Climate and Weather Impacts on Agriculture: The Case of Brazil

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This paper innovates as it tests two different hypotheses regarding climate impacts on agricultural markets in Brazil: farmers only observe the average climate conditions of their region when deciding the type and amount of crop/animal to grow/raise; and weather diversions from normal climate conditions deviate farmers from their optimal profits. Both hypotheses are not rejected by the data. The modeling approach used is the translog profit frontier. The 2006 estimated loss from rainfall anomalies was 15 billion dollars (in values of December 2011).

Introduction

The world population might reach approximately 10.6 billion people by 2050 (UN 2004). From this expected population growth, food demand might double present day's consumption.[1] Consequently, the agricultural sector will be challenged to ensure future food security.

This article focuses on the measurement of specific climate effects on agriculture. It is well know that climate is an important factor influencing agricultural production. In order to analize climate effects, climate is assumed to affect agricultural production in two different forms in this paper: in the long-term, defined by the historical observed climate, climate is considered a direct input for crop and animal production[2] impacting land use configuration; and in the short-term, weather condition is also an important determinant of crop/livestock failure and loss of productivity[3]. Particularly, the long-term effect assumes that average climate conditions of the region are relevant for farmers' decisions, as they observe past climate information. Once the farmers decided what and how much to produce, extreme weather events might impose production losses deviating them from optimal profit.

The central idea of the analysis is that long-term climate influences the planning decision of producers, while short-term weather events move production away from the production frontier. Thus, this article employs a stochastic profit framework in the empirical analysis as it treats short- and long-run climate effects in a separated form. The theory of how stochastic frontiers models relate to long run and short run models of producer behavior seems to be under developed. This paper is an attempt to fill in this gap.

Based on the idea of having a separation between short and run effects in a production frontier framework, the following question is addressed: how do the climate and weather variables relate to the long run and short run problems of the agricultural producer? The answers to these questions not only contribute to the current debate on how expected climate change might influence future human activities[4], but also address the proposition of short-term actions to reduce the climate variability effects' on poor communities. Climate variations are expected to adversely affect food production in some important foof production regions of the world, generating possibly significant losses, most likely affecting small farmers and poorer populations[5]. The policy actions to reduce harmful climate impacts should rely on consistent estimation taken into account long run decisions as well as short term weather changes impacting production outcome.

This article deals with Brazilian farming and livestock breeding. Brazil is one of the main grain producers and exporter. Besides that, the country has continental dimensions, with large climate variability from the equatorial North, which is 4,000 kilometers far from the temperate South.

This article innovates as it distinguishes between the effects of climate and weather in the production frontier framework using a translog profit frontier approach. Average climate, or long-run climate, effect on farmers' outcomes is tested and not rejected by the data, showing that temperature seems to be more important than rainfall in the long-run. The results also indicate that efficiency losses are significant, indicating that efficiency levels differ in a statistically significant way among Brazilian farmers. The tests show that weather events are jointly relevant to explain the differences in technical efficiency, with a major impact due to rainfall shortcomings. Simulations indicate that rainfall much lower than historical average, observed in the summer of 2005 and 2006, caused a loss of 5.6% in farm profits in 2006, representing almost 15 billion dollars (in values of December 2011). This amount may be interpreted as the farmers' maximum willingness to pay to protect themselves against the unforeseen rainfall shortcomings in Brazil in 2006.

Literature Review and Methodology

Studies measuring the impacts of climate on agricultural outcomes are normally based on two different modeling approaches: the Ricardian or hedonic approach[6] and the agro-economic or crop approach[7]. While the former measures the influence of climate on land values, the latter uses farmers' production structure to measure the optimal allocation of different crops to inputs and fixed factors. The choice between these two approaches is based on the relative advantages and disadvantages and on their data requirements. Some authors argue that studies following the Ricardian approach produce more aggregated results, which might be an obstacle for the measurement and proposal of adaptation measures (Deschênes and Greenstone 2007). This article adopts an agro-economic approach to try to identify the specific effects of climate on agricultural yields. The agro-economic literature bases the analysis on agricultural profits and production functions, which are briefly discussed next.

The next step is to understand how climate can be considered in this approach, as it impacts the model choice. Demir and Mahmud (2005) argued that the local agro-climatic conditions are historically known by farmers and therefore should not be treated as random, since they influence producers' choices. As a result, changes in average climatic conditions can modify the behavior of farmers as they take into account local climate patterns (temperature and precipitation) in deciding on the output-input mix (Kumbhakar and Lovell 2000; Kumar

2009). Assuming that farmers only observe the past climate conditions (average climate), it seems reasonable to consider that climate is a key input for crop and livestock outputs.[8]

Nevertheless, another relevant climate effect on agriculture is related to extreme weather events during growing and harvesting seasons, which are not observed by farmers when choosing the output-input mix that optimize their outcomes. Those extreme events can cause important damages which divert farmers from their optimal allocation. The errors/deviations in the production decision are translated into lower profits for producers, causing inefficiencies (Ali, Parikh and Shah 1994).[9] This short-term climate concern leads to the adoption of an efficiency analysis, which measures and helps to identify variations of the physical and financial performance achieved by farmers operating with the same environmental and economic constraints (Wilson, Hadley and Asby 2001).

Ali and Flinn (1989) argue that in order to measure efficiency, a production function approach may not be appropriate when the population of farmers faces different prices and has different factor endowments.[10] When facing heterogeneous farms, the authors urge the use of stochastic profit function models. The stochastic profit function model, or profit frontier approach, besides providing a compact form to summarize a multiproduct technology[11], is an effective way to introduce the theoretical constraints into the analysis (Mundlak 2001). The next subsection details the theoretical and empirical developments which support the measurement of the intended effects.

Profit frontier approach

It is assumed that producers allocate their g variable inputs to s types of production. The number of outputs plus the number of inputs represents the m products considered in the analysis, such that $m = s + g$. Producers decide on 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 exogenous[12]. Besides the prices of inputs and outputs, $p = (p_1,...,p_m)'$, each producer faces quasi-fixed inputs (exogenous variables for the time window considered), represented by $Z = (Z_1, ..., Z_f)'$, which significantly affect the production and factor decision, $q = (q_1,...,q_m)'$. The Z vector also includes other exogenous variables, such as local climate patterns (temperature and rainfall) and technological use by the farm. The vector q denotes the products amounts: $q_j \geq 0$, when j is an output; and $q_k \leq 0$ when k is an input.

Producers maximize a short-run profit function (or restricted profit function) by choosing allocation of multiple outputs and inputs given an endowment of fixed factors (fixed in the short-run): Z and p[13]. The solution of this problem gives the optimal allocation, q^*, or the output supply and demand for inputs, which depend on prices and on the fixed factors under the regularity conditions[14]:

$$q_j^*(p, Z), j=1, \dots, m \quad (1)$$

By replacing the above optimal solution in the profit (Π) function, the optimal profit function can be described as $\Pi^*(p,Z) = ArgMax_{\{q\}} \sum_{j=1}^{m} \Pi_j(p,q,Z)$. Thus, the profit function is a value function depending on the exogenous variables prices and other quasi-fixed inputs. In this model, agricultural markets are considered to be perfect, meaning there are no losses due to technical changes; therefore, farmers are assumed to be fully efficient in optimizing profit (Eaton and Panagariya 1982).

Kumbhakar and Lovell (2000) discussed the same approach above, but relaxed the assumption of full efficiency, based on the idea that inefficient farmers can survive in the short run. Assuming that the correct relative market prices are observed by the farmers, all the farmer inefficiency comes from technical issues. The efficiency analysis, as a result, helps to identify variations of the physical and financial performance achieved by farmers that operate under the same conditions. Thus, by relaxing the assumption of full efficiency, a profit (or technical) efficiency measure can be described as the ratio of the actual profit in terms of the potential maximum profit. Considering the potential inefficiencies (τ)[15] in the profit function and assuming the transcendental logarithm (translog) function for farmers' restricted profit function (Christensen, Jorgenson and Lau 1975),[16] the translog profit frontier normalized at product 1 is:

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

In which $j, k = 1, \ldots, m; r, h = 1, \ldots, f$; and $\beta, \delta, \theta, \gamma$, and τ are parameter vectors.

The normalized translog functional form is locally flexible and generates a closed-form solution. It also allows testing of profit convexity on prices, which means that the matrix of $\beta = [\beta_{jj}]$ is positive semidefinite for $j = 1,\ldots,m$. In order to estimate the parameters of the profit frontier estimation, an error component (v) is added to equation (2), leading to estimation of the following equation:

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

In which i represents the farmers, such that $i = 1, \ldots, N$. Note that τ is a positive component that shifts the profit from the optimum. 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: $y_i = (-\tau_i + v_i)$. Suppose that v_i is *i.i.d* and follows a normal distribution with mean zero and variance σ_v^2 and that τ_i is *i.i.d* and follows a normal distribution, positive and truncated at zero, with mean μ and variance σ_u^2. By using the linear transformation of random variables (DeGroot and Schervish 2002), the pdf of the composite error (y) can be written as:

$$g(y) = \int_{-\infty}^{+\infty} f_u(x_2) f_v(y + x_2) dx_2 \quad (4)$$

$$g(y/\mu,\sigma_u,\sigma_v)=\int_{-\infty}^{+\infty}\left(\frac{1}{\sigma_u}\right)\frac{\emptyset\left(\left(x_2-\mu\right)/\sigma_u\right)}{\left[1-\Phi\left(-\frac{\mu}{\sigma_u}\right)\right]}\emptyset\left(\left(x_2+y\right)/\sigma_v\right)\,dx_2 \tag{5}$$

In which $f_u(.)$ is the marginal density of the truncated distribution (mean μ and variance σ_u^2); $f_v(.)$ is the marginal density of a normal distribution (mean 0 and variance σ_v^2); and $x_2=\tau$. The pdf of the positive normal is: $f(x_2/\mu,\sigma_u,0)=\frac{1}{\sigma}\frac{\emptyset\left(\left(x_2-\mu\right)/\sigma_u\right)}{\left[1-\Phi\left(-\frac{\mu}{\sigma_u}\right)\right]}$. Following Stevenson (1980), the likelihood function for each y_i *(i=1,...,T)* is:

$$f(y_i/\beta,\mu,\sigma_u,\sigma_v)=\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)\exp\left\{\frac{1}{2\sigma^2}(y_i-\beta' x_i-\mu)^2\right\}\left[1-\Phi\left(\frac{1}{\sigma}\left(-\frac{\mu}{\lambda}-(y_i-\beta' x_i)\lambda\right)\right)\right]\left[1-\Phi\left(-\frac{\mu}{\lambda}(\lambda^{-2}+1)^{\frac{1}{2}}\right)\right]^{-1} \tag{6}$$

In which $\sigma=(\sigma_u^2+\sigma_v^2)^{1/2}$ and $\lambda=\frac{\sigma_u}{\sigma_v}$. The log-likelihood function for each y_i *(i=1,...,n)* is:

$$lnL(\beta,\mu,\sigma_u,\sigma_v)=-\frac{1}{2}\ln(2\pi)-\frac{1}{2}ln(\sigma_u^2+\sigma_v^2)-\frac{1}{2(\sigma_u^2+\sigma_v^2)}(y_i-\beta' x_i-\mu)^2+ln\left[1-\Phi\left((\sigma_u^2+\sigma_v^2)^{-\frac{1}{2}}\left(-\frac{\mu\sigma_v}{\sigma_u}-(y_i-\beta' x_i)\frac{\sigma_u}{\sigma_v}\right)\right)\right]-\ln\left[1-\Phi\left(-\frac{\mu}{(\sigma_u^2+\sigma_v^2)^{\frac{1}{2}}}\left(\left(\frac{\sigma_u}{\sigma_v}\right)^{-2}+1\right)^{\frac{1}{2}}\right)\right] \tag{7}$$

Assuming independence among the observations, the above log-likelihood is implemented in Stata and the translog profit frontier can be estimated.[17].

One of the advantages of using the normalized translog functional form is the possibility to test convexity and to directly assume linear homogeneity and symmetry. These hypotheses are sufficient conditions to ensure that producers are maximizing profits. Therefore, the profit frontier equation can be estimated imposing the symmetry and homogeneity assumptions. If the conditions are satisfied locally, or are satisfied for a price range, the results are consistent with maximizing profits (Hertel 1984). Another relevant piece of information from the model is that farmers from different climate conditions in the sample might change technical use of quasi-inputs and inputs due to distinct local climate. In this context, this different behavior among farmers allows the analysis of adaptation to expected climate change through the calculation of possible compensatory responses to climate variations.

Efficiency analysis

Note that τ measures the shifts of profit away from the optimum (namely Π^*) or the failure of the farmer to reach the maximum possible profit:

$$\tau=ln\Pi^*(p,Z)-ln\Pi\ ,j=1,2,...,m \tag{8}$$

In which Π is the actual profit level achieved, and $\tau \geq 0$ is the inefficiency term for both the underproduction of outputs and overuse of inputs. This measure can be interpreted as the intrinsic total profit/technical inefficiency of each farmer. Thus, the TE ratio is characterized by the loss of profits from not producing the desired levels and is obtained by comparing both optimal and achieved profits:

$$TE = \exp(-\tau) = \frac{\Pi(p,Z)}{\Pi^*(p,Z)} \tag{9}$$

As $\tau \geq 0$, the measure of TE varies from zero (least efficient) to the unity (fully-efficient)[18]. In equation (3), by assuming that $v_i \sim iidN(0,\sigma_v)$, $\tau_i \sim iidN^+(\mu,\sigma_\mu)$ and τ_i and v_i are distributed independently of the covariates of the profit function, the pdf of the composed error (y) can be derived, and consequently the log-likelihood function of this error term can be obtained. Assuming independence among the observations, the log-likelihood estimation method is implemented using Stata to obtain the estimated parameter values that maximize de ML which are the estimated coefficients of the profit frontier.

According to Kumbhakar and Lovell (2000), the estimation of τ_i, and consequently of TE_i, requires derivation of the conditional distribution of $\tau_i$on y_i, $f(\tau_i/y_i)$, which is a normal distribution with mean $\tilde{\mu}_i$ and variance $\tilde{\sigma}^2$, such that:

$$\tilde{\mu}_i = (-\sigma_u^2 y_i + \mu\sigma_v^2)/\sigma \tag{10}$$

and $\tilde{\sigma}^2 = \sigma_u^2\sigma_v^2/\sigma^2$ (11)

In which: $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$. Thus, the conditional mean $E(\tau_i/y_i)$ can be an estimate of τ_i and can then be replaced in equation (9) to estimate TE:

$$\widehat{TE}_i = E[\exp(-\tau_i)/y_i] = \frac{1-\Phi(\tilde{\sigma}-\tilde{\mu}_i/\tilde{\sigma})}{1-\Phi(-\tilde{\mu}_i/\tilde{\sigma})}\exp(-\tilde{\mu}_i + 1/2.\tilde{\sigma}^2) \tag{12}$$

In which $\Phi(.)$ is the normal cumulative distribution function. Kumbhakar and Lovell (2000) present this procedure, showing that it generates unbiased estimators for TE.

After valuing TE, the second step is to estimate the TE determinants, which will be discussed further. In order to generate unbiased TE estimators, the determinants should be uncorrelated with the covariates of the profit function, an assumption considered in this study.

An important article on TE determinants was developed by Battese and Coelli (1995), who state that efficiency can be explained by a set of exogenous variables.[19] As mentioned, the set of determinants must be exogenous to the farmer's choice. Formally, the technical efficiency determinant equation can be described as:

$$TE_i = f(C_i, X_i, D_i) + \varepsilon_i \tag{13}$$

In which: ε_i is a random shock with positive distribution for each farmer (represented by the representative farmer of municipality i); C_i is a vector of climate anomalies (extreme weather variables, for example) in the period for municipality i; X_i is a vector of farmer characteristics for municipality i; and D_i is a vector of other determinants. According to Gorton and Davidova (2004), the determinants can be divided into two main groups: human capital effects and structural effects. The former group includes information on the farmers' management, their characteristics and education[20], while the latter group comprises environmental conditions, credit access[21] and information on property rights, rural infrastructure[22], among others.

When it comes to environmental conditions, Kumar (2009) stated that weather deviations from normal conditions can influence crop growth and, consequently, the TE of farmers. The work of Sherlund, Barret and Adesina (2002) applied a translog production frontier model to Côte d'Ivoire and found that the exclusion of climate variables in the determinants equation might lead to biased parameters. Demir and Mahmud (2005) also included environmental factors to explain efficiency differences. They emphasized that the omission of climate variables, under the argument that they are beyond farmers' control, can lead to inaccurate interregional technical efficiency comparisons. They considered anomaly in rainfall (rainfall above or below the national average) as one of the main determinants of technical inefficiency. In Brazil, Igliori (2005) and Imori (2012) also considered climate in their approach to identify efficiency determinants for the Amazon region and Brazilian farmers, respectively. Imori found statistically significant impacts of temperature and precipitation on the estimated technical efficiency.

Dataset

Based on the theoretical framework proposed, this section presents the sources of data used, the definition of variables for the model and an overview of the proposed problem based on the data collected. Appendix A shows all descriptive statistics from the variables discussed below.

Data sources: Profit frontier

The most detailed information available in Brazil aggregates farmers into administrative districts, such as municipalities, to preserve the identity of farmers. In addition to that, data based on responses by fewer than three farm establishments are not reported for the same reason. Despite the loss of desired information on individual choice of farmers, this procedure does not preclude the analysis, as there are local homogeneities, mostly related to environmental and logistic conditions, among the grouped farmers (Disch 1983). Moreover, the price variability among regions is preserved. Pastore (1968) minimizes the aggregation problem when the model is estimated using the information available on the smallest regional unit. Thus, all the variables in the model are at a municipal level.

The main agricultural data source in the country is the Brazilian Agricultural Census, conducted by the Brazilian Institute of Geography and Statistics (IBGE). The last census was undertaken in 2006, for which the reference period encompasses the period from 1 January to 31 December 2006. The census refers to cross-sectional data and is the main database used by this article. Panel data, which could generate more accurate results, were not used for two reasons: the data incompatibility between the collection period of the last two agricultural censuses carried out in Brazil (2006 and 1995-96); and the lack of compatible variables between the census, mainly technological variables. Moreover, in climate-agricultural studies, fixed effects could absorb most of the average climate conditions of the municipality (Fisher *et al* 2012).

The 2006 Census contains information on output and input quantities and values, land type and use, and farmer and farm characteristics, among other aspects. The agricultural products considered are divided into nine components of four groups (share of agricultural production value in parentheses): (i) Annual crops (52.7%): soybeans; maize; others; (ii) Perennial crops (20.3%): coffee; and others; (iii) Livestock (22.4%): milk and beef cattle; and (iv) Forest (4.6%): wood; and other forest products.

These products were chosen according to their weight in each group, in terms of production value in 2006: soybeans and maize represent 24.3% and 14.9% of the total value generated by annual crops, respectively; and coffee represents 34.9% of the value of perennial crops. Beef and milk production represent approximately 55% of livestock production value. The choice of inputs was made using the same criteria, which selected four inputs: land, and fuel (quasi-fixed inputs); and labor and fertilizers (variable inputs).

Due to the different time windows between the decision to grow the crop, its harvest and sale of the output, farmers must have price expectations (p^e) when deciding on the crops/animals to grow/raise and the amount of expected return. In general, $p_t^e = E_{t-1}(p_t)$, for crop and livestock products, and $p_t^e = p_t$ for other agricultural products such as extraction of wood and other forest products. Several studies have addressed the price expectation problem using adaptive and rational expectations modeling (Pastore 1968; Castro 2008; Nerlove; Fronari 1998). Rausser and Just (1981) state that the use of future prices, for some agricultural commodities, performed better than econometrically based forecasts. The problem with future prices is that they do not exist for all agricultural products and also do not have any regional variation.

Barbosa (2011), studying the land-use pattern in Brazil, assumed that farmers' price expectations are the average of real prices observed in the five years before the decision, which is an approach more closely related to adaptive expectations over past prices. The prices used in this article tests Barbosa's estimated prices and also considers a different approach to the weighting process of Barbosa (2011) by modeling each product price using a dynamic model based on panel data. One-time lagged prices are also tested, but these prices might not be good approximations, mainly for perennial crops such as coffee, whose prices are highly cyclical. This procedure treats potential short run price movements associated with weather fluctuations. For the next sections, the superscript (^{e}) for prices will be omitted to simplify the equations.

The profit variable was measured by the difference between the sum of the agricultural production value of the products listed above (production in 2006 times the crop prices) and the sum of the costs of the fixed and variable inputs considered in the model. This measure includes the possible storage for that year, as considers the total production value of the year, and not total sales. However, it does not account other costs that might be omitted (such as farm household labor), which might cause a bias in climate estimates once it is considered that average climate is correlated with such implicit costs (Fisher et al 2012).

The total amount of fuel used by the farm can be considered a proxy for capital stock of the farm. The fuel variable is generated by summing the information on different energy sources. All types of fuels were converted into energy generation, kilocalories (kcal), using the density and power capacity figures from Petrobras and other sources of information.[23] When it comes to labor variables, labor prices were calculated as the average rural wage equal to the sum of farm workers' monthly wages divided by the number of employees, which include permanent workers, temporary workers, farm owners, and other workers.

The technological variables available in the 2006 Census are chosen based on the study of EMBRAPA (*Empresa Brasileira de Pesquisa Agrícola*, the government agricultural research agency) and IBGE (IBGE 2010). According to their technological variables mapping, the following aspects can be used as indicators for rural technology in Brazil: use of irrigation, in percent; proportion of establishments with mechanical harvesters; municipalities with 50% or more of the harvested area planted with certified and transgenic seeds; municipalities with 50% or more of agricultural establishments having access to technical assistance; number of establishments with tilled area; number of establishments with eucalyptus production; and for livestock, municipalities that have establishments with artificial insemination; animal screening; use of industrial feed; and animal confinement. Most of these data are available in the 2006 Census as a percentage of farmers in the municipality that adopt the technology.

Complementary data regarding Brazilian agriculture is available from the Municipal Agricultural Survey (PAM) conducted by IBGE. This survey also aggregates farmers by municipalities and collects important information regarding annual crop production, physical and financial production. These data are important to analyze farmers' price expectations about the crop and livestock markets.

Data sources: TE determinants analysis

Once the data above was used to estimate the profit frontier and its TE component, a group of variables identified by the literature as potential explanatory factors for TE, limited by data availability, is selected. These variables, except for climate, are described below:

<u>Farmer education and experience</u>: percentage of local population that completed each level of education (none or incomplete elementary, complete elementary, incomplete high school, complete high school, and higher education)[24], and the percentage of farmers who run establishments by years of experience: less than 1 year, 1-5 years, 5-10 years, over 10 years;

<u>Other farmer characteristics</u>: percentage of female farmers; percentage of farmers who own their land; percentage of tenants/sharecroppers;

<u>Soil type</u>: percentage of non-agricultural land in the municipality (namely, degraded areas) out of the total area;

<u>Farm size</u>: average size of farms in the municipality, calculated by hectares per establishment; and percentage of family farms in the municipality;

<u>Production diversification</u>: the general Herfindahl-Hirschman Index (HHI) is calculated based on the value of production among the following aggregated products: large animals,

midsize animals, small animals, perennial crops, annual crops, horticulture, forestry and plant extraction. The index represents agricultural diversification. A zero value denotes perfect diversification and a value of 1 denotes perfect specialization;

Access to credit: Percentage of establishments that obtained some type of loan from different sources (banks, cooperatives, among others);

Altitude: Altitude in meters, which is believed to increase the risk of frosts (Astolpho *et al.* 2005). The data were obtained from the IBGE database of cities and towns of 1998;

Infrastructure: Index for logistic cost to São Paulo in 1995, updated in 2009, based on the transportation costs to the city of São Paulo, whose costs are a result of applying a linear programming procedure for calculating the minimum shipping cost to São Paulo (NEMESIS 2009);

Membership in cooperatives: Percentage of producers that are members of a cooperative, union or other similar association;

Pest control: Percentage of agricultural establishments that perform pest control (biocontrol, burning waste, use of repellents, among others).

Data sources: Climate

The historical climate data for Brazil were obtained from the National Meteorology Institute (INMET), under the Ministry of Agriculture (MAPA). The institute collects information about average, minimum and maximum temperature, total precipitation (in millimeters and rainy days) and relative humidity by weather stations. To transform the data from the weather stations into municipal[25] data, the kriging method of interpolation is used (Haas 1990). For all the climatic variables, average data over the seasons are created, gathering the information over the months of each season. Climate information represents the average temperature, precipitation and relative humidity of the season.

There are two important temporal distinctions in how climate can be assessed: Long-term climate conditions, which are the average conditions of regions, where patterns can be identified, such as: the average precipitation in the Amazon Forest is higher than in the Northeast semiarid region, although both regions have the same high average temperatures throughout the year; and short-term climate variations, which represent the annual climatic deviations from long-term conditions. These deviations are usually dominated by inter-annual and seasonal variations and are observed due to the oscillations of the Earth's climate system regarding weather patterns at the local, regional and global levels.

The long-term average is calculated based on the year of the census (2006), so the climate information take into account the 30-year average of past data (from 1976-2005) to compute the current climate pattern observed by each farmer, namely *E(climate)*. The average is calculated by season, generating the long-term seasonal mean. Based on Cunha *et al*. (2012), this article considers only average summer and winter seasonal climate information. The authors state that Latin American countries in general do not have well defined seasons, so that summer and winter are representative seasons when it comes to the region's climate patterns.[26]

When it comes to short-term climate data, the 2005 and 2006 climate information by season (*climate*) is demeaned by the long-term climate data, *E(climate),* and this deviation from long-term mean is divided by the standard deviation, calculated from the former 30-year climate (σ_{climate}), to standardize the climate information. Both years are used as the 2006 harvest also depend on the previous year weather. Hence the new variable can be interpreted as climate anomaly or extreme weather intensity. Therefore, two subsets of indexes are created to test their impact on TE and, consequently, on profits: Drought Index, observed rainfall below the long-term average rainfall in standard deviations $Z_D < E(Rain) - \alpha\sigma_{Rain}$; and Cold Stress Index[27], observed air temperature below the long-term average in standard deviations $Z_C < E(Temp) - \alpha\sigma_{Temp}$. In this formulation, α represents the intensity of the extreme weather occurrence and all climate variables are transformed in terms of α. These indexes are used after testing the significance of the climate variables in the TE determinants equation, in order to simulate extreme weather events' effects on agriculture.

Results

The results were subdivided into: long-term analysis, which presents the results of the estimation of the profit frontier equation; short-term analysis that discusses the climatic effects on the farmers' profit deviation from the frontier profit function.

Average climate impact on profits

The final model estimated is a normalized profit frontier model against all the prices and exogenous variables of the model (the latter interacted with prices), as equation (3) shows.

The relevance of including climate variables in the profit model can be tested by the likelihood ratio (LR) test. The LR statistic is from 863.43 to 949.65 (depending on the price vector used, as footnote 10 describes), much higher than the critical value for 1% significance, indicating that average climate is relevant to explain farmers' profits. The homogeneity and symmetry restrictions are automatically imposed by the translog specification. The convexity assumption is tested using an LR test and the results indicated that, in general, the profit function estimated can be considered convex.[28]

By disaggregating the profit impacts into profit share effects, the climate variables show important effects: low rainfall levels impact only soybean profit shares; while places with higher average temperatures have negative effects on maize, coffee and beef [Table 1]. Soybeans, other annual crops and other forest products generate more profits when cultivated in smaller areas, as the land quantity effect indicates. More irrigated area means more profits for soybeans, maize and coffee – the main crops analyzed in this article.

Table 1: Average Partial Effect of Exogenous Variables (*r*) on Profit Shares for Product (*j*), 2006 Census

Effect on profit shares, by ouput (γ_{jr})	**Soybeans**	**Maize**	**Other annual crops**	**Coffee**	**Other peren. crops**	**Milk**	**Wood**	**Beef**	**Other forest products**
Fuel quantity	-9.4e-6	1.83e-05**	1.02e-5***	5.5e-06	2.5e-6	-3.93e-5***	1.94e-5***	9.5e-6	4.93e-06
Land quantity	-5.2e-6**	1.8e-6**	-2.99e-6***	2.4e-6***	-3.0e-7	6.16e-6***	2.9e-7	1.0e-6	-1.85e-6***
Irrigated area	6.343**	3.948***	-1.458***	3.992***	-1.859*	-0.451	-1.913***	-7.300***	0.708
Certified or transgenic seeds	-0.962**	-0.114	0.402***	0.072	0.126	0.393	0.241*	-0.147	-0.071
Confined cattle	3.705**	-0.460	-0.301	0.358	-0.019	-0.421	-0.388	-2.143*	0.148
Tilled area	-0.957	-0.835**	-0.178	-0.313	-0.086	1.777***	0.203	0.499	0.308
Mech.harvesting	0.915	-0.177	-0.172	-0.173	0.813**	-1.002	0.095	-0.659	0.048
Rainfall in summer	0.0237***	-4.6e-04	-9.8e-7	-0.00547***	-0.002*	-0.00893***	7.6e-04	-0.0058***	-2.8e-4
Rainfall in winter	0.0118***	0.0011	-0.0018***	-1.3e-4	-1.8e-4	-0.00827***	-0.00221***	0.0017	8.7e-4
Temperature in summer	1.208***	-0.207**	0.067	-0.264*	0.0014	-0.151	0.0806	-0.726***	0.0125
Temperature in winter	-0.464***	0.046	-0.018	6.5e-04	0.0234	0.0495	0.0063	0.352***	0.0113

*** p<0.01, ** p<0.05, * p<0.10.

For further investigation of the average climate impacts on agriculture, the model allows the calculation of the semi-elasticities of supply for each climate variable and each output considered $\left(\frac{\partial \ln(q_{ji})}{\partial Z_{ri}^{1}}\right)$. The effects can be calculated by municipality, when inputting municipal data into the marginal effect equation in order to identify the specific effects within the country. The average effects' calculation by each municipality's characteristics provides information on how these effects are distributed geographically in the country.

Table 2 summarizes the results obtained by estimating the effects by municipality (i) when $s_{ji} > 0$ (positive production of j in municipality i). Table 2 also shows both the percentage of municipalities where the effects are statistically significant at 10% and the average effect for Brazil.[29] The average semi-elasticity for Brazil is calculated by weighting the municipality's effect by its share of nationwide production. Thus, the effects better represent the marginal impacts of climate conditions on the production percentage of the country. It also shows the percentage of municipalities that accounted for significant effects (compared to all Brazilian municipalities and to the municipalities that produce a positive amount of the specific product).

Table 2: Semi-elasticities, Average Effects of Climate Variables on Production, by Product, Results by Municipality, 2006 Census

	Summer			**Winter**		
Output (*j*)	**% of Braz. munic. with stat. sig. effects**	**% munic. with q>0 and stat. sig. effects**	**Average effect for Brazil**	**% of Braz. munic. with stat. sig effects**	**% munic. with q>0 and stat. sig. effects**	**Average effect for Brazil**
Rainfall						
Soybeans	23%	97%	0.009	22%	94%	0.002
Maize	4%	4%	-0.002	3%	4%	-0.002
Other annual crops	11%	12%	-0.003	92%	96%	-0.011
Coffee	30%	97%	-0.035	2%	7%	-0.003
Other peren. crops	79%	95%	-0.048	4%	5%	-0.003
Milk	93%	97%	-0.182	93%	98%	-0.174
Wood	0%	0%	0.0E+00	26%	99%	-0.690
Beef	94%	99%	-0.017	4%	4%	2.9E-04
Other forest prod.	0%	0%	-3.1E-05	0%	0%	0.002
Temperature						
Soybean	23%	96%	0.440	22%	95%	-0.227
Maize	78%	87%	-0.764	2%	2%	0.010
Other annual crops	26%	27%	-0.013	9%	10%	0.002
Coffee	24%	79%	-0.281	1%	4%	-0.024
Other peren. crops	1%	1%	-0.021	1%	1%	0.003
Dairy	2%	2%	-0.026	1%	1%	0.002
Wood	0%	0%	0.0E+0	0%	0%	0.0E+0

Output (*j*)	Summer			Winter		
	% of Braz. munic. with stat. sig. effects	% munic. with q>0 and stat. sig. effects	Average effect for Brazil	% of Braz. munic. with stat. sig effects	% munic. with q>0 and stat. sig. effects	Average effect for Brazil
Beef	96%	100%	-1.870	96%	100%	0.900
Other forest prod.	0%	0%	-4.7E-4	0%	0%	2.4E-4

Note: Average effect for Brazil is calculated based on the weighted average of significant effects (weighted by the production amount of the municipality)

According to the estimated results, soybean production increases when summer temperature is above average. Increases in long-term average temperature in summer (by 1 Celsius degree), might raise soybean production by 44% on average in the municipalities that produce soybeans in Brazil. This effect is calculated based on 23% of the municipalities that presented statistically significant results (these municipalities account for 96% of the soybean production). Results in the same direction are observed for the average effect of rainfall in summer and winter. One possible explanation for this effect is that soybeans seem to have greater yields in rainier municipalities (both in summer and winter).

Municipalities with higher average rainfall during summer and winter produce less of most of the agricultural products analyzed: maize; other annual crops; coffee; other perennial crops; milk; wood; and beef. The average effects are not very high for many of these products. The products where output is affected the most are milk (both in summer and winter), coffee and other perennial crops (only in summer), and wood (only in winter). The results suggest that either these products are better adapted to drier places or the larger rainfall averages in the summer might have influenced the results.

The estimated impact of temperature seems to be much higher than of precipitation. The partial effects of higher average summer temperature seem to reduce production of maize, other annual crops, coffee, other perennial crops, milk and beef. Higher winter temperatures might adversely affect only coffee and soybeans.

Climate anomaly impact on efficiency

When it comes to the TE in 2006, the null hypothesis of no inefficient component is rejected by the data.[30] The histogram of the technical efficiency estimated is illustrated in Figure 1. The mean of this distribution is 51.3%. Approximately half of the municipalities where the efficiency is calculated have TE between 0.43 and 0.63. The highest efficiency measured is 0.87.

Since TE is a continuous variable limited to the range [0,1], Ordinary Least Square (OLS) regression might not be appropriate, as it can predict values outside this range. Besides its simplicity and linearity assumption, linear regression can also be justified when the values of the dependent variable fall mostly between 0.2 and 0.8. Thus, besides the OLS regression, a Generalized Linear Model (GLM) approach with a logit link function[31] is compared to the OLS results. Censored regression can also be estimated, such as a two-limit Tobit model (Long 1997), to control for the interval range of the dependent variable. The two latter options deal with the limited dependent variable problem. Standard errors are generated by bootstrap with 1000 replications. The complete results are described in Appendix B. There is no significant difference among the models, suggesting that the OLS approach is best suited for the analysis due to its simplicity and linearity.

The joint test for the significance of climate anomalies shows that these variables are relevant to explain the differences in efficiency among the municipalities. Defining droughts as a climate anomaly in which observed rainfall is two standard deviations below normal ($\alpha = 2$), the result indicates that droughts reduced farmer efficiency during the summer of 2005 (decreasing farmers' efficiency by 0.068) and 2006 (decreasing efficiency by 0.036) and in the winter of 2006 (decreasing efficiency by 0.13). The magnitude of these results is quite large compared to the previous effects discussed.

The only season that shows a positive effect of droughts (or negative effect of floods) is the fall of 2006, which is normally a harvest season for soybeans and maize. In harvest periods, floods are generally harmful, which is confirmed by the estimated results. However, fall is the growing season for winter crops (normally crops adapted to more temperate climate, such as wheat and triticale, among others). The net result from both of these forces is positive.

When it comes to cold stress effects on agriculture, colder temperatures in the winter of 2006 and spring of 2005 were harmful to producers, decreasing efficiency by approximately 0.062 and 0.1, respectively.
By using the estimated coefficients, the total profit loss or gain due to weather conditions in 2006 can be calculated by comparing the efficiency level when no anomalies occurred in rainfall or temperature in 2005 and 2006 ($\boldsymbol{C} = \boldsymbol{0}$) with the efficiency level considering the occurrence of the anomalies ($\boldsymbol{C}$ is as observed). Thus, the difference in efficiency (ΔTE) can be converted into profit difference for each municipality in the sample.

The impact of the 2005 and 2006 anomalie

s on TE (ΔTE) is calculated and transformed into variation in profits ($\Delta\Pi$), according to the following equation:

$$\Delta TE = \frac{\Delta\Pi(.)}{\Pi^*(.)} \therefore \Delta\Pi(.) = \Delta TE.\Pi^*(.) = \Delta TE\frac{\Pi(.)}{TE} \tag{14}$$

The change in profits is estimated by municipality, as well as the standard error of the estimates. Considering only the statistically significant effects by municipality, the average effect is a loss of profits due to rainfall anomaly at the end of 2005 and 2006 [Table 3]. The total loss from lack of rainfall is estimated at 5.6% of the current farmers' profits, in general. This result reflects the drier summer season observed both in 2005 (overall Brazil) and 2006 (northeastern and southern regions and Minas Gerais).

Table 3: Estimated Impact of Weather Anomalies on Profits, Brazil.

Estimates	% of profits	Loss (-) or gain (+) in million reais (Dec-06)	Loss (-) or gain (+) in million dollars (Dec-11)[32]
2005 and 2006 anomalies			
Rainfall	-5.60%	-21,440.7	-14,879.6
Temperature	3.34%	12,803.2	8,885.3
Drought or cold stress			
Drought	-30.50%	-116,689.1	-80,981.0
Cold stress	-13.19%	-50,474.2	-35,028.5

When it comes to the estimated temperature effects on profits, there is a gain in profits due to the year-end 2005 and year-end 2006 temperature conditions of 3.34%. As colder temperatures cause more harmful effects on crops than warmer temperatures, the above-average temperatures in 2005 and 2006 had a positive impact on farm efficiency.

Following the same procedure, droughts and cold stresses are simulated in the country, in order to give the sensitivity of the losses. Assuming a 2 standard deviation reduction in rainfall (droughts) and in temperatures (cold stresses) in Brazilian municipalities, the lost profit by municipality can be calculated. Considering only the statistically significant impacts, the total losses from these events are 13.2% and 30.5%, for cold stresses and droughts respectively.[33] The estimates suggest that droughts are the most harmful climate anomaly in Brazilian agriculture. These effects are summarized below, as well as the calculation in terms of monetary losses.

The average loss of profits that farmers face under the occurrence of extreme weather events could be seen as a proxy for farmers' maximum willingness to pay to protect themselves financially against drastic unforeseen weather changes. Thus, in 2006 the willingness to pay for rainfall shortcomings in the country was about 15 billion dollars, a considerable amount in terms of agricultural outcomes. The net effect, including the profit gain with increased temperature, is negative in 5 billion dollars (in 2011 values). This result is very similar to the direct damage of climate anomalies on agriculture in 2005 calculated by Porsse, Haddad and Pereda (2012). When it comes to the expected losses by region, the Midwest and South regions are slightly more affected by both harmful problems than the other regions [Table 4]:

Table 4: Percentage of profit losses due to climate anomalies, by region.

Region	Cold stress	Drought
North	-13.1%	-30.3%
Northeast	-13.0%	-30.0%
Southeast	-12.8%	-29.5%
South	-13.6%	-31.4%
Midwest	-15.5%	-35.9%

Concluding Remarks

The central idea of this article is that long-term climate influences the planning decision of producers, while short-term weather events can be treated as shocks which move production away from the planned production. This article employs a stochastic profit framework in the empirical analysis. Distinguishing between the effects of climate and weather in the production frontier framework is intuitively appealing. Still, it has not been deeply studied as shown by the relevant literature. Similarly, the theory of how stochastic frontiers models relate to long run and short run models of producer behavior seems to be still a caveat in the appropriate reference literature.

Thus, by using a translog profit frontier equation and data from the Agricultural Census of 2006 for Brazil, the average climate relevance on farmers' outcomes is tested and not rejected by the data. The marginal temperature effects calculated seem to be much higher than lower than historical rainfall levels. The partial effects of higher average summer temperature reduce production of maize and other annual crops, such as rice, beans, manioc, as well as coffee, milk, beef and other perennial crops, such as fruits. Places with higher winter temperatures might suffer adverse effect on coffee and soybean output. Only soybean production is affected positively by higher summer temperatures. One possible explanation is the current high adaptability of this crop to tropical regions, which may be able to explain these results.

The variation in technical efficiency levels is also not rejected by the data, indicating that efficiency levels differ in a statistically significant way among Brazilian farmers. The estimation of the TE leads to modeling possible determinants of farmers' deviation from optimum choices, which can be imposed by exogenous forces. This article proposes climate anomaly as a relevant determinant of farming inefficiency. The econometric test shows that climate anomalies are jointly relevant to explain the differences of technical efficiencies. The average effect due to rainfall shortcomings on farmer TE (during the summer months of 2005 and 2006) is a 5.6% reduction of the current farm profits, representing almost 15 billion dollars (in values of December 2011), which could be interpreted as the farmers' maximum willingness to pay to protect themselves against the unforeseen rainfall shortcomings in Brazil in 2006. As for the estimated temperature effects on profits, there was a gain in profits due to the year-end 2005 and year-end 2006 temperature conditions, on the order of 3.34%, or 8.9 billion dollars.

The estimates of simulated cold stresses and droughts throughout the country indicate lost profits of 13.2% to 30.5%, respectively, being slightly more intense in the southern and midwestern regions. These percentages represent 35 and 80 billion dollars of losses, respectively. Within this context, insurance instruments are important actions to protect farmers from such harmful situations. Weather index insurance is gaining importance as a possible intervention to overcome the negative impacts of climate risk on rural livelihoods and agricultural production. Weather index insurance is normally linked to rainfall anomalies (droughts, floods), extreme temperatures and precipitation (frosts, hail and rainstorms), or even to crop yield thresholds (Iturrioz 2009).

The use of a weather index linked to an insurance mechanism could be a potential policy action related to a market-driven solution, according to Hellmuth *et al*. (2009). Barnett and Mahul (2007) also underline the importance of understanding the mechanisms of weather impact on agricultural system models in order to design an index for this purpose.[34] This article could be helpful in identifying the important relationships for the index design.

This article innovates as it distinguishes between the effects of climate and weather in the production frontier framework using a translog profit frontier equation. Additionally, the majority of agricultural products were considered in the analysis, as well as many technological variables as quasi-fixed inputs inside a profit function approach. Another contribution of the article is the use of precise climate data from Brazilian weather stations, which allowed the measurement of extreme weather events' impact on agricultural outcomes. By using the method applied here, climate change effects can also be measured using data from INPE and, thus, compensation actions from the technological variables considered can be calculated.

APPENDIX A: DESCRIPTIVE STATISTICS

Table A.1: Information on Agricultural Production, 2006 Census

Variable	Total obs.	Mean	Std. Dev.	Min	Max
Maize (tonnes[35])	5548	6,826.75	25,470.49	0.00	596,645
Soybeans (tonnes)	5548	7,057.82	37,722.83	0.00	1,360,187
Other annual crops (tonnes)	5548	75,534.18	343,187.50	0.00	7,330,239
Coffee (tonnes)	5548	463.31	2,244.40	0.00	67,361
Other perennial crops (tonnes)	5548	3,855.21	18,816.18	0.00	479,138
Wood (m^3)	5548	7.34	53.93	0.00	1,675
Other forest products (tonnes)	5548	160.58	2,148.29	0.00	131,572
Milk (thd liters)	5548	3,057.84	5,776.21	0.00	125,104
Beef amount (cattle)	5532	604.93	948.66	0.00	10,565

Table A.2: Information Regarding Use of Inputs, 2006 Census

Variable	Total obs.	Mean	Std. Dev.	Min	Max
Input prices (Thousand reais per employee or hectares)					
Labor price (k R$/person)	5552	1.09	2.67	0.00	48.25
Price per fertilized hectare (kR$/ha)	5552	0.24	0.32	0.00	4.89
Input quantities (in thousand Kcal/hectares/employees)					
Total fuel (in k kcal)	5548	4,715	9,715	0.00	233,783
Total available land (ha)	5548	41,602	86,862	0.00	3,719,038
Total employees (number)	5548	4,698	7,761	0.00	306,279
Total fertilized area (ha)	5548	7,240	21,934	0.00	595,488

Table A.3: Technological Information Regarding Production, 2006 Census

Variable	Total obs.	Mean	Std. Dev.	Min	Max
Percentage of mechanical harvesting	5548	0.03	0.13	0.00	1.00
Percentage of certified seeds	5548	0.30	0.32	0.00	1.00
Percentage of transgenic seeds	5548	0.04	0.11	0.00	1.00
Percentage of certified or transgenic seeds usage	5548	0.33	0.35	0.00	1.00
Percentage of cattle confined	5548	0.03	0.07	0.00	1.00

Variable	Total obs.	Mean	Std. Dev.	Min	Max
Participation of artificial insemination	5427	0.08	0.14	0.00	1.00
Percentage of tilled area	4691	0.07	0.16	0.00	0.89
Percentage of irrigated area	5544	0.02	0.06	0.00	0.64
Percentage of animal tracking	5548	0.05	0.07	0.00	1.00
Percentage of industrial feed usage	5548	0.01	0.03	0.00	0.50

Table B.4: Descriptive Statistics, 2006 Census

Variable	Obs	Mean	Std. Deviation	Min.	Max.
% of farmers in cooperatives or assoc.	5547	0.245	0.201	0.00	1.00
% of farmers that own the land	5547	0.798	0.180	0.00	1.00
% of tenant farmers	5547	0.045	0.064	0.00	1.00
% of farms that use pest control	5547	0.113	0.134	0.00	1.00
% of pop. with 0 to 4 years of schooling	5548	63.314	9.812	26.00	90.62
% of pop. with 5 to 8 years of schooling	5548	15.653	3.113	4.33	35.13
% of pop. with 9 to 11 years of schooling	5548	16.433	5.583	1.52	40.88
% of pop. > 12 years of schooling	5548	4.169	2.613	0.18	26.69
% of pop. with undetermined schooling	5548	0.431	0.516	0.00	6.48
% of farmers that used any credit	5547	0.180	0.144	0.00	0.85
Altitude of the municipality	5499	412.310	293.070	0.00	1628.00
Average size of farms (in hectares)	5543	34.343	79.918	0.00	1561.98
Agricultural HHI	5546	0.462	0.210	0.00	1.00
% of female farmers	5547	10.977	6.349	0.00	100.00
% of farmers 1 to 5 years of experience	5547	17.995	8.196	0.00	100.00
% of farmers 5 to 10 years of experience	5547	18.539	8.002	0.00	100.00
% of farmers: > 10 years of experience	5547	60.485	13.735	0.00	100.00
% of family farms	5547	78.568	15.424	0.00	100.00
Index for logistic cost to São Paulo	5547	0.299	3.381	0.00	100.00
Degraded agricultural area (in hectares)	5543	0.003	0.010	0.00	0.48

Table B.5: Descriptive Statistics, Rainfall and Temperature Deviations from Long-Term Average, 2005 and 2006, by Region

Variable (average)	North	Northeast	Southeast	South	Midwest	Brazil
Rainfall: $[Z_i^{Rain} - E(Rain)]/\sigma_{Rain}$						
Summer (2006)	0.226	-0.406	-0.135	-0.519	0.184	**-0.249**
Fall (2006)	0.620	0.448	0.093	-0.455	0.250	**0.146**
Winter (2006)	0.048	-0.043	-0.381	-0.230	-0.375	**-0.204**
Spring (2006)	0.200	0.337	0.503	0.057	0.421	**0.323**
Summer (2005)	-0.213	-0.358	0.285	-0.705	-0.119	**-0.209**
Fall (2005)	0.127	0.029	0.314	0.574	0.122	**0.246**
Winter (2005)	-0.328	0.175	0.074	0.327	-0.375	**0.091**
Spring (2005)	-0.315	-0.583	0.351	0.666	0.139	**0.045**
Temperature: $[Z_i^{Temp} - E(Temp)]/\sigma_{Temp}$						
Summer (2006)	0.792	0.751	0.372	0.543	0.659	**0.589**
Fall (2006)	0.134	0.157	-0.115	-0.243	-0.034	**-0.028**
Winter (2006)	0.868	-0.018	0.273	0.678	0.811	**0.359**
Spring (2006)	0.993	0.370	0.019	0.149	0.411	**0.272**
Summer (2005)	1.429	0.950	0.130	0.415	1.121	**0.644**
Fall (2005)	1.131	0.644	0.402	0.323	0.662	**0.544**
Winter (2005)	1.193	0.299	0.472	0.625	0.795	**0.534**
Spring (2005)	1.362	0.724	0.400	-0.141	0.943	**0.513**

APPENDIX B: RESULTS FROM THE ESTIMATED PROFIT EQUATION

Table B.1: Complete Results, TE Determinants, 2006

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Variables	OLS	TOBIT	GLM#
% of farmers in cooperatives or associations	0.0790***	0.0790***	0.0802***
% of farmers that own the land	-0.00544	-0.00544	-0.00545
% of tenant farmers	0.162***	0.162***	0.165***
% of farms that use pest control	0.0116	0.0116	0.0117
% of population with 0 to 4 years of schooling	-0.00773***	-0.00773***	-0.00783***
% of population with 5 to 8 years of schooling	-0.00632***	-0.00632***	-0.00640***
% of population with 9 to 11 years of schooling	-0.0111***	-0.0111***	-0.0113***
% of population with undetermined schooling	0.000658	0.000658	0.000714
% of farmers that used some type of credit	0.0588**	0.0588**	0.0596**
Altitude of the municipality	3.20E-06	3.20E-06	3.30E-06
Average size of farms (in hectares)	-0.00050***	-0.00050***	-0.00051***
Squared average size of farms (in hectares)	3.98e-07***	3.98e-07***	4.11e-07***
Agricultural HHI	0.222***	0.222***	0.226***
% of female farmers	3.58E-05	3.58E-05	4.10E-05
% of farmers with 1 to 5 years of experience	-0.000463	-0.000463	-0.000465
% of farmers with 5 to 10 years of experience	0.000407	0.000407	0.000417
% of farmers with more than 10 years of experience	7.11E-05	7.11E-05	7.41E-05
% of family farms	0.00102***	0.00102***	0.00103***
Index for logistic cost to São Paulo	-0.0582	-0.0582	-0.0589
Degraded agricultural area (in hectares)	-0.223	-0.223	-0.229
[Rainfall - E(Rainfall)]/σ in the summer of 2006	0.0181*	0.0181*	0.0184*
[Rainfall - E(Rainfall)]/σ in the summer of 2005	0.0340***	0.0340***	0.0346***
[Rainfall - E(Rainfall)]/σ in the fall of 2006	-0.0341***	-0.0341***	-0.0345***
[Rainfall - E(Rainfall)]/σ in the fall of 2005	-0.012	-0.012	-0.0122*
[Rainfall - E(Rainfall)]/σ in the winter of 2006	0.0654***	0.0654***	0.0663***
[Rainfall - E(Rainfall)]/σ in the winter of 2005	-0.00472	-0.00472	-0.00486
[Rainfall - E(Rainfall)]/σ in the spring of 2006	-0.0108	-0.0108	-0.011
[Rainfall - E(Rainfall)]/σ in the spring of 2005	0.00176	0.00176	0.00172
[Temp. - E(Temp.)]/σ in the summer of 2006	-0.000871	-0.000871	-0.000776
[Temp. - E(Temp.)]/σ in the summer of 2005	0.00325	0.00325	0.0033
[Temp. - E(Temp.)]/σ in the fall of 2006	-0.0218	-0.0218	-0.0221
[Temp. - E(Temp.)]/σ in the fall of 2005	-0.0208	-0.0208	-0.021
[Temp. - E(Temp.)]/σ in the winter of 2006	0.0310**	0.0310**	0.0315**
[Temp. - E(Temp.)]/σ in the winter of 2005	-0.0448***	-0.0448***	-0.0455***
[Temp. - E(Temp.)]/σ in the spring of 2006	-0.0168	-0.0168	-0.0172
[Temp. - E(Temp.)]/σ in the spring of 2005	0.0499***	0.0499***	0.0506***
Sigma (Tobit model)		0.147***	
Constant	1.119***	1.119***	
Test for climate variables##: Chi-sq$_{(16)}$	**109.78*** **	**112.84*** **	**112.47*** **
Observations	**4,473**	**4,473**	**4,473**
AIC	**-4376.22**	**-4374.22**	**0.95**
BIC	**-4139.2**	**-4130.8**	**-36875.54**
log-likelihood		**2225.11**	**-2094.28**

*** p<0.01, ** p<0.05, * p<0.1; # marginal effects calculated at the sample mean.

Joint test for the H_0 that all climate variables' coefficients are zero.

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Footnotes

[1] Estimated based on FAO (2011) and USDA (2010). Both sources consulted in May, 2012.

[2] Beef and cow's milk production, which represent approximately 55% of livestock production value.

[3] In general, the negative effects of short-term climate on agriculture are related to crop failure or changes in crop or animal productivity, caused by droughts, frosts, hail, severe storms and floods, etc. In 2012, the governments of Rio Grande do Sul and Santa Catarina calculated that the agricultural losses due to droughts reached US$ 480 million for maize, dairy products and beans. In the same year, the soybean production in South America was 3% below the expected level due to adverse weather (*Valor Econômico*, 2012)

[4] Most scientists agree that climate change in the future is expected to be a multifaceted phenomenon, involving evolution in the distribution of climate over time, which might affect long-term average conditions as well as the variation of climate (IPCC, 2001; 2007). This article takes into account both concepts in the modeling, which can bring important evidence for future interventions.

[5] Extreme weather events also contribute indirectly to the existence of rural poverty. According to Rosenzweig and Wolpin (1993), poor (normally small) farmers avoid taking risks or spending assets, by obtaining larger loans or contracting insurance, under the threat of extreme weather events. This limits their productivity gains through investment in capital and innovations. Rosenzweig and Biswanger (1993) also suggest that uninsured weather risks can result in lower efficiency and lower profits for small farmers.

[6] See Mendelsohn, Nordhaus and Shaw (1994), Sanghi et al. (1997), Evenson and Alves (1998), Deschênes and Greenstone (2007) and Féres, Reis and Speranza (2008).

[7] See Lang (1999), Féres, Reis and Speranza (2010) and Nadal (2010).

[8] This article assumes that farmers do not have information about the next season's climate (or accurate information about it). The arguments in favor of this hypothesis are: (i) access to short-term forecasts is higher among large and medium farmers, who represent a small proportion of total farmers; (ii) the longer the weather forecast horizon, the less accurate it will be. For perennial crops, livestock and forest products closer forecasts might not be useful, although they are more reasonable for annual crops.

[9] To illustrate, assume two identical farmers (farmer 1 and farmer 2) that produce the same crop, using the same amount of inputs, and having similar average climate conditions. If farmer 1 is affected by a drought while farmer 2 is not, the former will probably have lower production/profits compared to the latter farmer

(lower profits might arise both from harvest failure and from the need to use more inputs to reduce damages). This difference in outcome between the farmers is called inefficiency. This example helps to motivate the use of an inefficiency approach, or efficient analysis, to consistently measure farmers' decisions.

[10] The production function approach might be biased and inconsistent if the profit maximization is valid, since the input mix is dependent on the error term of the production function (Coelli 1995).

[11] According to Kumbhakar and Lovell (2000), profit analysis offers a more complete approach as it better characterizes the production structure and technologies. Hence, this approach generates what is called "profit efficiency", which is defined as the ability of a farm to achieve the 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).

[12] Note on agricultural prices: Due to the different time windows between the decision to grow the crop, its harvest and sale of the output, farmers must have price expectations (p^e) when deciding on the crops/animals to grow/raise and the amount of expected return. Rausser and Just (1981) state that the use of future prices, for some agricultural commodities, performed better than econometrically based forecasts. However, future prices do not exist for all agricultural products and also do not have any regional variation. Barbosa (2011), studying the land-use pattern in Brazil, assumed that farmers' price expectations are the average of real prices observed in the five years before the decision, which is an approach more closely related to adaptive expectations over past prices. This article tests Barbosa's estimated prices and also considers a different approach to the weighting process of Barbosa (2011) by modeling each product price using a dynamic model based on panel data. One-time lagged prices are also tested, but these prices might not be good approximations, mainly for perennial crops such as coffee, whose prices are highly cyclical. The superscript (^{e}) for prices will be omitted to simplify the equations.

[13] The transformation function is called the joint production function $g(q/Z)$.

[14] The results depend on the regularity conditions of the profit function, which guarantee the existence of an optimum level (homogeneity, and convexity).

[15] The technical inefficiency measure, as Berger, Hancock and Humphrey (1993) point out, might also include idiosyncratic factors not included in the model (input quality, for example). This article assumes no correlation between these factors and the exogenous variables for the profit function.

[16] It is assumed that there are no allocative inefficiencies.

[17] Using duality in production theory and the Hotelling Lemma, the derivation of the profit logarithm generates output and input profit shares (sj). From the profit share equations, the effects of prices and other exogenous variables can be measured by their estimated elasticities. The product j's elasticity in relation to the exogenous variable r can be denoted by $\varepsilon_{jr} = z_r(\delta_r + \sum_{j>1}\gamma_{jr}\ln(p_j/p_1) + \frac{1}{2}\sum_{h=1}^{f}\theta_{hr}Z_h + \frac{\gamma_{jr}}{s_j})$.

[18] The dependent variable is limited to the range of [0,1], implying the use of specific econometric techniques.

[19] Battese and Coelli (1995) propose a joint estimation between the profit equation and the determinants equation, assuming that the average of τ_i (μ) is a function of those determinants. This procedure eliminates possible inconsistency, as τ_i is assumed to be identically distributed in the profit frontier equation, and is assumed in this analysis.

[20] According to the literature, the main variables that influence farm management are farmers' socioeconomic circumstances, such as education and farming experience. Many studies have identified farmer education and characteristics as important determinants of efficiency (See Xu and Jeffrey (1998), Abdulai and Huffman (1998), Bhasin (2002), Rahman (2003), Kolawole (2006) and Bozoglu and Ceyhan (2006)). An increase in the level of farmer education, *ceteris paribus*, increases the use of more advanced techniques due to the increased capacity to understand the technical aspects related to agricultural production (Ali, Parikh and Shah 1994; Coelli and Fleming 2004). Thus, better education can spur the spread of technical change (Huffman and Evenson 1989). Another relevant variable that influences efficiency of farmers is farm size (Ali, Parikh and Shah 1994; Ali and Flinn 1989; Wang, Wailes and

Cramer 1996; Xu and Jeffrey 1998; Tzouvelekas, Pantzios and Fotopoulos 2001). In general, the literature points to an inverse relation of size and efficiency, as small farmers might use an exceptional amount of work to compensate the failures of product and credit markets that they observe. See Barret (1996) for the theoretical development of this argument.

[21] Investigating credit constraints, Helfand (2003) and Imori (2012) posit that they can lead to non-optimal choices by farmers, being an important source of inefficiency in agriculture.

[22] Rural infrastructure is singled out as a key limiting determinant of efficiency by Ahmed and Hossain (1990). Other studies have also identified this influence by calculating the impact of the distance to markets and extension services (Bhasin 2002), agricultural infrastructure (Rahman 2003), and regional differences (Tzouvelekas, Pantzios and Fotopoulos 2001) on inefficiency. Soil conditions might also have a positive or negative influence on productivity, as highlighted by Rahman (2005) and Rahman and Parkinson (2007).

[23] See the following sources, consulted in November 2011: Petrobrás (2011) and ABEPRO (2011).

[24] For educational variable, the data source is the Demographic Census of 2010, from the IBGE.

[25] The local political unit in Brazil is the municipality, which as similar to a county, except there is a single mayor and municipal council. There are no unincorporated areas in Brazil.

[26] Cunha *et al*. (2012) based their analysis on Seo and Mendelsohn (2008) and Seo (2010, 2011).

[27] Frosts occur when there is ice deposition on external plants and objects. The occurrence of frosts is due to a combination of low temperatures and moisture in the atmosphere. Frost may cause death of plants when it entails the freezing of plant parts. Some specialists believe that between 0ºC and -4ºC may be the critical temperatures for more resistant plants, such as coffee, sugarcane and some fruits (Mota 1981). Temperatures above this range may cause even worse effects. Normally frosts are worse in the winter and at medium and high latitudes and on higher altitudes areas, mainly the south of Brazil and some higher areas in São Paulo and Minas Gerais states.

[28] Ho: all β_{jj} are zero; Ha: all β_{jj} are statistically significantly above zero. 10 degrees of freedom. Chi-square of 158.73 (statistically significant at 1%). Individual tests are also performed. The estimated results are not statistically significant from zero or negative for three products: soybeans; beef; and maize. Note: The higher log-likelihood value is obtained by using the 5-year average price as the proxy for expected price by farmers.

[29] The statistically insignificant results were disregarded.

[30] The statistic of the z-test is 94.89 (p-value of 0.000), rejecting the null hypothesis of full efficiency. The test is based on Coelli (1995), who proposed a test in the third moment of the compound error distribution. Note: Other results were suppressed of this version due to size limits, but can be requested to the authors.

[31] The GLM model is a relaxation of the previous model, allowing the linear model to be related to the response variable by a link function and the magnitude of the estimated variance to be a function of the predicted values (Nelder and Wedderburn 1972).

[32] Dollar amounts in 2011 are calculated by updating the 2006 values using the IPCA and converting it to dollars by the average exchange rate for the end of 2011. Source: Sisbacen PTAX800.

[33] Droughts are assumed to be two-standard deviation negative anomalies in rainfall; cold stress is assumed to be two standard deviation negative anomalies in temperatures.

[34]According to Baethgen *et al*. (2008), agricultural systems have an important role for modeling a weather index in three main areas: "*Designing indices that manage basis risk in its various forms; identifying and quantifying the right risk, and understanding and evaluating potential incentives, management responses, and benefits associated with index insurance and its interaction with advance information.*"

[35] Metric tons.