt to deal with the changes in climate that could be an obstacle to meet the future demand for food?

One of the objectives of this study is the measurement of the consequences of this externality in rural markets: agriculture; and livestock. They are measured as economic costs or damages to rural markets from climate change and climate variability in terms of farmers' profits.

Mapping the climate effects on agriculture and the potential adaptation actions became an important issue to governments, making the climate change debate moves from scientific circles to policy circles [Kumar, 2009]. Within this context, it is observed that governments are struggling in direction to policy responses to mitigate the greenhouse gases (GHG) emissions and to adapt to the impacts of climate.

The economics relevance on the issue is that it provides useful perspectives and theoretical tools to identify and measure opportunity costs and policy questions related to this matter. As stated by Adams (1989), economics is very useful in guiding to issues related to climate change adaptation measures.

An important caveat must be done: this study will only analyze the climate effects on agricultural and livestock profits, although it is known that agriculture and livestock are important GHG emitters. Therefore, the analysis is restricted to issues of adaptation, and not mitigation of climate changes.

In order to discuss and analyze the climate effects on agriculture and livestock, and the possible actions to reduce the latent problems, this study will disaggregate the analysis into five steps: (i) Evaluation of the impacts of climate on agricultural profits; (ii) Estimation of the expected effects of climate change on agricultural profits (assuming no adaptation); (iii) Analyze the effects of possible adaptations actions; (iv) Evaluation of the impacts of weather changes (short-term climate deviations) on profits deviation from the optimal; (v) Analyze the effects of potential farmer's actions to compensate weather changes from the expected.

This analysis will be applied to Brazilian agriculture and livestock. Besides Brazilian relevance in global grain exports market[4], the fact that Brazil is a continental-proportions country facilitates the identification of climate effects on agricultural production, due to the great climate variability observed inside the country[5].

2 Literature Review

The literature review was divided into two subsections. The first presents the agricultural approach focusing on the discussion of the technical and profit inefficiency methodology within the context of agriculture. The second subsection explains how climate impacts on agricultural production and profits, which will be essential to include climate variables into the agricultural model. This literature review will base the modeling approach used in the subsequent section.

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[4] Brazil is one of the main grain producers in the world: in 2009/2010, the country was responsible for 5.8% of total grains exports, and in 2010/2011, this rate was about 4.01%[Internat. Grains Council, 2012].
[5] However, the methodology to be presented in this study can be applied to any country where the necessary information is available.

2.1 Efficiency and climate impacts in agriculture: Profit vs Production Function

An important issue that arises from agricultural production analyses is the efficiency of outputs and inputs usage considered into those models [Ozkan et al, 2009]. The producer facing exogenous relative prices achieves maximum efficiency at output-input on the profit frontier. Assuming that the right relative prices are observed by the farmers, all the profits deviation from optimal (frontier) are considered inefficiency from technical issues (technical inefficiency).

Thus, the efficiency analysis helps to identify variations of the physical and financial performance achieved by farmers operating with same environmental and economic constraints. The identification of these variations (inefficiencies), allows the study of possible determinants of farmers' deviations from optimum choices[6]. Ozkan et al (2009) provided a complete survey of the studies concerning the measurement of efficiencies in agriculture using agro-economic models.

Complementarily, Ali and Flinn (1989) argue that, in order to measure efficiency, a production function approach may not be appropriate when the population of farmers face different prices and have different factor endowments. When facing heterogeneous farmers, the authors argue in favor of stochastic profit function models[7]. According to Kumbhakar and Lovell (2000), the profit analysis offers a more complete approach as it characterizes better the production structure and technologies. Thus, this approach generates what is called "profit efficiency", which is defined as the ability of a farm to achieve highest possible profit (on the profit frontier) given the output and input (netputs) prices and levels of fixed inputs of that farm (Ali and Flinn, 1989).

The profit frontier approach, besides providing a compact form to summarize a multiproduct technology, is an efficient way to introduce the theoretical constraints from theory [Mundlak, 2001]. The approach allows the measurement of a profit inefficiency measure, which captures the farmers fail to meet the production plan defined[8].

2.2 Effects of climate on agricultural activity

Climate and farming activity have a two-way causal relationship [Dale, 1997]. On the one hand, agricultural activity influences the flow of mass and energy in the atmosphere. As land use patterns change, these flows are altered, changing the climate[9]. On the other hand, and more important for this study analysis, climate change affects directly agricultural activity.

When it comes to this latter effect of climate on agricultural production, climate is considered as a key input for crops, forests and livestock outputs production. Changes in climate not only influence directly crop growth (called "weather effect" from rainfall and temperature observed during the season), but also change the behavior of farmers in deciding the production structure as farmers take into account climate local patterns in deciding the input mix (called "climate effect" from expected rain and temperature locally) [Kumar, 2009]. This study will take into consideration both of the

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[6] See Bozoglu and Ceyhan (2006), Demir and Mahmud (2005), Rahman (2003), among others.

[7] See Ali and Flinn, 1989; Kumbhakar and Bhattacharya, 1992; Ali et al.,1994; and Wang et al., 1996.

[8] Those inefficiencies can be analyzed in the profit relationship (therefore both in output side and input side) controlling for differents prices and fixed inputs of the farmers. The errors/deviations in the production decision are assumed to be translated into lower profits for the producer (Ali et al., 1994).

[9] This study is not concerned with the first effect, as the analysis time window does not allow to identify the flows of agriculture changing the climate.

abovementioned effects of climate/weather on agriculture. Specifically, the analysis considers the following relationship between climate and agriculture and livestock:

- Average climate conditions are considered inputs in the production structure of farmers, as the producers considers the local climate patterns when deciding the use of inputs (fertilizers, labor force, irrigation and other inputs in the production) and the amount of outputs to be produced; and
- Short-term climate (weather) conditions are considered as shocks or deviations from average climate conditions. The shocks might result in harvest failures (or cattle loss, for example) or increases in crops and livestock yields, depending on the signal (negative or positive) and magnitude of the short-term weather deviation. Thus, short-term climate influences the farmer's actual profits.

Having those potential climate effects in my mind, the next sections present the theoretical and empirical model which supports the measurement of the relationships presented.

3 Profit Frontier and technical determinants

This section develops the profit frontier model and the subsequent model for profit inefficiencies determinants. At the end of the section, a discussion over the way agricultural prices must be added to the analysis is introduced in order to understand farmer's decision instruments when deciding to grow any specific crops.

3.1 Profit Approach: Profit function and Profit Inefficiency

The profit approach is a partial equilibrium model founded on the microeconomics production theory. By specifying profits, it is possible to obtain the farmer's optimal input-output allocation by optimizing profits choosing the farmers allocation. It is assumed that producers allocate their *g* variable inputs for *s* types of production. The number of outputs plus the number of inputs represent the *m* products considered in the analysis (namely, *netputs*), such that *m = s + g*.

The producers decide the amount of production and the amount of inputs to be purchased by solving a variable profit maximization problem in a competitive market. Thus, prices are considered as taken/exogenous. Besides the prices of inputs and outputs, *p = (p₁,...,pₘ)'*, each producer faces quasi-fixed inputs (exogenous variables for the time window considered[10]) represented by $Z = (Z_{1, ..., } Z_f)'$ which significantly affect the production and factor decision, *q = (q₁,...,qₘ)*'[11]. Thus, the farmer's optimization problem can be described by the following expression:

$$Max_{\{q_1,...,q_m\}} \sum_{j=1}^{m} \Pi_j(p, q, Z), \text{ subject to a technology } F(q) \leq 0 \quad (1)$$

In which *F(.)* represents a production function that transforms inputs into outputs. Producers maximize a short-run profit function (or restricted profit function) by choosing multiple outputs and inputs allocation given an endowment of fixed factors (fixed in the short-run), prices and time, *Z,* and *p*[12]. The solution of the equation (1)

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gives the optimal allocation, $q*$, which depend on prices and on the fixed factors[13]: $q_j^*(p, Z)$, $j=1, ... , m$. By replacing the optimal solution with the profit function, the optimal profit function becomes:

$$\Pi^*(p, Z) = ArgMax_{\{q\}} \sum_{j=1}^{m} \Pi_j(p, q, Z) \quad (2)$$

The profit function is a value function depending on the exogenous variables: prices; and other quasi-fixed inputs. As already mentioned, prices are exogenous as the approach considers that the farmers are price-takers and agricultural markets are perfect (no losses due to technical changes), then the farmers are assumed to be fully efficient in optimizing profit (Eaton and Patagariya, 1982).

By using the same approach but relaxing the assumption of no-inefficiency, Kumbhakar and Lovell (2000) discussed that a profit efficiency measure (PE), which can be described as the ratio of the actual profit in terms of the potential maximum profit. The idea behind the deviation of the fully efficiency is that the inefficient farmers can survive in the short-run. Considering that farmers face the right relative prices, the inefficiency might arise for technical issues: the producers do not achieve the maximum profit they could achieve, because they employ more of an input or produce less of an output than a hypothetically fully efficient producer [Berger et al, 1993].

Considering the potential technical inefficiencies (τ) into the model and assuming the widely used transcendental logarithm (translog) function for the farmer's restricted profit function [first proposed by Christensen et al, 1972; and Lau, 1973]:

$$\ln\left(\frac{\Pi}{p_1}\right) = \beta_0 + \sum_{j>1} \beta_j ln(p_j/p_1) + \frac{1}{2}\sum_{j>1}\sum_{k>1} \beta_{jk} ln(p_j/p_1)ln(p_k/p_1)$$
$$+ \sum_{j>1}\sum_{r=1}^{f} \gamma_{jr}Z_{jr}ln(p_j/p_1) + \sum_{r=1}^{f} \delta_r Z_r$$
$$+ \frac{1}{2}\sum_{h=1}^{f}\sum_{r=1}^{f} \theta_{hr}Z_h Z_r - \tau \quad (3)$$

In which $j, k = 1, ..., m; r, h = 1, ..., f$; and $\beta, \delta, \theta, \gamma$, and τ are parameters vectors. The normalization in product 1 guarantees the homogeneity assumption in the prices. Young theorem holds with this profit function, guaranteeing the symmetry assumption under the existence of the twice differentiation of the Π^*. This specification is called *translog* frontier profit function[14]. The model is adopted from Rahman (2002, 2003) with some modifications. Using duality in production theory and the Hotelling Lemma, the output and input profit shares (s_j) can be written as follows[15]: $s_j = \frac{p_j q_j}{\pi} = \beta_j + \sum_{k>1}\beta_{jk}ln(p_k/p_1) + \sum_{r=1}^{f}\gamma_{jr}Z_{jr}$, $j=2,...,m$. The form of the elasticities can be calculated by a linear combination of coefficients and observed variables[16].

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[13] The results depend on the regularity conditions of the profit function, which guarantee the existence of an optimum. The regularity conditions are the homogeneity and convexity of profits in prices.

[14] The normalized translog functional form is locally flexible and generates closed form solution. It also allows the testing of profit convexity on prices, which means that the matrix of $\beta = [\beta jj]$ is positive semidefinite for $j = 1,…,m$. The prices and other exogenous variables effects can be measured by the elasticities

[15] This lemma presumes that the profit function is differentiable.

[16] Own-Price Elasticities (netput j): $E_{jj} = s_j - 1 + \beta_{jj}/s_j$; Cross-Price Elasticities (netput k on j): $E_{jk} = s_k - 1 + \beta_{jk}/s_j$; Exog. Variables Elasticities: $E_{jr} = z_r(\delta_r + \sum_{j>1}\gamma_{jr}Z_{jr} + \frac{1}{2}\sum_{h=1}^{f}\theta_{hr}Z_h + \frac{\gamma_{jr}}{s_j})$.

The main advantage of using the normalized translog functional form is the possibility to easily test convexity and to assume linear homogeneity and symmetry directly. These hypotheses are sufficient conditions to ensure that the producers are maximizing profits and the maximum exists [Diewert, 1973]. This functional form also allows the measurement of technical efficiency radially, then profit losses can be calculated independently on the units of measurement [Kumbhakar and Lovell, 2000]. At that juncture, the technical inefficiency term measures the failure to reach the desired level of profit. Then, the total inefficiency is characterized by the loss of profits from not producing the desired levels (or overusing inputs) and it is obtained by comparing profits with technical inefficiency and without it:

$$PE(q, p, Z) = \frac{\Pi^*(p, Z, \tau)}{\Pi^*(p, Z, \tau = 0)} \qquad (4)$$

Where $\Pi^*(p, Z, \tau = 0)$ can be obtained from replacing $(\tau = 0)$ in equation (3).

Despite the theoretical advantages of the profit frontier approach, it is important to consider the potential negative bias of the estimation, since this approach disregards the farmers' possible compensatory responses to climate variations, as emphasized by Féres et al. (2008)[17]. Moreover, the technical inefficiency measure, as Berger et al (1993) point out, might also include idiosyncratic factors not included in the model (input quality, for example). Therefore, the profit frontier equation can be estimated imposing the symmetry and homogeneity assumptions. The estimation procedures and empirical hypothesis will be further developed.

3.2 Technical Inefficiency Determinants

Once the profit inefficiency is identified, the analysis regarding the determinants of such inefficiencies arises. One of the most important works on technical inefficiency determinants is the Battesi and Coelli (1995), which strongly influenced the agricultural studies on this subject. The authors consider the technical efficiency as a function of exogenous variables, most related to farmers' characteristics.

Many of the applied studies in the field identified farmer' education and other household characteristics as the main factors influencing the technical inefficiency[18]. Farm size, distance to markets, and infrastructure are also emphasized on explaining the difference in efficiency among farms[19].

When it comes to the accountability of climatic variables, Sherlund et al (2002) found that the exclusion of those variables in agricultural model might lead to biased parameters by using a production function model applied to Cotê d'Ivore. Furthermore, Demir and Mahmud (2005) included environmental factors for explaining efficiency differences. The authors emphasized that the omission of climatic variables, under the argument that they are beyond farmer's control, may lead to inaccurate interregional technical inefficiency comparisons. By estimating the technical inefficiency model using a translog stochastic frontier production function for Turkish farmers, they showed that not only that the agro-climatic variables are statistically significant but also

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[17] According to the authors, farmers may alter their use of inputs or change their crops mix due to changes in climate and since farmers' adaptations are constrained in the production approach, the estimates might be biased downward.

[18] Xu and Jeffrey, 1998; Abdulai and Huffman, 1998; Bhasin, 2002; Rahman, 2003; Kolawole, 2006; and Bozoglu and Ceyhan, 2006.

[19] Xu and Jeffrey, 1998; Tzouvelekas et al, 2001; Bhasin, 2002; Rahman, 2003; and Bozoglu and Ceyhan, 2006.

that their omission substantially affects mean output elasticities and relative technical efficiencies. They considered that technical inefficiency is a function of land quality and ownership, general cropping pattern, and an anomaly in rainfall (rainfall above the national average).

Based on Battese and Coelli (1995) and Demir and Mahmud (2005), the model for the profit efficiency (PE) determinants can be described as[20]:

$$PE_i^{Index} = \alpha D_i + \varepsilon_i \qquad (5)$$

Where: ε_i is a random shock with positive distribution; D_{it} is a matrix of determinants (farmers' characteristics, local accessibility and infrastructure measures, climate anomaly variables, credit use opportunity, and information about farmer's use of adaptation measures).

According to Gorton and Davidora (2004), the determinants can be divided into two groups: human capital; and structural effects. The former includes information on the farmer's management, their characteristics and education and the latter comprises environmental conditions, credit access and information on property rights. The dependent variable is limited to the range of [0,1], implying the use of specific econometric techniques, which will be discussed further.

3.3 Note on the Agricultural prices

Agricultural prices are an important issue when it comes to the farmer's decisions. Due to the different time window between the decision to grow the crop, the harvest, and the production selling, the farmers must have price expectations (p_t^e) when deciding the crop amount to grow. Thus, the farmer's optimization problem takes into account p^e instead of p.

The formulation for the expectation means that farmers use available information (in t-1) in order to form expectations over the crop prices in t. Several studies tried to attain the price expectation problem using adaptive and rational expectations modeling found that the use of future prices[21], for some agricultural commodities, performed better than econometrically based forecasts[22]. The problem with future prices is that they do not exist for all prices and also do not offer any regional variation.

Barbosa (2011), studying the land-use pattern in Brazil, used a model assuming that the farmer' price expectation is the average of real prices observed in the five years before the farmer decision, which is an approach more closely related to adaptive expectations over past prices. This study will test Barbosa's prices and will also consider an improvement of the weighting process of Barbosa (2011) by modeling each crops prices using a dynamic model using panel data from the Pesquisa Agricola Municipal (PAM)[23] and estimating by Arellano-Bond.

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[20] In general, the results of the determinants of inefficiency showed no systematic differences between the stochastic production function and stochastic profit frontier studies. However, production frontier approaches are more used when the sample of farmers is not very heterogeneous, as expected. Most of the results differences are mostly due to the distinct specifications among the studies.

[21] Pastore, 1968; Nerlove (1956); Castro, 2008; Nerlove and Formari, 1998]. Just and Rausser (1981) [apud Lovell and Fornari, 1995.

[22] Performance was measured in mean square error terms.

[23] This Survey (PAM) is an annual agricultural research conducted by IBGE that collects physical and monetary agricultural production in the country.

4 Estimation Strategy

The estimation of the profit frontier will be discussed next, detailing the econometric hypothesis behind the procedure. The following subsection describes how climate information is included, both long-term and short-term variables, into the model. The measurement of adaptation technologies and techniques is presented subsequently.

4.1 Profit frontier estimation

In order to estimate the parameters of the profit frontier equation, an error component (v) is added to equation 3, leading to the following equation to be estimated:

$$
\ln\left(\frac{\Pi_i}{p_{1,i}}\right) = \beta_0 + \sum_{j>1} \beta_j \ln\left(\frac{p_{j,i}}{p_{1,i}}\right) + \frac{1}{2}\sum_{j>1}\sum_{k>1} \beta_{jk} \ln\left(\frac{p_{j,i}}{p_{1,i}}\right) \ln\left(\frac{p_{k,i}}{p_{1,i}}\right)
$$
$$
+ \sum_{j>1}\sum_{r=1}^{f} \gamma_{jr} Z_{jr,i} \ln\left(\frac{p_{j,i}}{p_{1,i}}\right) + \sum_{r=1}^{f} \delta_r Z_{r,i}
$$
$$
+ \frac{1}{2}\sum_{h=1}^{f}\sum_{r=1}^{f} \theta_{hr} Z_{h,i} Z_{r,i} - \tau_i + v_i \qquad (3)'
$$

In which i represents the farmers, such that $i = 1, \dots, T$. Note that τ is a positive component that shifts the profit from the optimum, given the reasons discussed in the former sections. In order to estimate this equation, Kumbhakar and Lovell (2000) suggested a Maximum Likelihood Estimation, using the probability density function (pdf) of the composite error, $y = -\tau_i + v_i$[24]. Suppose that v_i follows a normal distribution with mean zero and variance σ_v and that τ_i follows a normal distribution, positive and truncated at zero, with mean μ and variance σ_u[25]. Considering independence among the observation, the maximum likelihood procedure is implemented in Stata, generating the first results of inefficiency from the profit frontier approach.

4.2 Inclusion of climate variables in the model

The climate effect on agriculture will be divided into a long-term climate effect and a short-term climate effect. Following Kumar (2009), changes in climate influence both crop growth and producer's behavior. In order to account for these effects, it was defined:

i) *Climate long-term pattern*: Temperature and precipitation measures will be considered as fixed inputs in the profit function as the local climate pattern is observed for the farmers, having influence on their choices [Kumbhakar and Lovell, 2000; p. 262]. Demir and Mahmud (2005) argued that the local agro-climatic conditions are historically known and therefore should not be treated as random as they influence farmer's choice. Thus, climate patterns are included inside the Z

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[24] In addition, the parameter estimates are invariant to the equation dropped (product which is the normalizer) when the model is estimated by the maximum likelihood estimation method.

[25] By using the linear transformation of random variables [DeGroot and Schervish, 2002], the log-likelihood function for each y_i ($i = 1, \dots, n$) is: $lnL(\beta, \mu, \sigma_u, \sigma_v) = -\frac{1}{2}\ln(2\pi) - \frac{1}{2}ln(\sigma_u^2 + \sigma_v^2) - \frac{1}{2(\sigma_u^2+\sigma_v^2)}(y_i - \beta' x_i - \mu)^2 + ln\left[1 - \Phi\left((\sigma_u^2 + \sigma_v^2)^{-\frac{1}{2}}\left(-\frac{\mu\sigma_v}{\sigma_u} - (y_i - \beta' x_i)\frac{\sigma_u}{\sigma_v}\right)\right)\right] - ln\left[1 - \Phi\left(-\frac{\mu}{(\sigma_u^2+\sigma_v^2)^{\frac{1}{2}}}\left(\left(\frac{\sigma_u}{\sigma_v}\right)^{-2} + 1\right)^{\frac{1}{2}}\right)\right]$

vector in Equation 3. The climate information will account the 30-year average of historical data, to compute the current climate pattern for each farmer. The mean was calculated for each season, giving the long-term seasonal mean;

ii) *Climate short-term shocks (weather change)*: Climate short-term shocks will be considered as responsible for deviating farmers from equilibrium (in terms of production and of input demand). Therefore, these variables can be considered as important determinants of the farmer's technical efficiency. Thus, climate shocks are included inside the *D* vector in Equation 5. The shocks will be calculated as the current year anomalies in temperature and precipitation by farmer and season in a year. Anomaly is defined as the difference between the current observed value and the long-term average mentioned above[26].

5 Data

The Brazilian crop and livestock production are mainly divided between two regions: the temperate region (mostly temporary crops), covering the South and Southeast regions, and the tropical Midwest region (mostly livestock). There are also different farming and livestock patters within each of these regions.

Overall in Brazil, 41.8% of farms are focused on livestock production and 50.4% on growing crops (both permanent and temporary crops). There are more than 3.6 million farms. When it comes to the total revenue by type of product, temporary crops is the group generating the highest farm income, followed by livestock and permanent crops. Temporary crops account for more than 85% of the crop planted area in the country.

5.1 Agricultural data

Cross-section data from Brazilian Agricultural Census of 2006 was used as empirical support in this study. The agricultural census in Brazil is produced by the Brazilian Institute of Geography and Statistics (IBGE). Panel data was not used because of data incompatibility between the last two agricultural censuses carried out in Brazil (2006 and 1995/96's Census)[27].

The unit of analysis was Brazilian municipalities and farmers were aggregated into municipalities. The 2006 Census contains information on output quantities and values, input quantities and values, land type and use, investment values and information about the farmer, among others. The output products considered were divided into nine components of four groups: Temporary crops: soybeans; maize; other temporary crops; Permanent crops: coffee; and other permanent crops; Livestock: dairy and beef cattle; Planted forests: wood; and other forest products.

These products were chosen according to their weight in each group, in terms of production value. For the inputs chosen, the same criterion was used, selecting four inputs: land, and fuel (quasi-fixed inputs); and labor, and fertilizers as variable inputs. The total amount of fuel used in the farm can be considered a proxy for capital stock of the farm (Burniaux and Truong, 2002).

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[26] Those short-term variables can also be interpreted as extreme weather indexes, as anomalies are normally defined as the extremes of the distribution.

[27] Technological variables were not available in the 1995/96 Census.

The fuel variable was created based on the total fuel used by the farm. All types of fuel were converted into energy generation (in kcal), using the density and power capacity from Petrobras. Labor prices were calculated as the average rural wage equal to the sum of the farm workers' monthly wages divided by the number of workers.

The technological variables available at the Census were: Percentage of rural establishments that uses certified or transgenic seeds; Percentage of rural establishments with cattle confined; Percentage of rural establishments with livestock crawled; Percentage of rural establishments that uses techniques of artificial insemination in animals; and percentage of establishments that use the technique of tillage.

The farmer and farm characteristics considered were: Farmer education: the available information is the percentage of famers that completed each level of education (none or incomplete elementary, complete elementary school, high school, and college); Land type: percentage of degraded land in the municipality; percentage of agricultural land in the municipality; Farm size: average size of farms in the municipality.

5.2 Climate data

The climate historical data were obtained from the National Meteorology Institute (Portuguese acronym: INMET). The institute collects information about average, minimum and maximum temperature, total rainfall (in millimeters and rainy days) and relative humidity by weather stations.

To transform the data from the weather stations into municipal data, we used the kriging method of interpolation (Haas, 1990). This method assumes that each geographical coordinate is a realization of a spatial process. It allows the interpolation of data with flexibility to specify the covariance between the outputs.

The climate forecasts for Brazil are produced by CPTEC/INPE (the department of weather forecasting and climate studies of the National Institute for Aerospace Research). The forecasts are based on the ETA Regional Model for the South American region. This model is an atmospheric model based on surface pressure, horizontal wind components, temperature, specific humidity, turbulent kinetic energy and cloud hydrometeors. INPE base its predictions on two different Scenarios regarding 2070 to 2100.

5.3 Price information

Following a quasi-rational expectation procedure, as discussed before, and on the Brazilian literature on profit function estimations, three types of prices were calculated for the crops production in order to test the model:

- Estimated price: Calculated from a GMM procedure (Arellano-Bond Estimator) testing the lagged structure of price formation;
- Lagged price: Implicit prices in the previous year were generated by dividing the total production value by the total quantity produced;
- Average lagged price: Implicit prices for the five previous years were generated by averaging out the total production value by the total quantity produced among the five previous years.

The Appendix A presents the map of the prices distributions, which indicates that all three measures are close to the spatial distribution of the actual prices.

5.4 Descriptive Statistics

The profit by municipality was calculated using the total production generated by the municipality less the expenses with variable inputs (labor and fertilizer). The figure below shows the histogram of the variable both in level and in logarithm[28].
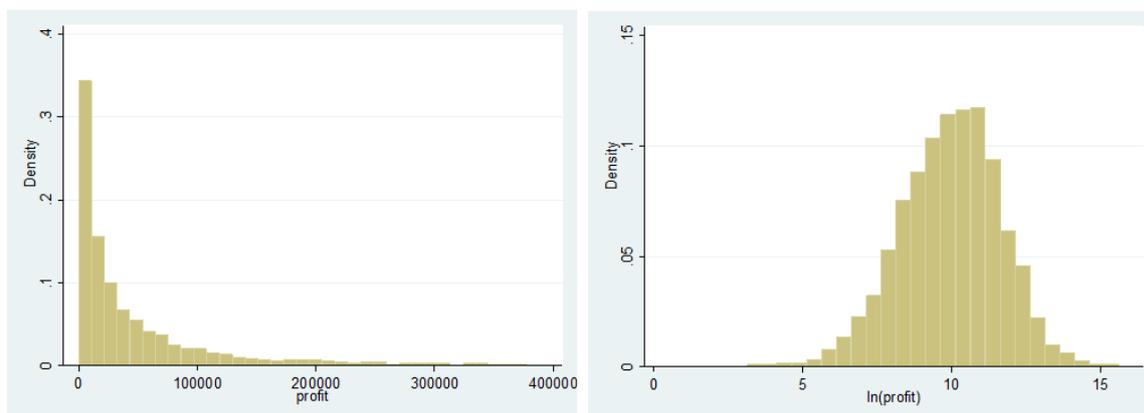

Figure 1 – Profit values (level and logarithm), in thousand reais, 2006 Census

The profit distribution indicates that a logarithm transformation of profits may adjust better the dependent variable. The translog functional form considers the logarithm operators in most of the variables, especially profits and prices[29].

Almost all quantities information are in tons, except from dairy production, which is expressed in thousand liters, and wood production, informed in thousand cubic meters of wood. When it comes to the inputs physical amounts, quantity of fuel (proxy for capital stock in the model) is measured in thousand kcal power, due to the units transformation of available information. Land quantity and fertilizers use are measured in hectares. Fertilizers were measured by land area fertilized. Labor amount is measured in terms of number of rural workers in the municipality.

The technological variables are measured by percentages, as the Census questionnaire only permits the farmers to answer if they have this kind of activity in the farm or not. The average percentage of farmers using certified seeds are about 30%. The analysis of the averages shows that, except for the use of certified seeds, almost all variables have a limited use in national farm properties.

The available data for farm characteristics shows the average size of farmers in the municipality and the usage of some techniques within the farm, such as irrigation and compost, pest control and usage of animals for transportation. Information regarding the association of farmers into cooperatives is also observed.

The farmer' characteristics available in the 2006 Census are mainly related to education. Dummies for the educational cycle of the farmer are available.

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[28] The graphic showing the levels of profits were restricted to 400 million reais. Above this value, 7% of the municipalities has profits equally distributed until 7 billion reais, making it difficult to visualize the distributional patterns.

[29] The tables for the descriptive statistics will not be exhibited due to lack of space, but comments regarding their values are included below. The tables are available if requested.

5.5 Climate description: 2005-2006

Since Brazil is a huge country in terms of area, the Brazilian climate varies considerably, from a mostly tropical area (northern part of the country) to temperate areas below the Tropic of Capricorn (southeastern and southern Brazil). The tropical area has higher temperatures and little variability during the year. Rainfall in Brazil has seasonal patterns, being heavier during the summer, from December to March.

On the other hand, the southernmost areas can have frosts/snowfall during the winter (June to September). The North region, which includes the Amazon Forest, is very humid, with rainfall reaching more than 3,000 mm per year. The rainy season also lasts longer in this region, contrasting with the climate of the neighboring Northeast region, where there are higher temperatures but less rainfall. The widespread semi-desert vegetation is a reflection of the climate pattern of this region.

When it comes to the climate observed in 2005 and 2006, which is considered to have affected the 2006 production, it is observed droughts in the southern region of the country (during summer, mainly). The amazon region also suffered with droughts in almost all seasons 2005, and so some northeastern states, together with Minas Gerais, whose droughts occurred in the summer of 2006.

Normally frosts are worse in the winter and on medium and high latitudes and on higher altitudes areas, mainly the south of Brazil and some higher areas in São Paulo state and Minas Gerais[30].

6 Preliminary Results

Long-term climate relevance

The Likelihood Ratio (LR) Test indicates that climate variables are relevant to explain farmers' profits[31]. The same test was performed for the technological variables, which also suggested that the technological variables are jointly significant to explain profits[32].

It is noteworthy that all the models estimated showed that technical inefficiencies are significantly different from zero, according to the LR test on the technical inefficiencies estimations. The final models include all variables to understand their impact on profits and to perform the potential compensation measures. It is noteworthy that this model only adds the exogenous variables iterated with prices.

$$\ln\left(\frac{\Pi_i}{p_{1,i}^e}\right) = \beta_0 + \sum_{j>1}\beta_j \ln\left(\frac{p_{j,i}^e}{p_{1,i}^e}\right) + \frac{1}{2}\sum_{j>1}\sum_{k>1}\beta_{jk}\ln\left(\frac{p_{j,i}^e}{p_{1,i}^e}\right)\ln\left(\frac{p_{k,i}^e}{p_{1,i}^e}\right)$$
$$+ \sum_{j>1}\sum_{r=1}^{f}\gamma_{jr}Z_{jr,i}\ln\left(\frac{p_{j,i}^e}{p_{1,i}^e}\right) - \tau_i + v_i$$

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[30] Frosts, in meteorology, occur when there is ice deposition on external plants and objects. The occurrence of frosts is due to a combination of air temperature around 0° C and moisture in the atmosphere (Pereira et al, 2002) and may cause death of plants when it entails the freezing of plant parts. Some specialist believe that -4 ℃ may be the critical temperature for more resistant plants, such as coffee, sugarcane and some fruits [Mota, 1981]. Temperatures below this temperature may cause even worse effects.

[31] LR statistic was 863.43 to 949.65 (depending on the price variable used), much higher than the critical value for 1% of significance.

[32] LR statistics = 3403.60 to 3571.85, for df* = 55.

The homogeneity and symmetry restrictions are automatically imposed by the translog specification. The convexity assumption was tested indicating that, in general, the profit function estimated can be considered convex. Only for some of the results, soybean, maize, and beef, the estimated results were not statistically significant from zero or negative. The following tables show the price elasticities calculated for each variable at the sample mean.

Price Elasticities	Other Perm crops	Other Temp crops	Soy-bean	Maize	Coffee	Beef	Dairy	Fertili-zers	Other Forest Prod.	Wood
Other Permanent crops	2.67**	-0.81***	1.09	-1.35*	-3.98**	-6.44*	-2.32***	-0.9***	-24.1	26.48
Other Temporary crops	-0.21	-0.003	-1.46**	-0.74	1.15	-1.99	-1.46***	-0.77***	64.37***	-49.06***
Soybean	3.33	-1.23***	2.97	2.78	-18.07***	23.41**	0.34	0.37	-37.74	-247.6***
Maize	-1.43	-0.92***	1.25	0.63	-0.92	-0.79	-4.28***	-0.72***	3.82	21.91
Coffee	-3.83**	-0.51**	-8.85***	-0.94	10.36***	-3.96	1.11	-1.16***	84.43*	93.11*
Dairy	-3.22**	-1.18***	-0.46	-5.5***	2.75	-1.82	3.62*	-0.62*	-82.61**	4.87
Fertilizers	-1.17***	-1.09***	-2.13***	-1.39***	-0.71	0.61	-1.38***	-0.29***	-7.18	-11.37
Beef	-3.6**	-1.11***	4.63**	-0.92	-2.49	-22.93***	-1.23	-1.45***	-44.3	143.1**
Other Forest Prod.	-1.62***	-0.58***	-1.48	-0.89	1.41	-3.43	-2.3***	-0.9***	64.51***	-34.51*
Wood	-0.19	-1.34***	-4.5***	-0.45	1.9	7.86**	-0.9	-0.82***	-37.67*	78.13***

Statistical significant: * at 10%; ** at 5%; *** at 1%.

Table 1 – Price elasticities estimation and statistical significance

The following table measures the exogenous partial variables effects on farmers' profit. Remember that the exogenous variables were included in level and the dependent variable (profits) in the logarithmic form, generating semi-elasticities:

Variables	Coefficients	
% of tilleaged área	1.0399	***
Fuel quantity in kcal (Capital)	0.0001	***
Land quantity (hectares)	0.0000	***
% Certified or GTO seeds	0.4106	***
% Confined Cattle	0.8406	***
Avg rain - Summer (mm/month)	-0.0039	***
Avg rain - Fall (mm/month)	-0.0016	*
Avg rain - Spring (mm/month)	0.0002	
Avg Temperature - Summer (^{o}C)	0.0237	
Avg Temperature - Fall (^{o}C)	-0.2681	***
Avg Temperature - Spring (^{o}C)	0.2025	***

Statistical significant: * at 10%; ** at 5%; *** at 1%.

Table 2 – Semi-elasticities, exogenous variables, Census 2006.

Some of the climate variables were statistically significant to explain farmer's profits: both the increase in rain patterns in summer and fall influence negatively on profits. When it comes to temperatures, the results diverge depending on the considered season: greater long-term temperatures affect positively in spring, but negatively in fall. The fall season is the period close to the harvest and it seems that the farmer's profits are more sensitive to the climate during this season.

The technological variables showed positive statistically significant effects on profits. All those variables are measured as percentage of farmers in the region. Thus, the results indicate that an increase in 1% of GTO seed, for example, might increase farmer's profits in 0.41%. The variables measuring local technologies can be ranked as: % of tillage area; % Confined Cattle; and % Certified or GTO seeds, in order of importance to improve farmers' profits.

By using the magnitudes of the coefficients estimated, it is possible to calculate the expected climate change impact on profits and ways of reducing the potential harm effects that climate changes might cause on Brazilian agriculture. Next figure summarizes the potential harm effects of climate change on the farmer's profits:
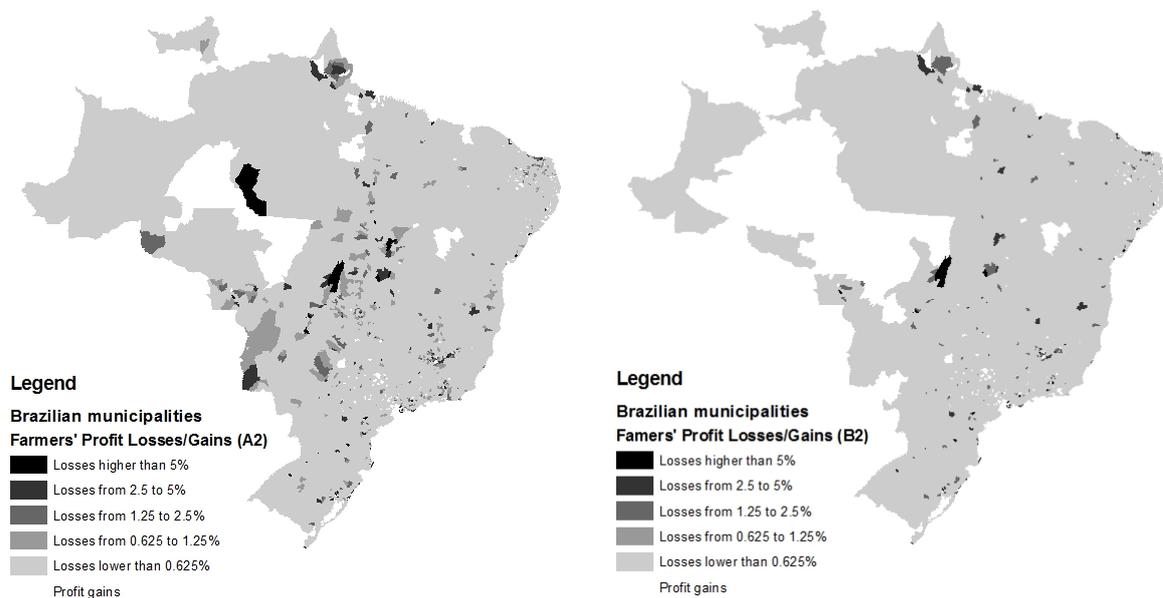

Figure 2 – Climate change Effects on Profits, Census 2006 and INPE Projections.

Figure 2 compares the total profit losses from the changes in long-term climate. The average losses (accounted all the positive and negative climate change effects) are about 0.4% of profit losses. The expected increase in temperature in the Fall season for 2070-2100 is the responsible for most of the negative results. The negative impact on profits is about 0.124% (Scenario A2) and 0.85% (Scenario B2), which means a total loss of 530 and 370 million Brazilian reais, respectively for Scenarios A2 and B2.

In general, to compensate an average of 2 degrees increase in temperatures during fall season, it would be necessary an increase in tillage area of 0.52% in tillage area. When it comes to the compensation using GTO seeds, in order to adapt to an increase in fall's temperature, the necessary increase in usage of GTO or certified seeds would be about 1.3%.

Short-term climate relevance

Short-term climate relevance is measured by understanding the climate seasonality effect on the optimal deviation. Battesi and Coelli (1995) identified technical inefficiency determinants by considering technical efficiency as a function of exogenous variables, most related to farmers' characteristics.

The evidences emphasized by Ozkan (2009) were important to base the choice of determinants. The Equation 5 was estimated as a truncated regression as the model dependent variable (profit technical inefficiency) is between 0 and 1.
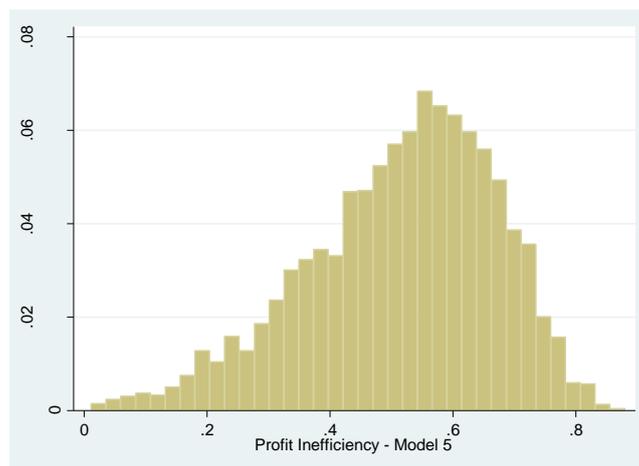

Figure 3 – Estimated Profit Inefficiency Distribution among municipalities

It is assumed that the error terms in the truncated regression model have a truncated normal distribution. The complete results are described on Table below:

Variables	TE Coeff.	Variables	TE Coeff.
Truncated Regression: Limits [0,1]			
Dependent variable: Profit Inefficiency			
rain_summ_dev2006	0.000106	tmed_spr_dev2006	-0.0086
rain_fall_dev2006	-0.000481***	associado	0.0737***
rain_wint_dev2006	0.000841***	area_irrigada	0.236***
rain_spr_dev2006	0.000235	prod_propriet	-0.0321
rain_summ_dev2005	0.000384***	prod_arrend	0.210***
rain_fall_dev2005	-1.78E-05	contr_pragas_sim	-0.0330*
rain_wint_dev2005	-0.000547***	usa_adubo	0.132***
rain_spr_dev2005	-0.000466**	analf	0.0299
tmed_summ_dev2005	0.00576	ensfun_inc	-0.00939
tmed_fall_dev2005	-0.0113	ensfun_comp	0.113*
tmed_wint_dev2005	-0.0592***	ensmed_comp	-0.121*
tmed_spr_dev2005	0.0225***	enssup	-0.258***
tmed_summ_dev2006	0.0116	altitude	-9.03E-06
tmed_fall_dev2006	-0.0239**	Constant	0.499***
tmed_wint_dev2006	0.0510***	Sigma	0.149***
Wald chi2(28)	**351.1***	**Observations**	**4,473**

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3 – Preliminary Results for Profit Inefficiency Determinants

The climate variables effects can be divided into four groups:

I) Negative impacts of excessive rainfall: For the 2006 profits, excessive rainfall during harvest (fall of 2006) and during the planting seasons (winter and spring of 2005) might cause loss in production and, consequently, profit losses to farmers;

II) Negative impacts of lack of rainfall (droughts): The model indicated that lack of rainfall during the end of the harvest (winter of 2006) might cause losses of profits to farmers;

III) Positive effects of excessive temperature during the planting and growing season (spring of 2005);

IV) Negative effects of unexpected decrease in temperatures during the harvest might affect negatively farmers' profits.

When it comes to the farmer and farm' characteristics that increase the efficiency of the farmers in generating profits, the main determinants might be ranked as: Use of irrigation; Use of composts; and association to cooperatives. Other relevant information about the farmer might elucidate some important aspects related to efficiency. While the education does not seem to be very important in Brazilian agriculture, the farmers that rent the land, instead of owning it, seem to be more efficiency, after controlling all the other effects.

7 Concluding Remarks

Previous studies did not consider technological influences on their projections of climate change effects on agriculture, which could considerably affect the finding results. Nadal (2010) is one of the only studies for Brazil that considers investments in order to measure how climate change might affect agricultural production. Nevertheless, only crops are considered in the study. Without taking into account the forests and the livestock in the analysis, the impacts of climate change on agricultural activity were minimized.

Another important contribution of this study is the inclusion of an inefficiency approach linking short term climate variations inside the model. Short-term seasonal climate events are assumed to deviate farmers' from their optimal profits. Therefore, it is possible to measure short and long terms climate effects on agricultural activity together with the analysis of the policies that can be implemented to deal with the agricultural losses caused by climate change, which has never been done for Brazil.

Adaptation technology for climate change

We analyze how the farmer's profits are affected by climate and technological changes by using a profit frontier. The aim was to compare the adaptation cost and benefits from various agricultural practices. When it comes to the expected climate change impacts on agriculture, the increase in temperatures during the fall season might cause the greatest damage, when it comes to the agricultural profits. This season is normally the harvest season for many crops.

The results indicate that the main technological variables that might increase farmer's profits are % of tillage area, % Confined Cattle, and % Certified or GTO seeds, in order of importance. The usage of GTO and certified seeds are examples of sustainable use of genetic resources in agricultural products which are essential to achieve food security. The development and use of genetics will serve as an insurance policy to respond to potential changes in production conditions and must be taken into account when addressing adaptation measures [FAO, 2010]. Adapting crop varieties to local ecological conditions can reduce risks induced by climate change.

Technical Inefficiency and weather effect on agriculture

It is well known that climate volatility is an important aspect of agricultural production. The approach considered here models climate volatility as a determinant of profit inefficiency of farmers. The inclusion of climate short-term effects are relevant once the uncertainty associated with climate variability might be a disincentive to investment, adoption of new agricultural technologies and market opportunities [Baethgen et al., 2008][33].

The results showed that climate deviations might affect negatively profits due to the lack of rainfall (droughts) during the end of the harvest (winter of 2006) might cause losses of profits to farmers and due to unexpected decrease in temperatures during the harvest might

Some actions by the farmers might diminish the climate problem, such as use of irrigation techniques, as well as association to cooperatives.

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[33] Some of the problems involving farmers' risks are: less effective exchange-traded futures and options hedges for production risk (those markets are only effective for prices); imperfect insurance market due to the positive spatial correlation in losses (limiting the risk reduction capacity); existence of asymmetric information among farmers, since some of them are better informed than others about loss probability distribution.

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Appendix A – Expected Price Comparison for Coffee

Figure 1A – Comparison among prices of coffee: 2006 real prices; Estimated prices (Arellano-Bond); Prices in t – 1 (2005); and last four years average, in R$ per Kg.