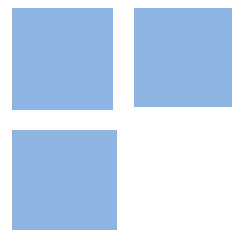




Climate and Weather Impacts on Agriculture: The Case of Brazil

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Abstract:

The world's population will rise exponentially in the coming decades, increasing the demand for food and challenging the agricultural sector to ensure food security. Due to the importance of climate conditions for agriculture, this article analyzed two different hypotheses regarding climate impacts on agricultural markets in Brazil. First, farmers only observe the average climate conditions of their region when deciding the type and amount of crop or animal to grow or raise. Second, weather diversions from normal climate conditions cause farmers to deviate from optimal profits. Neither hypothesis was rejected by the data. The 2006 estimated loss from rainfall anomalies was 12.8 billion dollars (in 2014 values).

Keywords: translog profit function; climate change; climate and weather impacts; profit frontier; agricultural economics.

JEL Codes: D21; Q11; Q12; Q54; Q56.

Climate and Weather Impacts on Agriculture: The Case of Brazil

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September 20, 2018

Abstract

The world's population will rise exponentially in the coming decades, increasing the demand for food and challenging the agricultural sector to ensure food security. Due to the importance of climate conditions for agriculture, this article analyzed two different hypotheses regarding climate impacts on agricultural markets in Brazil. First, farmers only observe the average climate conditions of their region when deciding the type and amount of crop or animal to grow or raise. Second, weather diversions from normal climate conditions cause farmers to deviate from optimal profits. Neither hypothesis was rejected by the data. The 2006 estimated loss from rainfall anomalies was 12.8 billion dollars (in 2014 values).

Resumo

A população mundial crescerá exponencialmente nas próximas décadas o que desafiará o setor agrícola a garantir segurança alimentar. Devido à importância das condições climáticas para a produtividade agrícola, esse artigo testa duas hipóteses sobre o efeito do clima no mercado agrícola brasileiro. Primeiro, produtores observam as condições climáticas médias quando decidem o que e quanto produzir. Segundo, anomalias climáticas desviam os produtores do lucro ótimo. Nenhuma das hipóteses foi rejeitada pelos dados. A perda estimada pelo modelo das anomalias de chuva foi de US\$12,8 bilhões.

Keywords: translog profit function; climate change; climate and weather impacts; profit frontier; agricultural economics.

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Palavras-chave: função lucro translog; mudanças climáticas; impactos do clima; fronteira de lucro; economia agrícola.

JEL Classification: D21; Q11; Q12; Q54; Q56

1 Introduction

This study aimed to measure specific climate effects on agriculture because climate is an important factor influencing agricultural production. Climate is assumed to affect agricultural production on two different temporal scales: in the long-term because historical climate may be a direct input for crop and animal production affecting land use configuration, and in the short-term because weather conditions are an important determinant of crop/livestock failure and loss of productivity¹.

The central idea of this analysis was that long-term climate influences the planning decisions of producers, while short-term weather events move production away from the production frontier. Thus, this study employed a stochastic profit framework in the empirical analysis and treats short- and long-term climate effects separately. The theory of how stochastic frontiers models relate to long-term and short-term models of producer behavior is currently underdeveloped, so this study addresses this deficiency while also discussing an important matter for public policy.

The following question is addressed in this study: how do climate and weather variables relate to the long-term and short-term problems of the agricultural producer? The answer to this question not only contributes to the current debate on how expected climate change may influence future human activities², but also addresses the efficacy of propositions for short-term actions intended to reduce climate variability effects on poor communities. Climate variations are expected to adversely affect food availability and generate significant losses, likely affecting small farmers and poorer populations the most³. The policy actions taken to reduce harmful climate impacts should rely on consistent estimations that take into account long-term trends as well as short-term weather changes that affect the production outcome.

This study focused on Brazilian farming and livestock breeding. Brazil is one of the leading grain producers and exporters in the world. The country has continental dimensions, with correspondingly large climate variability from the equatorial North to the temperate South, 4 thousand kilometers away. The effects of climate and weather on production are distinguished by the frontier framework using a translog profit frontier approach. The results corroborate the hypothesis, showing that temperature seems to be more important than rainfall in the long-term, while rainfall more adversely affects agricultural production in the

¹As caused by droughts, frosts, hail, severe storms and floods. In 2012, the soybean production in South America was 3% below the expected level due to adverse weather conditions ([Valor Economico \(2012\)](#)).

²Climate change involves an evolution in the distribution of climate over time, which may affect long-term average conditions as well as the variation of climate ([IPCC \(2007\)](#))

³[Rosenzweig and Wolpin \(1993\)](#) found that extreme weather events contribute indirectly to the existence of rural poverty, as poor (small) farmers avoid taking risks or spending assets under the threat of extreme weather events. This limits their productivity gains through investment in capital and innovations ([Rosenzweig and Binswanger, 1993](#)).

short-term. Simulations indicated that rainfall levels much lower than historical average, such as that observed during the summer of 2005 and 2006, have caused a loss of 5.6% in farm profits in 2006, representing almost 12.4 billion dollars (in 2014 values). This can be interpreted as the farmers' maximum willingness to pay to protect themselves against the unforeseen rainfall shortcomings in Brazil during that year.

2 Theoretical Background

2.1 Agricultural Approach

Studies measuring the impact of climate on agricultural outcomes are usually based on the following two different modeling approaches: The Ricardian or hedonic approach (Mendelsohn et al. (1994); Deschs and Greenstone (2007)) and the agronomic or crop approach (Lang (2001)). While the former measures the influence of climate on land values, the latter uses the 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 their relative advantages and disadvantages and their data requirements. Some authors argue that studies following the Ricardian approach produce more aggregated results, which may be an obstacle for the measurement and the proposal of adaptation measures (Deschs and Greenstone (2007)). This study adopted an agro-economic approach to identify the specific effects of climate on agricultural yields. The agro-economic literature bases this analysis on agricultural profits and production functions, which are briefly discussed here.

The next step is to understand how climate can be considered in this approach, as it impacts the model choice. Demir and Mahmud (2002) argued that the local agro-climatic conditions are historically known by farmers and therefore should not be treated as random because they influence the producers' choices. As a result, changes in average climatic conditions can modify the behavior of farmers as they take into account local climate patterns, such as temperature and precipitation, in deciding on the output-input mix (Kumbhakar and Lovell (2000); Kumar and Parikh (2001)). Assuming that farmers only observe the past climate conditions (average climate), it seems reasonable to consider that the historical climate is an important input for crop and livestock outputs⁴.

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

⁴We assume that farmers do not have accurate information about the next season's climate. 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, and (ii) the longer the weather forecast horizon, the less accurate it will be. For perennial crops, livestock and forest products short-term forecasts might not be useful, although they are more relevant for annual crops.

output-input mix that optimizes 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 et al. (1994)). This short-term climate concern has led to the use of an efficiency analysis, which measures and helps to identify variations in the physical and financial performance achieved by farmers operating with the same environmental and economic constraints (Wilson et al. (2001)).

Ali and Flinn (1989) argued that to measure efficiency, a production function approach may not be appropriate when the population of farmers faces different prices and has different factor endowments⁵. When facing heterogeneous farms, the authors urge the use of stochastic profit function models. The stochastic profit function model, or profit frontier approach, in addition to providing a compact form to summarize a multiproduct technology⁶, is an effective way to introduce theoretical constraints into the analysis. Next, the theoretical and empirical developments are detailed, which support the measurement of the intended effects.

2.2 Profit frontier approach

It was assumed that producers allocate their variable inputs (g) to types of production (s). The products (m) considered in the analysis are such that $m = s + g$. Producers decide production and total inputs by solving a variable profit maximization problem in a competitive market. Thus, prices are exogenous. Each producer also faces quasi-fixed inputs (exogenous variables in the short-term), represented by ($Z = (Z_1, \dots, Z_f)'$), which affect the farmer's decision ($q = (q_1, \dots, q_m)'$).⁷ The Z vector includes other exogenous variables, such as local climate patterns in temperature and rainfall, and technological use by the farm.

Producers maximize a short-term profit function, or a restricted profit function, by choosing the allocation of multiple outputs and inputs given an endowment of fixed factors Z and p . By replacing the optimal solution, q^* , in the profit (Π) function, the optimal profit function can be described as $\Pi^*(p, Z)$, depending on the exogenous variables prices and other quasi-fixed inputs. In this model because markets are perfect, there are no losses and farmers are fully efficient in optimizing profit.

Kumbhakar and Lovell (2000) relaxed the assumption of full efficiency because inefficient farmers can survive in the short-term. Assuming that the correct relative market prices are observed by the farmers, all the farmer inefficiency comes from technical issues. Considering the potential inefficiencies (τ) in the profit function and assuming the transcendental loga-

⁵ 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)).

⁶ According to Kumbhakar and Lovell (2000), profit analysis offers a more complete approach as it better characterizes the production structure and technologies.

⁷ The vector q denotes the products amounts: $q_j \geq 0$, when j is an output; $q_k \leq 0$ and when k is an input.

rithm (translog) function for farmers' restricted profit function (Christensen et al. (1975)), the translog profit frontier normalized at product 1 is:

$$\begin{aligned} \ln\left(\frac{\Pi}{p_1}\right) = & \beta_0 + \sum_{j>1} \beta_j \ln(p_j/p_1) + \frac{1}{2} \sum_{j>1} \sum_{k>1} \beta_{jk} \ln(p_j/p_1) \ln(p_k/p_1) + \\ & \sum_{j>1} \sum_r \gamma_{jr} Z_{jr} \ln(p_j/p_1) + \sum_r \delta_r Z_r + \frac{1}{2} \sum_h \sum_r \theta_{hr} Z_h Z_r - \tau \end{aligned} \quad (1)$$

In which $j, k = 1, \dots, m$; $r, h = 1, \dots, f$; and $\beta, \delta, \theta, \gamma$, and τ are parameter vectors. The normalized translog functional form generates a closed-form solution.

Note that τ is a non-negative component that shifts the profit from the optimum. To estimate this equation, Kumbhakar and Lovell (2000) suggested a maximum likelihood estimation using the probability density function (pdf) of the composite error $(-\tau_i + v_i)$ ⁸. Thus, assuming independence among the observations, the log-likelihood is implemented in Stata and the translog profit frontier can be estimated⁹.

One of the advantages of using the normalized translog functional form is the flexibility of testing and assuming the theoretical hypothesis to ensure that producers are maximizing profits. Therefore, the profit frontier equation can be estimated by imposing the symmetry and homogeneity assumptions. Another relevant piece of information from the model is that farmers from different climate conditions in the sample could change the technical use of quasi-inputs and inputs due to distinct local climate. In this context, different behaviors among farmers allow for the analysis of adaptation to expected climate change through the calculation of possible compensatory responses to climate variations.

2.2.1 Efficiency analysis

τ measures the shifts of profit away from the optimum, or the failure of the farmer to reach the maximum possible profit, as follows: $\tau = \ln \Pi^*(p, Z) - \ln \Pi$, $j = 1, 2, \dots, m$; in which Π is the actual profit level achieved, and $\tau \geq 0$ is the inefficiency term. This measure can be interpreted as the intrinsic total profit/technical inefficiency of each farmer. Thus, the *TE* ratio is the loss of profits from not producing the desired production levels:

$$TE = \exp(-\tau) = \frac{\Pi(p, Z)}{\Pi^*(p, Z)} \quad (2)$$

⁸When v_i is *i.i.d.* and follows $N(0, \sigma_v^2)$ and τ_i is *i.i.d.* and follows $N^+(\mu, \sigma_\mu^2)$, the pdf of the composite error can be found (DeGroot and Schervish (2012))

⁹The derivative of the profit logarithm is the output/input profit shares (s_j). Thus, 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 $\varepsilon_{jr} = z_r \left(\delta_r + \sum_{j>1} \gamma_{jr} \ln(p_j/p_1) + \frac{1}{2} \sum_h \theta_{hr} z_h + \frac{\gamma_{jr}}{s_j} \right)$.

As $\tau \geq 0$, the measure of TE varies from zero, the least efficient, to unity, fully-efficient. [Kumbhakar and Lovell \(2000\)](#) proposed an unbiased estimator for TE , considering that the determinants of the TE should be uncorrelated with the covariates of the profit function. Within this context, [Battese and Coelli \(1995\)](#) stated that efficiency can be explained by a set of exogenous variables. The authors proposed a joint estimation of the profit equation and the determinants equation, assuming that the average of $\tau_i(\mu)$ 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. Thus, the TE determinants equation is:

$$TE_i = f(C_i, X_i, D_i) + \varepsilon_i \quad (3)$$

In which ε_i is a random shock with positive distribution for each farmer (representative farmer of municipality i)¹⁰; C_i is a vector of climate anomalies (e.g., extreme weather variables) in the municipality i ; X_i is a vector of farmer characteristics; and D_i is a vector of other determinants. [Gorton and Davidova \(2004\)](#) divided the determinants into two groups: human capital and structural factors. The former group includes information on the farmers' management, their characteristics and education¹¹, while the latter group comprises environmental conditions, credit access¹², rural infrastructure¹³ and information on property rights, among others.

In regard to environmental conditions, [Kumar and Parikh \(2001\)](#) stated that weather deviations from normal conditions influence crop growth and, consequently, the TE of farmers. The work of [Sherlund et al. \(2002\)](#) found that the exclusion of climate variables in the determinants equation could lead to biased parameters. [Demir and Mahmud \(2002\)](#) included environmental factors to explain efficiency differences. They emphasized that the omission of climate variables under the argument that they are beyond the farmers' control, can lead to inaccurate interregional technical efficiency comparisons. They considered rainfall anomalies (i.e., rainfall above or below the national average) as one of the main determinants of technical inefficiency. In Brazil, [Imori et al. \(2012\)](#) found statistically significant impacts of

¹⁰ The local political unit in Brazil is the municipality, which is similar to a county except there is a single mayor and municipal council. There are no unincorporated areas in Brazil.

¹¹ The literature identifies education and farming experience as the main farm management determinants ([Xu and Jeffrey \(1998\)](#); [Rahman \(2005\)](#); [Bozoğlu and Ceyhan \(2007\)](#)). Another relevant variable that influences efficiency of farmers is farm size ([Ali et al. \(1994\)](#); [Ali and Flinn \(1989\)](#); [Wang et al. \(1996\)](#); [Xu and Jeffrey \(1998\)](#); [Tzouvelekas et al. \(2001\)](#)). [Barrett \(1996\)](#) 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.

¹² [Helfand \(2003\)](#) and [Imori et al. \(2012\)](#) posit that they can lead to non-optimal choices by farmers.

¹³ [Ahmed and Hossain \(1990\)](#) say that rural infrastructure is the key limiting determinant of efficiency. Other studies have identified this influence by calculating the impact of the distance to markets and extension services, agricultural infrastructure, and regional differences ([Rahman \(2005\)](#); [Tzouvelekas et al. \(2001\)](#)) on inefficiency. Soil conditions might also have a positive or negative influence on productivity, as highlighted by [Rahman and Parkinson \(2007\)](#).

temperature and precipitation on the estimated technical efficiency.

3 Material and Methods

This section presents the sources of the 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 of the variables discussed.

3.1 Data sources: Profit frontier

The main agricultural data source in the country is the Brazilian Agricultural Census, conducted by the Brazilian Institute of Geography and Statistics (IBGE). The census aggregates farmers into administrative districts, such as municipalities, to preserve the identity of farmers. Additionally, data based on responses by fewer than three farm establishments are not reported for the same reason. Despite the loss of desired information on the individual choices of farmers, this procedure does not preclude this analysis, as there are local homogeneities among the grouped farmers (Disch (1985)). Moreover, the price variability among regions is preserved. Pastore (1968) minimizes the aggregation problem when the model is estimated by using the information available for the smallest regional unit.

The last census was conducted in 2006, from January to December, and represents a cross-section of average municipal farmers. Panel data, which could generate more accurate results, were not used for two reasons: first, the data incompatibility between the collection periods of the last two agricultural censuses carried out in Brazil (2006 and 1995-96), and second, the different variables among the censuses. 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 the 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 in four groups with the share of the agricultural production value shown in parentheses: (i) annual crops (52.7%): soybeans, maize, and 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 terms of production value in 2006¹⁴. The choice of inputs was made using the same criteria, which selected four inputs: land and fuel as quasi-fixed inputs, and labor and fertilizers as variable inputs.

¹⁴ 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.

Farmers must have price expectations (p^e) when deciding on the crops or animals to grow or raise and the amount of expected return. [Rausser and Just \(1981\)](#) stated that the use of future prices performed better than econometric forecasts. However, future prices do not exist for all agricultural products and do not have regional variation. [Barbosa \(2011\)](#) assumed that the farmers' expectations are the average of real prices observed in the five years before the decision (adaptive expectations). This article tested Barbosa's estimated prices and also different weights by modeling each product price using a dynamic panel-data model. The superscript (e) for prices will be omitted to simplify the equations.

The profit variable was measured using 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 well as the total production value of the year, and not total sales. However, it does not account for other minor costs that might be omitted, such as farm household labor. This would cause a bias in climate estimates only if the average climate is correlated with such implicit costs.

The total amount of fuel used by the farm was considered a proxy for the capital stock of the farm. The fuel variable was generated by summing up the data on different energy sources. All types of fuels were converted into energy generation as kilocalories (kcal), using the density and power capacity figures. In regard 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, including permanent workers, temporary workers, farm owners, and others.

The technological variables available in the 2006 Census were chosen based on the study of EMBRAPA (*Empresa Brasileira de Pesquisa Agrícola*, the government agricultural research agency) and IBGE (2010). They mapped the following technological variables: use of irrigation, 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.

Complementary data regarding Brazilian agriculture is available from the Municipal Agricultural Survey (PAM), conducted by IBGE, which collects annual crop production. These data were used for the price expectation estimations.

3.2 Data sources: TE determinants analysis

Based on the TE determinants literature and data availability, a group of variables was selected for the study. These variables are described below:

Table 1: Complete description of variables and their sources.

Variable	Description	Source
Farmer education and experience	Percentage of local population that completed each education level, and the percentage of farmers, by experience years, who run establishments: less than 1 year, 1-5 years, 5-10 years, over 10 years	Demographic Census of 2010 (IBGE)
Other farmer characteristics	Farmer gender; percentage of land owners; percentage of tenants/sharecroppers; Soil type: percentage of non-agricultural land in the municipality (namely, degraded areas)	Agricultural Census of 2006 (IBGE)
Farm size	Average farms in the municipality in hectares per farm and percentage of family farms in the municipality. 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 (one) denotes perfect specialization	Agricultural Census of 2006 (IBGE)
Production diversification	Percentage of establishments that obtained some type of loan from different sources (banks, cooperatives, among others)	Agricultural Census of 2006 (IBGE)
Access to credit	Altitude in meters, which increases the risk of frosts.	IBGE Cities and Towns (1998)
Altitude	Index for logistic cost to Sao Paulo in 1995, updated in 2009, based on the transportation costs to the city of Sao Paulo, whose costs are a result of applying a linear programming procedure for calculating the minimum shipping cost to Sao Paulo	NEMESIS (2009)
Infrastructure	Percentage of producers that are members of a cooperative, union or other similar associations	Agricultural Census of 2006 (IBGE)
Membership in cooperatives	Percentage of agricultural establishments that perform pest control (biocontrol, burning waste, use of repellents, among others)	Agricultural Census of 2006 (IBGE)
Pest control		

3.3 Data sources: Climate

The historical climate data for Brazil were obtained from the National Meteorology Institute (INMET), which collects information about average, minimum and maximum temperature, total precipitation (millimeters, days of rain) and relative humidity by weather stations. To transform the data from the stations into municipalities, the kriging method of interpolation was used (Haas (1990)). For all the climatic variables, average data for the seasons was calculated, gathering the information over the months of each season. Climate information represents the average temperature, precipitation and relative humidity of the season.

Long-term climate represents the average climate conditions of regions where patterns can be identified. An example of this is that 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.

Short-term climate variations 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 that impact weather patterns at the local, regional and global levels.

The long-term average was calculated based on the 30-year average past data (from 1976-2005), namely $E(\textit{climate})$. The use of such a long period is standard in climate studies, to avoid the measurement of other specific climate cycles. The average was calculated by season. This article considered only average summer and winter seasonal climate information because Latin American countries in general do not have well-defined seasons. Thus, summer and winter are representative seasons in regard to a region's climate patterns (Cunha et al. (2014); Seo (2010, 2011); Seo and Mendelsohn (2007)).

In regard to short-term climate data, the 2005 and 2006 climate information by season (*climate*) was demeaned by the long-term climate data, $E(\textit{climate})$, and this deviation from long-term mean was divided by the standard deviation as calculated from the former 30-year climate ($\sigma_{\textit{climate}}$), to standardize the climate information. Both years were used because the 2006 harvest depended on the previous year's weather. The new variable can be interpreted as the climate anomaly or extreme weather intensity. Therefore, two subsets of indexes were created to test their impact on TE and, consequently, on profits: the drought index, which is the observed rainfall below the long-term average rainfall in standard deviations $Z_D < E(\textit{Rain}) - \alpha\sigma_{\textit{Rain}}$; and the cold stress index¹⁵, which is the observed air temperature below the long-term average in standard deviations $Z_C < E(\textit{Temp}) - \alpha\sigma_{\textit{Temp}}$. In this

¹⁵ 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. Temperatures above a specific range may cause 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 Sao Paulo and Minas Gerais states.

formulation, α represents the intensity of the extreme weather occurrence, and all climate variables are transformed in terms of α . These indexes were used for testing the significance of the climate variables in the TE determinant equation, to simulate the effects of extreme weather events on agriculture.

4 Results

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

4.1 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 and its interactions. The relevance of including climate variables in the profit model was tested by the likelihood ratio (LR) test. The LR statistic ranged from 863.43 to 949.65 depending on the price expectation used, indicating that average climate is necessary to explain farmers' profits at a 1% level of significance. The homogeneity and symmetry restrictions were automatically imposed by the translog specification. The convexity assumption was tested using an LR test, and the results indicated that, in general, the profit function estimated can be considered convex at 1% of significance level¹⁶.

By disaggregating the profit impacts into profit share effects, the climate variables showed important effects: low rainfall levels impacted only soybean profit shares while places with higher average temperatures had negative effects on maize, coffee and beef (Table 1)¹⁷. Soybeans, other annual crops and other forest products generate more profits when cultivated in smaller areas, as indicated by the land quantity effect. Higher irrigation means more profits for soybeans, maize and coffee, the main crops analyzed in this article.

¹⁶ Ho: all β_{jj} are zero; Ha: all β_{jj} were statistically significantly above zero with 10 degrees of freedom and a Chi-square of 158.73 (statistically significant at 1%). Individual tests were also performed. The estimated results were not statistically significant from zero or negative for three products: soybeans; beef; and maize. Note: The higher log-likelihood value was obtained by using the 5-year average price as the proxy for expected price by farmers.

¹⁷ Note: Other results were suppressed from this article due to size limits, but can be requested from the authors.

Table 2: Average Partial Effect of Exogenous Variables (r) on Profit Shares by Product (j) from 2006 Census

Effect on profit shares by output (γ_{jr})	Soybeans	Maize	Other annual crops	Coffee	Other perennial crops	Milk	Wood	Beef	Other forest products
Fuel quantity	-9.40e-6	1.83e-5**	1.02e-5***	5.5e-6	2.5e-6	-3.93e-5***	1.94e-5***	9.5e-6	4.93e-6
Land quantity	-5.2e-06**	1.80e-6**	-2.99e-06***	2.4e-6***	-3.0e-7	6.16e-6***	2.9e-7	1.00e-6	-1.85e-6***
Irrigated area	6.343**	3.948***	-1.458***	3.992***	-1.859*	-0.451	-1.913***	-7.3***	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**	-0.46	-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	-9.80E-07	-0.00547***	-0.002*	-0.00893***	7.60e-4	-0.0058***	-2.8e-4
Rainfall in Winter	0.0118***	0.0011	-0.0018***	-1.30e-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	6.5eE-4	0.0234	0.0495	0.0063	0.352***	0.0113

*** p<0.01, ** p<0.05, * p<0.1

To further investigate the average climate impacts on agriculture, the model allows for 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 the municipality, when inputting municipal data into the marginal effect equation, to identify the specific effects within the country. According to the estimated results (Table 2), soybean production increased when summer temperature was above average. Increases in long-term average temperature during summer by one degree Celsius, could thus raise soybean production by 44% on average in the soybean-producing municipalities in Brazil. This effect is calculated based on 23% of the municipalities that presented statistically significant results and accounted for 96% of the soybean production. The same trend was observed for the average effect of rainfall during summer and winter. One possible explanation for this effect is that soybeans have greater yields in rainier municipalities during both summer and winter.

Table 3: Semi-elasticities: Average effect of Climate Variables on Production by Product and Municipality from the 2006 Census

Output (j)	Summer		Average effect for Brazil	Winter		Average effect for Brazil
	% Brazilian munic. with stat. sig. effects	% munic. with $q>0$ and stat. sig. effects		% Brazilian munic. with stat. sig. effects	% munic. with $q>0$ and stat. sig. effects	
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 perennial crops	79%	95%	-0.048	4%	5%	-0.003
Milk	93%	97%	-0.182	93%	98%	-0.174
Wood	0%	0%	0.000	26%	99%	-0.69
Beef	94%	99%	-0.017	4%	4%	2.9e-4
Other forest products	0%	0%	-3.1e-5	0%	0%	0.002
Temperature						
Soybeans	23%	96%	0.44	22%	95%	-0.227
Maize	78%	87%	-0.764	2%	2%	0.01
Other annual crops	26%	27%	-0.013	9%	10%	0.002
Coffee	24%	79%	-0.281	1%	4%	-0.024
Other perennial crops	1%	1%	-0.021	1%	1%	0.003
Milk	2%	2%	-0.026	1%	1%	0.002
Wood	0%	0%	0.00e+0	0%	0%	0.000
Beef	96%	100%	-1.87	96%	100%	0.9
Other forest products	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)

For most of the agricultural products analyzed, including maize, other annual crops, coffee, other perennial crops, milk, wood, and beef, municipalities with higher average rainfall during summer and winter had lower production. The average effects were not very high for

many of these products. The products where output was affected the most included milk during both summer and winter, coffee and other perennial crops during summer and wood during winter. The results suggest that either these products are better adapted to more arid locations or the larger rainfall averages during the summer may have influenced the results.

The estimated impact of temperature appears to be much higher than that of precipitation. The partial effects of higher average summer temperature reduced the production of maize, other annual crops, coffee, other perennial crops, milk and beef, while higher winter temperatures adversely affected only coffee and soybeans.

4.2 Climate anomaly impacts on efficiency

The null hypothesis that there were no inefficient components was rejected by the data¹⁸. Approximately half of the municipalities where the efficiency was calculated have a TE between 0.43 and 0.63. The highest efficiency measured was 0.87 and the mean was 0.51.

The complete results are described in Appendix B. Standard errors were generated by a bootstrap analysis with 1000 replications. Multiple different model specifications were tested, and no statistically significant difference was found among them, suggesting that the OLS approach is best suited for this analysis due to its simplicity and linearity.

The joint test for the significance of climate anomalies indicates that these variables are important to explain the differences in production efficiency among the municipalities. When droughts are defined as a binary variable equal to one when observed rainfall is two standard deviations below normal ($\alpha = 2$), results indicated that droughts reduced farmer efficiency during the summer of 2005 by 0.068, again in 2006 by 0.036, and in the winter of 2006 by 0.13. The magnitude of these results is quite large compared to the previous effects discussed. The only season that showed a positive effect from droughts, or alternately a negative effect of floods, was the fall of 2006 which is harvest season for soybeans and maize. During such periods, floods are generally harmful as is confirmed by the estimated results. However, fall is also the growing season for winter crops, such as wheat and triticale, which are adapted to the more temperate climate. The net result from both of these forces was positive.

In regards to the effects of cold stress on agriculture, colder temperatures in the winter of 2006 and spring of 2005 were found to be 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

¹⁸ 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.

in rainfall or temperature in 2005 and 2006 ($C = 0$), the efficiency level considering the occurrence of the anomalies (C is observed). Thus, the difference in efficiency (ΔTE) can be converted into the profit difference for each municipality in the sample. The impact of the 2005 and 2006 anomalies on TE (ΔTE) was calculated and transformed into variation in profits ($\Delta \Pi$), according to the Equation (4):

$$\Delta TE = \frac{\Delta \Pi(.)}{\Pi^*(.)} \therefore \Delta \Pi(.) = \Delta TE \Pi^*(.) = \Delta TE \frac{\Pi(.)}{TE} \quad (4)$$

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

Table 4: Estimated Impact of Weather Anomalies on Profits in Brazil

Estimates	% of profits	Loss (-) or gain (+) in million Reais (Dec-06)	Loss (-) or gain (+) in million dollars ^[1] (Jan-14)
2005 and 2006 anomalies			
Rainfall	-5.60%	-21,440.70	-12,373.70
Temperature	3.34%	12,803.20	5,127.82
Drought or cold stress			
Drought	-30.50%	-116,689.10	-67,342.75
Cold stress	-13.19%	-50,474.20	-29,129.30

^[1]Dollar amounts in Jan. 2014 are calculated by updating the 2006 values using IPCA and converting it to dollars by the average exchange rate for 1/1/2014.

Source: Sisbacen PTAX800

The estimated effect of temperature on profits showed a gain of 3.34% due to the year-end 2005 and year-end 2006 temperature conditions. Because colder temperatures were more harmful to 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 were simulated in the country to determine the sensitivity of the losses. Assuming a two-standard deviation reduction in

rainfall for droughts and in temperature for cold stress, the lost profit in each municipality was calculated. Considering only the statistically significant impacts, the total losses from these events were 13.2% and 30.5% , for cold stress and droughts, respectively¹⁹. 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 the 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 approximately 16.8 billion dollars, a considerable amount in terms of agricultural outcomes. The net effect, including the profit gain with increased temperature, was negative 7.2 billion dollars (in 2014 values). This result is very similar to the direct damage of climate anomalies on agriculture in 2005 calculated by [Haddad et al. \(2013\)](#). In regard to the expected losses by region, the Midwest and South regions were slightly more affected by both harmful climate anomalies than the other regions.

5 Discussion and Conclusions

The central idea of this study is that long-term climate influences the planning decision of producers, while short-term weather events are shocks which move actual production away from the planned production. This article employed 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 well studied, as shown by the literature. Similarly, the theory of how stochastic frontiers models relate to long-term and short-term models of producer behavior is still just a caveat in the 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 was tested. The marginal temperature effects calculated seemed to be much more significant than the decreased rainfall levels. The partial effects of higher average summer temperature reduced the production of maize and other annual crops, such as rice, beans, manioc, and coffee, milk, beef and other perennial crops, such as fruits. Places with higher winter temperatures could suffer adverse effects on coffee and soybean output. Only soybean production was positively affected by higher summer temperatures. A possible explanation for this result is the high adaptability of this crop to tropical regions.

The hypothesis of variation in technical efficiency levels was not rejected by the data, indicating that efficiency levels differ in a statistically significant way among Brazilian farm-

¹⁹ Droughts are assumed to be two-standard deviation negative anomalies in rainfall, while cold stress is assumed to be two standard deviation negative anomalies in temperature.

ers. The estimation of the TE allowed for the modeling of possible determinants of the farmers' deviation from optimum choices, which can be imposed by exogenous forces. This article proposed climate anomalies as relevant determinants of farming inefficiency. The econometric test showed that climate anomalies are jointly relevant to explain the differences in technical efficiencies. The average effect due to rainfall shortcomings on a farmer's TE during the summer months of 2005 and 2006 was a 5.6% reduction of the current farm profits, representing almost 12.4 billion dollars (values of 2014). This can be interpreted as the farmers' maximum willingness to pay to protect themselves against the unforeseen rainfall shortcomings in Brazil during 2006. The estimated temperature effects on profits showed a gain due to the year-end 2005 and year-end 2006 temperature conditions, on the order of 3.34% or 5.1 billion dollars.

The estimates of simulated cold stress and droughts throughout the country indicated lost profits of 13.2% to 30.5% , respectively and were slightly more intense in the Southern and Midwestern regions. These percentages represent 35 and 80 billion dollars of losses, respectively. Within this context, insurance is an important action to protect farmers from such harmful situations. Weather index insurance is gaining importance as a possible intervention technique to overcome the negative impacts of climate risk on rural livelihoods and agricultural production. Weather index insurance is normally linked to rainfall anomalies such as droughts and floods, extreme temperatures, extreme precipitation such as frosts, hail, and rainstorms, and 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. [Barnett and Mahul \(2007\)](#) also underlined the importance of understanding the mechanisms of weather impact on agricultural system models to design an index for this purpose. This article could be helpful in identifying the important relationships for the design of the index.

This study is innovative because it distinguishes between the effects of climate and weather on the production frontier framework by using a translog profit frontier equation. Additionally, the majority of Brazilian agricultural products were considered in the analysis, as well as many technological variables as quasi-fixed inputs inside a profit function approach. This study also used precise climate data from Brazilian weather stations, which allowed for the assessment of the impact of extreme weather events 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.

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Appendix A

Table 5: Descriptive Statistics

Variable	Total obs.	Mean	Std. Dev.	Min	Max
Information on Agricultural Production					
Maize (tonnes)	5548	6,826.75	25,470.49	0	596,645
Soybeans (tonnes)	5548	7,057.82	37,722.83	0	1,360,187
Other annual crops (tonnes)	5548	75,534.18	343,187.50	0	7,330,239
Coffee (tonnes)	5548	463.31	2,244.40	0	67,361
Other perennial crops (tonnes)	5548	3,855.21	18,816.18	0	479,138
Wood (m^3)	5548	7.34	53.93	0	1,675
Other forest products (tonnes)	5548	160.58	2,148.29	0	131,572
Milk (thd liters)	5548	3,057.84	5,776.21	0	125,104
Beef amount (cattle)	5532	604.93	948.66	0	10,565
Input prices (Thd reais per employee or hectares)					
Labor price	5552	1.09	2.67	0	48.25
Price per fertilized hectare	5552	0.24	0.32	0	4.89
Input quantities(in thousand Kcal/hectares/employees)					
Total fuel (in k kcal)	5548	4,715	9,715	0	233,783
Total available land (ha)	5548	41,602	86,862	0	3,719,038
Total employees (number)	5548	4,698	7,761	0	306,279
Total fertilized area (ha)	5548	7,240	21,934	0	595,488
Technological Information Regarding Production					
Percentage of mechanical harvesting	5548	0.03	0.13	0	1
Percentage of certified seeds	5548	0.30	0.32	0	1
Percentage of transgenic seeds	5548	0.04	0.11	0	1
Percentage of certified or transgenic seeds usage	5548	0.33	0.35	0	1
Percentage of cattle confined	5548	0.03	0.07	0	1
Percentage of artificial insemination	5427	0.08	0.14	0	1
Percentage of tilled area	4691	0.07	0.16	0	0.89
Percentage of irrigated area	5544	0.02	0.06	0	0.64
Percentage of animal tracking	5548	0.05	0.07	0	1
Percentage of industrial feed usage	5548	0.01	0.03	0	0.5
Other variables					
% of farmers in cooperative assoc.	5547	0.245	0.201	0	1
% of farmers that own the land	5547	0.798	0.18	0	1
% of tenant farmers	5547	0.045	0.064	0	1
% of farms that use pest control	5547	0.113	0.134	0	1
% of pop. with 0 to 4 years of schooling	5548	63.314	9.812	26	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	6.48
% of farmers that used any credit	5547	0.180	0.144	0	0.85
Altitude (in meters)	5499	412.310	293.07	0	1628
Average size of farms (in hectare)	5543	34.343	79.918	0	1561.98
Agricultural HHI	5546	0.462	0.21	0	1
% of female farmers	5547	10.977	6.349	0	100
% of farmers 1 to 5 years of experience	5547	17.995	8.196	0	100
% of farmers 5 to 10 years of experience	5547	18.539	8.002	0	100
% of farmers >10 years of experience	5547	60.485	13.735	0	100
% of family farms	5547	78.568	15.424	0	100
Index for logistic cost to São Paulo	5547	0.299	3.381	0	100
Degraded agricultural are (in hectares)	5543	0.003	0.01	0	0.48

Appendix B

Table 6: Results from the estimated profit equation

Variables	OLS	TOBIT	GLM ^[1]
% of farmers in cooperative 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 pop. with 0 to 4 years of schooling	-0.00773***	-0.00773***	-0.00783***
% of pop. with 5 to 8 years of schooling	-0.00632***	-0.00632***	-0.00640***
% of pop. with 9 to 11 years of schooling	-0.0111***	-0.0111***	-0.0113***
% of pop. >12 years of schooling	0.000658	0.000658	0.000714
% of pop. with undetermined schooling	0.0588**	0.0588**	0.0596**
% of farmers that used any credit	3.20E-06	3.20e-6	3.30e-6
Altitude	-0.00050***	-0.00050***	-0.00051***
Average size of farms (in hectare)	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 1 to 5 years of experience	-0.000463	-0.000463	-0.000465
% of farmers 5 to 10 years of experience	0.000407	0.000407	0.000417
% of farmers >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 Sao Paulo	-0.0582	-0.0582	-0.0589
Degraded agricultural are (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 variable ^[2] :			
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	-36,875.54
log-likelihood		2225.11	-2094.28

*** p<0.01, ** p<0.05, * p<0.1;

[1] marginal effects calculated at the sample mean.

[2] Joint test for H_0 that all climate variables' coefficients are zero.

Short Bio of the authors

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