Agriculture and Adaptation to Climate Change:

The Role of Insurance and Technology Dissemination in Brazilian Risk Management

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Abstract

This study examines potential policy instruments for agricultural climate change adaptation based on empirical analysis of a theoretical model for Brazil. Risk management approaches, such as agricultural insurance and research and development investments in technological change, particularly call for analysis. The results for a weather index effect on loss of profits and amount of insurance indicate that it is important to insure against droughts and against temperature extremes. In addition, extensive research and development investment is found to be necessary to mitigate the effects of climate change on almost all agricultural sectors, particularly soy, cattle, maize and milk production.

JEL classifications: G22, G35, 013, Q14, Q54
Keywords: Risk management, agriculture, climate change, Brazil

1. Introduction

Since the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007a) the discussion has shifted from the existence of climate change to its magnitude and longer-term impacts and appropriate adaptation measures. Before the report, several uncertainties limited the in-depth discussion of some issues.

It is noteworthy that climate change has relevant consequences for human health, water availability and quality, agricultural production (and productivity), rural development and poverty. In regard to agriculture, climate itself is a direct input for crop production, and climate change has the potential to modify agricultural land use.

Some of these abovementioned effects of climate on agriculture have already been studied in some Latin American and Caribbean countries. However, there are not many studies exploring the effectiveness of some mechanisms, such as investments and insurance instruments, to reduce climate effects. Those issues are notable since poverty limits people's capacity to manage climate risks even as such risks contribute to keeping people poor (Hellmuth et al., 2009). New instruments are needed not only to help farmers, mainly small farmers, but also to help the government plan specific measures to address extreme weather events and climate change.

Climate effects on agriculture consist mainly of the following:

1. Change in land use and soil moisture in agriculture, livestock and planted forest due to the changes in the region's climate patterns; and
2. Crop failure and productivity losses due to drought, frost, hail, severe storms, and floods; loss of livestock in harsh winter conditions and frosts; and other losses due to extreme short-term weather events.[1]

When it comes to the first effect, we believe that medium and long-term changes in climate might lead to changes in soil moisture and land use, some crops can be more susceptible or tolerant to climate change than others in the long term. Thus, governments should be prepared for changes in land use due to deviations from normal climatic conditions, which implies new investments in crop modification and in productivity improvements.

[1] According to the Intergovernmental Panel on Climate Change (IPCC, 2007b): "climate variability and change also modify the risks of fires, pest and pathogen outbreak, negatively affecting food, fiber and forestry."

In addition, agricultural productivity and production depend on changes in temperature and rainfall patterns. Temperature increases might lengthen the growing season in regions with a relatively cool spring and fall, adversely affect crops in regions where summer heat already limits production, increase soil evaporation rates and increase the chances of severe droughts. On the other hand, changes in rainfall might affect soil erosion rates and soil moisture, both of which are important for crop yields (IPCC, 2007b).

Regarding those short-term effects, Rosenweig and Wolpin (1993) emphasized that poor people/farmers avoid taking risks under the threat of possible extreme weather events, which limits improvement in productivity as well as investment in innovation since poor farmers do not exhaust important assets for crisis survival. According to Goes and Skees (2003), governments struggle to finance relief and recovery efforts; besides, government disasters responses can be delayed many months, which can result in higher human and economic costs.

This study's objective is to analyze the susceptibility of agricultural outputs to climate variations. In order to perform this analysis, two definitions of climate variation were developed: i) a long-term approach, in order to analyze climate change impacts and compensation measures; and ii) a short-term approach, which uses a weather index approach in order to estimate the amount of insurance needed by farmers based on expected loss of profits.

We believe that governments should be prepared for changes in land use and agricultural production due to climatic deviations in both the long and short term. Climate change effects on agriculture can be smoothed by new investments in crop modification and in productivity improvements. Due to the time lag of those effects, such long-term measures are expected to prove very effective forms of adaptation.

When it comes to climate shocks, it is not possible to manage investments with adaptation measures. For this reason, this study developed a weather index approach, which has become increasingly important in the recent literature, to model the average insurance needed based on the occurrence of weather shocks in Brazilian agriculture.

The following steps summarize the study:

1. Development of the following indexes:
    a. Short-term: Drought/flood and heat/cold indexes to measure extreme weather events; and

b. Long-term: Rainfall and temperature long-term mean to measure the climate patterns of the region.

2. Estimation of short and long-term climate impact on crop production and farmers' profit in Brazil using the profit function model. These results will be used in Steps 3 and 4.
3. Examination of the role of Research and Development (R&D) in compensating for long-term climate change effects.
4. Calculation of the amount of insurance needed based on the profit change due to the incidence of weather extreme events by stressing short-term weather indexes.

The contribution of the study is to incorporate policy instruments based on empirical analysis of a theoretical model. We believe that the exploration of risk management approaches such as agricultural insurance as well as R&D investments in technological changes is a relevant opportunity for analysis. Risk transfer approaches might additionally play an important role in mitigating climate risks (Hellmuth et al., 2009).

The results for the weather index effect on loss of profits and amount of insurance indicate that it is important to insure against droughts as well as against temperature extremes. If small droughts occur across Brazil, the average loss in profits for the farmers would be approximately US$ 1 billion in 2006 dollars, and insurance for the same amount would be needed.

The estimations additionally indicated that the only crops unlikely to be unaffected by long-term changes in climate are coffee and wood. The other crops analyzed are expected to be impacted by variation in climate trends in temperature and rainfall. The highest increases in R&D investments, in order of importance, are: i) other permanent crops, ii) other temporary crops, iii) soybeans, iv) cattle, v) maize and vi) milk. For soybeans, maize and cattle, for example, R&D investment must increase between 70 and 90 percent over the peak investments of Embrapa[2] in 2010 to compensate for the impacts of climate change on farmers' production and profits.

We believe that the results presented here could be used to monitor the most important features of the impact of climate change on agricultural production and rural development.

[2] Embrapa is the acronym for the Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation).

2. Literature Review

2.1 Climate Change Effects on Agricultural Activity

As pointed out by Dale (1997), change in agricultural activity is related to climate change as a causal factor. On one hand, agricultural activity influences the flow of mass and energy. As land-cover patterns change, these flows are altered, changing the climate. On the other hand, climate change affects agricultural activity directly since climate can be considered an input for crops, forest and livestock. Consequently, projected climate change will produce changes in land-cover patterns at a variety of temporal and spatial scales, although human uses of land are expected to override many effects.

The studies that attempt to measure the impacts of climate change on agricultural activity have tended to use the Ricardian approach (Mendelsohn, 1994; Sanghi et al., 1997; Evenson and Alves, 1998; Deschênes et al., 2007; and Féres, Reis and Speranza, 2008) or the agronomic approach (Lang, 1999; Féres, Reis and Speranza, 2009; Nadal, 2010).

The agronomic approach uses the profit function method to measure the optimal allocation for different crops from different climate elements and technologies, beyond other factors. Its main advantage, as pointed out by Féres, Reis and Speranza (2008), is the flexibility of this approach in regard to output and input variation in the model. Its disadvantages include the impossibility of considering products not initially placed in the model. Concerning the Ricardian approach, the objective is to measure the influence of climate on property values.

In general, empirical evidence from both cited methodologies shows that countries in lower latitudes tend to suffer more from climate change than other countries since those areas already have high average temperature. The foremost difference between the conclusions of the two approaches mainly involves the expected magnitude of costs and benefits.

The first Brazilian studies that tried to estimate the effects of climate change on agricultural activity using a Ricardian approach found that the Northeast and Central West regions are among the most affected areas in terms of agricultural consequences (Sanghi et al., 1997; Siqueira, Farias and Sans, 1995).

Evenson and Alves (1998) included technology variation to measure effects on agricultural productivity and found similar results for the most affected areas: the Northeast, Central West and North regions. The authors additionally found that, in the southern and southeastern areas, agricultural productivity might be positively affected by changes in precipitation and temperature. Those results were similar to the findings of Féres, Reis and Speranza (2008), which applied the same Ricardian approach with the correction proposed by Deschênes and Greenstone (2007).

It should be noted, however, that previous studies did not consider the potential influence on their projections of investments, which could considerably affect the finding results. Nadal (2010) is the only study for Brazil that, by using the profit function approach, considers investments in order to measure how climate change can affect agricultural production. Nevertheless, only crops are considered in the study. Unless forestry and livestock are considered as well, the impacts of climate change on agricultural activity can be understated. Moreover, short-term climate variations were not included in the model.

Therefore, we believe that one contribution of this study is the measurement of R&D investment effects on agricultural activity together with short and long-terms climate effects and the analysis of those impacts as a policy to deal with the problem. These efforts have never been previously undertaken for Brazil.

In particular, we analyze how the production of different crops is affected by climate and R&D investment changes by using a profit function. This approach permits measurement of crop production variation together with different optimal land allocations, whereas the Ricardian approach does not.

Moreover, by the introduction of an investment in R&D variable, together with climate variables, it becomes possible to quantify the needed investment, or insurance, for mitigating both long and short-term climate impacts. For long-term impacts, additional R&D investment can compensate the average climate variation impact, which can be measured in value due to the profit function methodology. For the short-term effect, however, the needed insurance is connected with the average profit loss due to climate risk, which we intend to measure by using a weather index approach.

2.2 Climate Risk Measured by an Insurance Index

It is well known that climate volatility represents an important aspect of agricultural production. As emphasized by Baethgen et al. (2008), the uncertainty associated with climate variability is a disincentive to investment, adoption of agricultural technologies and response to market opportunities. Some of the problems involving the producer's risks are described below:

1. Less effectiveness of exchange-traded futures and options hedges for production risk (those markets are only effective for prices);
2. Imperfect insurance market due to the positive spatial correlation in losses (limiting the risk reduction capacity);
3. Existence of asymmetric information for the farmers since some of them must be better informed than others about loss probability distribution.

Weather index insurance is one of the possible interventions for overcoming the negative impacts of climate risk on rural livelihoods and agricultural production. Index insurance is normally linked to rainfall anomalies (drought, floods), extreme temperatures and humidity (frosts, hails), or even crop yields (Iturrioz, 2009).

The use of a weather index linked to an insurance mechanism is a market-driven solution, shifting part of the responsibility to public agencies, which can provide interventions in a more sustainable development model. Hellmuth et al. (2009) emphasize that a public-private partnership and the development of the private sector are important for the success of this approach.[3]

Recently, many researchers have been exploring the potential use of weather index insurance to provide risk management opportunities for the rural poor. Barnett and Mahul (2007), for example, pointed out that understanding insurance mechanisms through agricultural system models is important for index design.[4] No less important is the correlation of an index with the targeted loss. A profit function model can be very useful, as it identifies these relationships.

Climate risk management using indicators is also important to address variations in rainfall by installing irrigation systems (Dercon, 1998; Ellis, 2000), to aid the development of new crop varieties adapted to differences in climate or more resistant to droughts, and to enable farmers to change land management practices in order to increasing the soil's moisture-holding

[3] This section will be based on the document issued by Hellmuth et al. (2009). This document presents many theoretical developments in terms of index insurance, mainly focused on underdeveloped and developing countries.

[4] According to Baethgen et al (2008), agricultural systems have an important role for modeling a weather index in mainly three 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.*"

capacity. All these uses might help farmers to escape poverty by being more productive and also by protecting their investments.[5]

The great advantages of this approach are the following: i) lower transaction costs (as it is based on objective measures[6] calculated from publicly available data, leading to more rapid payouts[7]); ii) less adverse selection due to information asymmetries (i.e., less hidden information between the borrowers and insurers about the risk exposures); and iii) fewer problems with moral hazard (insurers cannot modify their risk exposure). Moreover, this mechanism allows producers to save part of their production, a marked contrast to current practices in which insurance companies take a long time to visit farmers and do not allow for salvaging the non-affected portion of production.[8] It is additionally important to consider how much farmers spend avoiding risks. Gautam, Hazell and Alderman (1994) present evidence that farmers often sacrifice 10-20 percent of their income using traditional risk management strategies.

For all of its advantages, an indicator-based approach is not without drawbacks, as highlighted by Hellmuth et al. (2009) for the following reasons:

1. *It is a new tool and it has some learning costs*. If the mechanism is proven to be effective after a period of use, however, this disadvantage can be minimized.
2. *It is vulnerable to basis risk* (loss without payouts, or payout with no loss), although risk vulnerability can be mitigated by contract design.
3. *The definition of a threshold for the index can be difficult*. Nonetheless, the definition of a threshold can be solved by daily monitoring and/or the achievement of a threshold for a number of consecutive days, for example.

Barnett and Mahul (2007) state that index insurance is an effective option if it offers transparency and acceptability to clients; it is thus important to check the robustness of the method. In addition, in order to realize the potential of an index-based approach, governments

[5] The simplest form of a weather index measures a specific weather variable at a specific weather station over a period of time and weather index insurance policies specify a threshold which can be crossed in a warning situation.
[6] The requirements for such approach, following Barnett and Mahul (2007), would be the availability of accurate historical weather data, correlation between available weather variables and realized losses, and time periods in which losses are most likely to occur.
[7] The insurance company does not need to visit the farmers to assess losses, as the payout is related to objective criteria.
[8] Normally farmers can use the non-affected part to feed animals, for example.

must establish an appropriate legal and regulatory framework and adequately disseminate information to all families and producers involved.

3. Methodology

3.1 Profit Function Model

In order to measure the impact of climate on agricultural production, a partial equilibrium model based on the microeconomics production theory was used. By specifying a profit function, it is possible to obtain the optimal input-output allocation for each type of crop use.

It is assumed that producers allocate k inputs for j types of production: temporary crops other than soybean and maize, soybean, maize, permanent crops other than coffee, coffee, livestock, milk, wood, and other forest products. The total output plus the total input represent the m products considered in the analysis.

Producers decide how to allocate their inputs by solving a profit maximization problem in a competitive market. Besides the input and output prices, $p = (p_1,...,p_m)'$, each producer faces a vector of exogenous climate variables, $z = (z_1,...,z_q)'$, and a set of technology's variables, $g = (g_1,...,g_r)'$, both affecting the production and profit function. Other variables, such as soil type, farmer's schooling (Huffman and Evenson, 1989)[9] and other fixed factors, represented by $X = (X_{1,\dots,} Xr)'$, also significantly affect the production decision.

The optimization problem can be described by the following expression:

$$\underset{n_1,n_2,\dots,n_m}{Max}\left(\sum_{i=1}^{m}\Pi_i(p_i,z,g,X,n)\right) \qquad (1)$$

The first order condition is:

$$\frac{\partial \Pi_i}{\partial n_i} = 0, \quad i = 1,\dots,m \qquad (2)$$

Solving equation (2), we have the optimal allocation for the outputs supply and inputs demand (n_i), which depends on prices, climate and environmental variables, investments, and other factors.

$$n_i^*(p_i,z,g,X), \quad i = 1,\dots,m \qquad (3)$$

[9] According to Schultz (1953), an increase in the level of farmer's education, when all other things equal, is expected to lead to an increase in the use of more advanced techniques. Thus, education might be a vehicle of technical change.

The chosen functional form for the restricted profit function, adopted by the farmers, is the quadratic normalized form. This representation is locally flexible and allows the test of theoretical constraints: linear homogeneity on prices and symmetry. Moreover, the first derivatives of the quadratic normalized profit function with respect to n_i are linear, and thus tractable. The *m* equations, obtained from deriving the profit equations in respect to the *j* outputs and *k* inputs are described above.

$$n_i^* = \beta_0^i + \sum_{f=1}^{m} \beta_{1f}^i p_f + \beta_2^i z + \beta_3^i g + \beta_4^i X + \varepsilon_i, \ i = 1,...,m \qquad (4)$$

The linear homogeneity restriction of the prices works by construction. For the symmetric restriction, it must be imposed:

$$\beta_{1f}^i = \beta_{1i}^f \qquad (5)$$

Then, the system of *m* equations in (4) can be solved when subjected to (5). The final solution is n^*_i which, multiplied by p_i generates whether the output revenue or the input costs depending on the climate vector z^0 and the technology vector g^0. Subtracting the costs from the revenue of each farmer, the profit is obtained, in monetary values, at $t=0$.

Despite the theoretical advantages of the profit function approach, it is important to consider the potential negative bias as this approach disregards the farmers' possible compensatory responses from climate variations, as emphasized by Féres, Reis and Speranza (2008).

3.2 Climate Variables in the Model

The climate variables of the model, *z*, are represented by temperature and precipitation measures. For both variables, we consider:

- z_{mean}: The 15-year average of historical data, to compute the 2006 current climate pattern in each municipality.[10] The mean was calculated for each first month of season, giving the monthly seasonality long-term mean; and
- z_{var}: The 2006 anomalies in temperature and precipitation by municipality and first month of the season in a year. Anomaly is defined as the difference between the observed value in 2006 and the long-term average mentioned above.

[10] Due to time restrictions we could not work with a broader time window.

In regard to the short-term variable, the anomalies can also be interpreted as weather index instruments. To develop further the idea of anomaly, we have created four subsets of indexes which will be relevant for the analysis of the model developed by this study:

- Drought Index: Rainfall below the long-term mean in standard deviations: $I_D < E(Rain) - n\sigma_{Rain}$, n = 1, and 2;
- Flood Index: Rainfall above the long-term mean in standard deviations: $I_F > E(Rain) + n\sigma_{Rain}$, n = 1, and 2;
- Cold Stress Index: Temperature below the long-term mean in standard deviations: $I_D < E(Temp) - n\sigma_{Temp}$, n = 1, and 2; and
- Heat Stress Index: Temperature above the long-term mean in standard deviations: $I_D > E(Temp) + n\sigma_{Temp}$, n = 1, and 2.

Including these definitions of climate variables, the model turns to be specified as:

$$n_i^* = \beta_0^i + \sum_{f=1}^{m} \beta_{1f}^i p_f + \beta_{2.1}^i z_{mean} + \beta_{2.2*}^i z_{\text{var}} + \beta_3^i g + \beta_4^i X + \varepsilon_i, \;\; i = 1,\ldots,m \qquad (4')$$

Moreover, since climate variability allows the measurement of short-term deviations in agricultural production and profitability, it works as a weather index.[11] The design of drought indexes, for example, is based on the difference, in standard deviations, from the long-term mean, such as we propose later in Section 6.

3.3 R&D Stock Variable in the Model

The variable that measures Brazilian stock in Research and Development for the agricultural sector was calculated based on Embrapa's expenses. These expenses are used as a proxy for Brazil's R&D expenses. In addition to Embrapa's historical importance in adapting crops to Brazilian climate patterns since the 1970s, its strategic and political importance also justify the use of this institution's R&D spending as a proxy for Brazilian agricultural expenses.[12] By verifying the effect of this variable on crop production, it is possible to analyze how much of the

[11] See more details on Index Insurance Implementation in Appendix D.
[12] Futher information about the Brazilian investments in R&D can be found in Appendix G.

research already undertaken by Embrapa could be internalized in other sectors as the climate evolves.

The method for calculating the Brazilian stock of R&D in agriculture is based on Evenson and Alves (1998). This method involves the following procedures:

1. The expenses in the national Embrapa agencies were divided nationally using the same criteria above;
2. The time lag between the research conduction and the technology development was considered as four years;
3. After eight years, the technology developed is fully implemented;
4. Between four and eight years, the implementation follows a linear rate of development;
5. After 20 years, the research can be considered obsolete.

The variable design can be summarized by the following equation:

$$R\&D\_Stock_i = 0.2Exp_{i,t-4} + 0.4Exp_{i,t-5} + 0.6Exp_{i,t-6} + 0.8Exp_{i,t-7} + \sum_{j=8}^{20} Exp_{i,t-j} \quad (6)$$

In order to create a R&D stock for each municipality, an Embrapa state research agency is assigned and its stock divided by the municipalities' share of agricultural machines in the state. This procedure is also similar to the distribution used and commented upon in Appendix A of Evenson and Alves (1998).

3.4 Climate Change Compensations

Once climate change and R&D effects are significant ($\beta_{2.1}^i \neq 0 \;\; for \; i = 1,...,m$ and $\beta_3^i \neq 0 \;\; for \; i = 1,...,m$), the next step consists of multiplying the coefficients of the estimation of (3.4') subject to (3.5) by climate predicted values "z_{mean}", the output prices, input prices, investments/technology, climate variability (z_{var}) and other features remaining constant, in order to calculate the profit for *t=1*.

The variation in profit from *t*=0 to *t*=1 gives the gain/loss value from the climate and R&D stock change as equation (3.7) shows.

$$\Delta\pi = \pi\left(p, z_{mean}^1, z_{\mathrm{var}}, g^1, X\right) - \pi\left(p, z_{mean}^0, z_{\mathrm{var}}, g^0, X\right) \quad (7)$$

The investment in R&D needed to reduce the effects of climate change in agricultural activity is given by g^1, which makes $\Delta\pi$ of the crops equations non-negative.

3.5 Climate Variability Effects and Insurance Index

The model for index insurance based on Carriquiry and Osgood (2008) shows the possible adverse consequences of uncertainty that may arise from production decisions, which makes the link between the profit function model and the Insurance Index.

Considering insurance (*I*) for systematic shocks, farmers' profit depends on the amount of outputs and inputs (*n*) and observed climate conditions. Suppose z_h represents an extreme weather occurrence, z_h, which is embedded in the profit function. The farmers' optimization problem, replicating the profit by maximizing behavior of risk-neutral farmers, shows that the increasing/decreasing expected profits equal the optimal amount of insurance:[13]

$$I^* = \pi\left(N_h^*, z_h\right) - \pi\left(N_l^*, z_l\right) \qquad (8)$$

The equation above becomes useful for testing how extreme events affect the output supply and input demand. The average loss that farmers face under the occurrence of extreme weather events is a proxy for the amount of insurance needed.

As an empirical exercise, the change in profit due to the short-term climate variation will be calculated as a proxy for the average loss of farmers. Due to the datasets' characteristics, we assume the hypothesis that we only observe quantities produced and sold, which tolerates the use of the change in profits as an approximation of the optimal insurance amount:

$$\hat{I}^* = \Delta\pi = \pi\left(p, z_{\text{var}}^1, z_{mean}, g, X\right) - \pi\left(p, z_{\text{var}}^0, z_{mean}, g, X\right) \qquad (9)$$

where z_{var}^1 indicates the occurrence of an extreme weather event, where the short-term indicator is below/above the weather index's threshold. If the climate variability effect is proved ($\beta_{2.2*}^i = 0$; $i = 1,...,m$), there will be profit change due to climate volatility.

3.6 Estimation

In order to estimate the equations in (3.4'), the *Iterated Seemly Unrelated Regression* (ISUR) method was used. The model of simultaneous equations allows to jointly estimate the $m-1$

[13]It is noteworthy that the farmers are still not fully insured against idiosyncratic shocks, whose expected value is zero.

equations to the *i* observations, taking into account the correlation in the variance-covariance matrix of the residuals (Cameron and Trivedi, 2008). Estimation by Maximum Likelihood (ML)[14] assures the occurrence of iterations on the variance-covariance matrix and on the parameters, besides the price convexity predicted by microeconomic theory.

The ISUR model is also compatible with the imposition of cross-equation restrictions expressed by (5).

4. Data

4.1 Data Sources

Cross-section data were used as an empirical support in the research. Panel data, which could generate more accurate results, have not been used because of data incompatibility between the last two agricultural censuses carried out in Brazil. The unit of analysis was Brazilian municipalities.

Agricultural data were obtained from the Brazilian Agricultural Census of 2006, produced by the Brazilian Bureau of Geography and Statistics (IBGE).[15] The Census contains information on output quantities and values, input quantity and values, land type and use, investment values, and information on the land manager, among other kinds of data.

The output products considered were divided into nine components of four groups:

- Temporary crops: soybean; maize; other temporary crops;
- Permanent crops: coffee; and other permanent crops;
- Livestock: milk; and cattle; and
- Planted forest: wood; and other forest products.

[14] We would rather estimate using the ML model (iterations) than the *Feasible Generalized Least Squares* since ML performs better when the probability density function is correctly specified. It means that this estimator has the lower asymptotic variance-covariance matrix (Cameron and Trivedi, 2008).

[15] The Brazilian Bureau of Geography and Statistics (IBGE) conducts the Brazilian Census of Agriculture every 10 years with the objective of updating population estimates and information about the economic activities carried out in the country by members of society and agricultural companies. The last edition of the survey was characterized by a technological refinement, mainly related to the introduction of new concepts in order to encompass the transformations that had taken place in agricultural activities and in rural areas since the previous edition of the survey.

These products were chosen according to their weight in each group, in terms of production value.[16] For the inputs chosen, the same criterion was used, and four inputs were selected: land, labor, fuel and fertilizers.

Implicit prices were generated by dividing the total value by the total quantity produced. The quantities were normalized for groups that contain many crops.

As to fuel quantities normalization, we converted all types of fuel into energy generation (in kcal), using density and power capacity from Petrobras.[17] The land prices for each municipality were calculated using data from rental value and renting area. For the municipalities where prices were not computed (null production), the median price of the province was considered. Labor price was calculated as the average rural salary equal to the sum of rural workers' salaries divided by the number of rural workers.

For the agricultural stock of technology variable, Section 3.3 above summarizes how the variable was calculated. As noted, the dollar value of R&D expenses was used.

Other control variables, considered fixed variables in the profit function, were also collected from the Agricultural Census. They are the following:

- Land manager education: the available information is the percentage of managers that completed each level of education;
- Land type: percentage of degraded land in the municipality; percentage of agricultural land in the municipality; and
- Farm size: average size of farms in the municipality.

Climate data were obtained from different sources. Historical temperature information was obtained from the National Meteorology Institute in Brazil (INMET); historical rainfall data were collected from CPC Morphing/NOAA.[18] For further information on how the climate variables were used, see Section 3.2. Additional database details can be found in Appendix C.

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[16] The tables confirming the choice can be visualized in Section 5.

[17] For power capacity information: http://www.petrobras.com.br/ri/Show.aspx?id_materia=RZEgAf3viH6tC/8BZ/JSyQ==&id_canal=8HXhVHfEy3ykamp+JQ1S2Q==&id_canalpai=TClwGEUaHBF8+uTYXJS/Og==; for charcoal densities: http: //ecen.com/eee21/emiscar2.htm; for oil information: http://www.sumarios.org/sites/default/files/pdfs/54904_6336.PDF; for other conversions: http://www.woodmacresearch.com/cgi-bin/wmprod/portal/energy/overview.jsp?overview_title=energyconversiontool. Information consulted on October 25, 2011.

[18] CPC Morphing technique for the production of global precipitation estimates.

4.2 Data Description

Brazil is a large country with a wide variety of climate patterns and highly diverse agricultural production. In order to implement the empirical strategy underlined in the previous section, many different data sources were used. Appendix C describes the collection and organization of the agricultural data for this analysis and shows the organization of climate data organization. The following sections present the main statistics on climate patterns in Brazilian municipalities and the main information on the distribution and dimension of the agriculture sector in Brazil.

4.2.1 Climate Description in Brazil

As Brazil is a huge country in terms of area, the country's climate varies considerably from a mostly tropical area (north of the country) to temperate areas below the Tropic of Capricorn (southeastern and southern Brazil). The tropical area has higher temperatures and little variability during the year. Rainfall in Brazil has more seasonal patterns, being stronger during the summer months of December to March (Figures B.1 to B.3 in Appendix B[19]).

On the other hand, the south of Brazil can have lower temperatures and even frosts/snowfalls during the winter time (mostly from June to September). The north region, which includes the Amazon Forest, is very humid, with rainfall exceeding 3,000mm per year (Map 5.2 to Map 5.5 in Appendix B). The rainy season also lasts longer in this region, while the neighboring northeast region, which has the country's highest temperatures and driest seasons. Climate patterns in the latter are in part explained by semidesert vegetation.

4.2.2 Agriculture Description in Brazil

Brazil's field crop and livestock production are mainly divided between two regions: the southern temperate region (mostly temporary crops), including the southeastern part of the country, and the tropical Central West region (mostly livestock). These regions also have different climate patterns, as mentioned above, as well as different cropping patterns and farm features (Schnepf, Dohlman and Bolling).

Overall, 41.8 percent of establishments in Brazil are oriented to livestock production and 50.4 percent to field crops (both permanent and temporary crops), and the country's rural areas have more than 3.6 million farms (Table B.1 and Figure B.4 in Appendix B).

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[19] Appendix B shows the maps and the figures that illustrate the different climate patterns in the country.

In terms of total revenues, temporary crops general the largest amount, followed by livestock and permanent crops. We can also observe that temporary crops represent more than 85 percent of all planted area in the country, a share that seems to have increased from the mid-1990s until 2008 (the last year for which complete information is available). Temporary crops additionally lead permanent crops in production, in monetary terms, when compared to planted area.[20]

Brazil's main temporary crops are soybeans, maize, and sugarcane, which together account for 75 percent of area planted in temporary crops and 66 percent of the value generated by temporary crops. Coffee and oranges represent the most important permanent crops, with 46 percent of planted area and 55 percent of value in their category. These data are illustrated by the graphs in Appendix B.

In terms of financing production, the use of loans increases with the size of farm. Small farmers often use financing for investments, while larger farmers use financing to purchase inputs.[21]

5. Results

A system of 12 equations, out of 13, was estimated (9 products and 4 inputs). One equation should be dropped from the system in order to avoid the singularity problem. The parameters of the equation dropped can be recovered from the assumption of the homogeneity restrictions.[22] The software used was Stata (Statistics/Data Analysis) 11.1 - Special Edition.

Appendix E shows the variables description in order to help the interpretation of the model. It also presents the sample statistics and description of the data.

The system of equations was estimated after normalizing the variables into a standard normal distribution. This normalization was performed to facilitate the model interpretation since many of the variables have different measurement units. This does not influence the results, as the transformation proposed does not change the variability of the variables. After the normalization, the results are measuring effects not in terms of the original units, but in standard

[20] Inflationary years were excluded (before 1994).
[21] According to the last Brazilian Agriculture Census (2006), banks are the major financing institutions for all farmers (representing about 90 percent of all the financing, especially for smaller farmers). Larger farmers additionally make use of financing provision from suppliers and credit cooperatives.
[22] The parameter estimates are invariant to the equation dropped when the model is estimated by the maximum likelihood method.

deviation units (called *beta coefficients*). According to Wooldridge (2002: 182), this procedure makes the scale of the independent variables irrelevant, putting the explanatory variables on equal footing.

The symmetry conditions were also assumed for the estimation. The regressions information and main results are presented in the following tables and the Stata commands can be accessed in Appendix A.

Table 1. Information on Model's Fit

Equation	Total Observations	Number of Parameters	RMSE	R-square	chi2	P-value
qt_maize_s	5,485	38	0.92878	14.64%	944	0
qt_soybean_s	5,485	38	0.92536	15.29%	986	0
qt_ot_temp_s	5,485	38	0.93144	14.16%	854	0
qt_coffe_s	5,485	38	0.94988	10.73%	640	0
qt_ot_perm_s	5,485	38	0.98249	4.50%	296	0
qt_milk_s	5,485	38	0.88728	21.94%	1,594	0
qt_cattle_s	5,485	38	0.79455	37.50%	3,253	0
qt_wood_s	5,485	38	0.98742	3.57%	290	0
qt_land_s	5,485	38	0.76027	42.72%	4,069	0
qt_labor_s	5,485	38	0.93978	12.39%	889	0
qt_fuel_s	5,485	38	0.89023	21.18%	1,464	0
qt_fert_s	5,485	38	0.89555	20.61%	1,428	0

The joint tests performed for each equation show that all the regressions were significant at a 1 percent significance level. The R^2 measures are around 10-20 percent in most of the equations, which is common when using cross-section databases.

Tables 2 and 3 show the coefficients estimated for the climate variables. The former shows the short-term coefficients and the latter the long-term and the R&D effect on production. As the model estimated here is different from those elsewhere in the literature, it is not possible to compare them. A simple analysis, however, identifies that the results found are according to expectations. The climate effects will be better explored in Section 6.

Appendix F shows the results for other variables in the model, which will not be discussed or used by this paper.

Table 2. Marginal Effects for Short-Term Weather Indexes

SUR - Restricted	qt_maize_s	qt_soybean_s	qt_ot_temp_s	qt_coffe_s	qt_ot_perm_s	qt_milk_s	qt_cattle_s	qt_wood_s	qt_land_s	qt_labor_s	qt_fuel_s	qt_fert_s
Short-term: Weather Indexes												
rain_mar_var_s	-0.0220	-0.00623	-0.0130	-0.00115	-0.00304	-0.0244	-0.0357***	-0.0279*	-0.00988	-0.00960	-0.0132	-0.0143
	(0.0159)	(0.0158)	(0.0159)	(0.0161)	(0.0167)	(0.0151)	(0.0135)	(0.0169)	(0.0130)	(0.0161)	(0.0152)	(0.0153)
rain_jun_var_s	-0.0353**	-0.0202	0.00486	-0.00531	0.0560***	0.0309**	-0.0371***	0.00628	-0.0454***	-0.0764***	-0.0310**	-0.0236*
	(0.0148)	(0.0147)	(0.0148)	(0.0150)	(0.0155)	(0.0141)	(0.0126)	(0.0157)	(0.0121)	(0.0149)	(0.0141)	(0.0142)
rain_sep_var_s	0.121***	0.0527***	0.00313	0.00535	-0.0340*	-0.0435**	0.0214	0.0693***	0.0337**	-0.0122	0.0496***	0.0788***
	(0.0183)	(0.0183)	(0.0184)	(0.0187)	(0.0193)	(0.0175)	(0.0157)	(0.0195)	(0.0150)	(0.0186)	(0.0176)	(0.0177)
rain_dec_var_s	0.00593	0.0554***	0.0504***	0.0813***	-0.0139	0.0645***	0.0688***	0.0236	0.0293**	-0.0469***	0.0592***	0.0500***
	(0.0160)	(0.0159)	(0.0160)	(0.0163)	(0.0169)	(0.0153)	(0.0136)	(0.0170)	(0.0131)	(0.0162)	(0.0153)	(0.0154)
temp_mar_var_s	-0.0241	-0.0481***	0.0337**	0.0550***	0.0260	-0.0499***	-0.0212	-0.00421	-0.0208	0.0250	-0.000746	-0.0264*
	(0.0157)	(0.0156)	(0.0158)	(0.0160)	(0.0166)	(0.0152)	(0.0135)	(0.0167)	(0.0129)	(0.0159)	(0.0151)	(0.0151)
temp_jun_var_s	-0.00318	-0.0345	0.144***	-0.242***	0.0871***	-0.00512	0.182***	-0.0773**	0.0554**	-0.0775***	0.0457*	-0.0106
	(0.0287)	(0.0285)	(0.0287)	(0.0289)	(0.0299)	(0.0275)	(0.0244)	(0.0301)	(0.0233)	(0.0290)	(0.0275)	(0.0276)
temp_sep_var_s	0.0633**	0.204***	-0.0353	-0.0980***	-0.0968***	0.0800***	0.111***	-0.0369	0.0833***	-0.0689**	0.00888	0.148***
	(0.0272)	(0.0271)	(0.0273)	(0.0277)	(0.0286)	(0.0260)	(0.0233)	(0.0288)	(0.0222)	(0.0275)	(0.0261)	(0.0262)
temp_dec_var_s	-0.0183	-0.0114	0.0481*	-0.0736***	-0.00535	-0.0509**	-0.00342	0.0510*	0.0485**	-0.0160	0.0403	0.0148
	(0.0265)	(0.0264)	(0.0266)	(0.0270)	(0.0280)	(0.0253)	(0.0227)	(0.0282)	(0.0217)	(0.0268)	(0.0254)	(0.0255)

Standard errors in parentheses

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

Table 3. Marginal Effects for Long-Term Climate Change

SUR - Restricted	qt_maize_s	qt_soybean_s	qt_ot_temp_s	qt_coffe_s	qt_ot_perm_s	qt_milk_s	qt_cattle_s	qt_wood_s	qt_land_s	qt_labor_s	qt_fuel_s	qt_fert_s
Long-term: Climate Change Effects												
rain_mar_m_s	0.0317	0.0529*	-0.0938***	0.0560**	0.0475*	0.0505*	0.0997***	0.118***	0.0735***	-0.0447	0.109***	0.0314
	(0.0275)	(0.0274)	(0.0275)	(0.0278)	(0.0288)	(0.0265)	(0.0235)	(0.0290)	(0.0224)	(0.0278)	(0.0263)	(0.0265)
rain_jun_m_s	-0.0936***	-0.118***	0.0602**	-0.0417	-0.0391	-0.0887***	-0.264***	0.0929***	-0.170***	-0.139***	-0.154***	-0.0951***
	(0.0257)	(0.0255)	(0.0257)	(0.0262)	(0.0271)	(0.0247)	(0.0220)	(0.0272)	(0.0210)	(0.0260)	(0.0246)	(0.0247)
rain_sep_m_s	0.228***	0.288***	-0.224***	0.136**	-0.104*	0.0213	0.0431	-0.00836	0.0256	0.00983	0.149***	0.234***
	(0.0531)	(0.0529)	(0.0533)	(0.0538)	(0.0556)	(0.0511)	(0.0454)	(0.0559)	(0.0433)	(0.0538)	(0.0509)	(0.0512)
rain_dec_m_s	-0.225***	-0.151***	0.0107	0.0695*	-0.0954**	-0.0317	-0.0571*	-0.0379	-0.0919***	-0.0352	-0.236***	-0.191***
	(0.0360)	(0.0358)	(0.0361)	(0.0365)	(0.0378)	(0.0351)	(0.0310)	(0.0385)	(0.0294)	(0.0365)	(0.0345)	(0.0346)
temp_mar_m_s	-0.0269	0.217***	-0.0271	-0.0214	0.127	0.135*	0.324***	-0.00329	0.277***	-0.266***	0.130*	0.204***
	(0.0774)	(0.0770)	(0.0777)	(0.0781)	(0.0808)	(0.0750)	(0.0662)	(0.0813)	(0.0631)	(0.0784)	(0.0743)	(0.0745)
temp_jun_m_s	-0.333**	-0.375***	0.0795	-0.0176	-0.0180	-0.550***	0.0551	0.0673	-0.177*	0.379***	-0.334***	-0.400***
	(0.131)	(0.131)	(0.131)	(0.132)	(0.136)	(0.123)	(0.110)	(0.136)	(0.107)	(0.133)	(0.126)	(0.126)
temp_sep_m_s	0.445***	0.366***	0.156	-0.0972	0.105	0.559***	-0.0870	-0.145	0.179**	-0.327***	0.446***	0.403***
	(0.109)	(0.108)	(0.109)	(0.110)	(0.113)	(0.102)	(0.0913)	(0.114)	(0.0885)	(0.110)	(0.104)	(0.105)
temp_dec_m_s	-0.176**	-0.277***	-0.172**	0.156*	-0.244***	-0.220***	-0.313***	0.0756	-0.327***	0.352***	-0.285***	-0.312***
	(0.0830)	(0.0827)	(0.0833)	(0.0840)	(0.0869)	(0.0796)	(0.0708)	(0.0873)	(0.0677)	(0.0840)	(0.0796)	(0.0800)
rd_stock_2006_s	**0.264*****	**0.191*****	**0.0642*****	**0.104*****	**0.0746*****	**0.285*****	**0.214*****	**0.0363*****	**0.255*****	**0.288*****	**0.333*****	**0.280*****
	(0.0130)	**(0.0130)**	**(0.0130)**	**(0.0133)**	**(0.0138)**	**(0.0124)**	**(0.0111)**	**(0.0139)**	**(0.0106)**	**(0.0132)**	**(0.0125)**	**(0.0125)**

Standard errors in parentheses

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

6. Measuring Climate Effects

After presenting the weather indexes and estimating short and long-term climate impacts on crop production and farmers' profit, this section measures those effects extrapolating the results to understand their importance. Section 6.1 calculates the insurance amount based on the profit change due to the incidence of weather extreme events by stressing short-term weather indexes, while Section 6.2 measures the Research and Development (R&D) expense needed to compensate for long-term climate change effects.

6.1 Insurance Amount and Weather Index

The weather indexes developed by this study, based on the difference (in standard deviations) between the actual rainfall and the long-term mean, indicate the occurrence of droughts/floods and heat/cold waves. These indexes are good measures for extreme weather events. It is noteworthy that the simulations performed here consider only a short term variation in climate, which means that the long term mean was preserved fixed for the analysis.

Two scenarios for each weather extreme event were analyzed for each agricultural output considered in the analysis:

1. Drought: Rainfall below the long-term mean in standard deviations: $I_D < E(Rain) - n\sigma_{Rain}$, n = 1, and 2;
2. Flood: Rainfall above the long-term mean in standard deviations: $I_F > E(Rain) + n\sigma_{Rain}$, n = 1, and 2;
3. Cold Stress: Temperature below the long-term mean in standard deviations: $I_D < E(Temp) - n\sigma_{Temp}$, n = 1, and 2; and
4. Heat Stress: Temperature above the long-term mean in standard deviations: $I_D > E(Temp) + n\sigma_{Temp}$, n = 1, and 2.

Based on these scenarios, changes in production and profits were calculated, the latter being taken as a proxy for expected loss from weather extreme events, according to the evidences shown in the theoretical model. The results for the change in production are summarized below (in standard deviations):

Table 4. Short-Term Effects from Extreme Weather Events, in Production Standard Deviations

Change in Production	Droughts		Floods		Heat Stress		Cold Stress	
	< 1 σ	< 2 σ	> 1 σ	> 2 σ	> 1 σ	> 2 σ	< 1 σ	< 2 σ
Maize[1]	0.121	0.242	0.035	0.071	*	*	0.063	0.127
Soybean[2]	0.055	0.111	*	*	0.048	0.096	0.204	0.408
Other temporary crops[3]	0.050	0.101	*	*	*	*	0.144	0.288
Coffee[4]	0.081	0.163	*	*	0.242	0.484	0.055	0.110
Other permanent crops[5]	0.056	0.112	0.034	0.068	0.097	0.194	0.087	0.174
Cattle[6]	0.069	0.138	0.037	0.074	*	*	0.182	0.364
Milk[7]	0.065	0.129	0.044	0.087	0.050	0.100	0.080	0.160
Wood[8]	0.069	0.139	0.028	0.056	0.077	0.155	0.051	0.102
Average effect	**0.071**	**0.142**	**0.036**	**0.071**	**0.103**	**0.206**	**0.108**	**0.217**

* Non-significant effect

1 Drought: damages in september / Floods: damages in June / Low temperatures: damages in september

2 Drought: damages in september and december / Low temperatures: damages in september / High temperatures: damages in march

3 Drought: damages in december / Low temperatures: damages in march, june and september.

4 Drought: damages in december / Low temperatures: damages in march / High temperatures: damages in december, june and september.

5 Drought: damages in june / Floods: damages in september / Low temperatures: damages in june / High temperatures: damages in september.

6 Drought: damages in december / Floods: damages in march and june / Low temperatures: damages in june and september.

7 Drought: damages in june and december / Floods: damages in september / Low temp: damages in september / High temp: damages in december, and march.

8 Drought: damages in september / Floods: damages in march / Low temperatures: damages in december / High temperatures: damages in june

Table 4 shows the average profit change, in terms of standard deviations, related to the occurrence of extreme weather such as floods, drought, heat stress and cold stress. The table is useful for identifying the sensitivity of crops to extreme weather events in the short run. An important finding in the results is that droughts are worse than floods for all the products analyzed, in general. Heat and cold stresses symmetrically impact the production of the crops analyzed in this study.

In order to calculate the profit impact, we need to convert those standard deviations into profits by finding the total quantity change and multiplying by the prices. Table 5 shows the final results, by unit of analysis.

Table 5. Short-Term Effects from Extreme Weather Events in Loss of Profits, Measured in Thousands of USD[23]

Change in Profits (loss)	Droughts		Floods		Heat Stress		Cold Stress	
	< 1 σ	< 2 σ	> 1 σ	> 2 σ	> 1 σ	> 2 σ	< 1 σ	< 2 σ
Maize	481	963	140	281	*	*	252	503.67
Soybean	405	810	*	*	352	703	1,491	2,982
Other temporary crops[1]	143	286	*	*	*	*	409	817
Coffee	177	354	*	*	526	1,053	120	239
Other permanent crops[2]	13	26	8	16	22	45	20	40
Cattle	228	456	123	246	*	*	604	1,207
Milk	82	164	55	111	64	127	102	204
Wood	25	50	10	20	28	56	19	37
Average effect (in k USD)	**194**	**389**	**67**	**135**	**198**	**397**	**377**	**754**
Total effect (in million USD)	**1,066**	**2,132**	**370**	**739**	**1,088**	**2,177**	**2,067**	**4,135**

1: 31 crops are considered in the analysis

2: 32 crops are considered in the analysis

* Non-significant effect

The profit losses calculated above show the average profit loss in thousands of dollars by municipality due to the occurrence of the events mentioned above. The crops most affected by drought are maize, soybean, cattle and other temporary crops. Floods and temperature stresses generate much smaller losses when compared to drought. It is thus possible to conclude that the drought index and the heat/cold stress index are the most relevant for mitigating losses in agricultural production.

The use of an insurance mechanism in a scenario where the actual droughts deviate from normal conditions by one standard deviation (in the whole Brazil) could cause the loss of more than US$ 1 billion to Brazilian agriculture. The situation for cold waves in Brazil is even worse, with damage that could total more than US$ 2 billion!

6.2 Climate Change Compensation from R&D Expenses

In order to measure how R&D expenses can compensate the losses caused by climate change, a long run perspective, the equation in (6) has been used. By keeping the climate volatility and the other factors fixed and changing the actual season climate means for projected future season climate means as published by INPE (National Institute for Space Research),[24] it is possible to calculate a monetary value for the gain/loss generated by climate change.

[23] Average exchange rate from 1/1/2006 to 12/31/2006 (BRL/ USD): 2.1756. Source: Bloomberg

[24] We tried to use the micro-level data regarding the climate long term predictions but only 2,872 out of 5,564 municipalities had predictions in the database. For this reason we decided to use the climate change expectations for each Brazilian region in order to calculate the R&D investments compensations.

The first step is to estimate the average quantity loss/gain due to climate change. These quantities are shown in Table 6 below.

Table 6. Change in Quantities Due to Long-Term Climate Variation, in Standard Deviation

Average Change in Quantities (loss/gain)	Change in Quantities (st. dev.) - A2 Scenario	Change in Quantities (st. dev.) - B2 Scenario
Maize	-0.545	-0.358
Soybean	-0.516	-0.339
Other temporary crops	-0.437	-0.287
Coffee	0.390	0.257
Other permanent crops	-0.516	-0.340
Cattle	-0.473	-0.311
Milk	-0.458	-0.301
Wood	0.168	0.111

Based on the total loss in production generated by climate change, the variation in investment required to compensate for agricultural profit reduction can be estimated. Table 7 summarizes the total of R&D investments needed to compensate for such effects.

Table 7. R&D Investment Compensation Due to Long-Term Climate Variation Effects per Year, in Thousands of USD

Investment in R&D (compensation)	R&D Compensation in USD per year A2 Scenario	R&D Compensation in USD per year B2 Scenario
Maize	206.3	135.7
Soybean	269.8	177.3
Other temporary crops	680.4	447.5
Coffee	*n/a*	*n/a*
Other permanent crops	691.9	455.0
Cattle	220.8	145.2
Milk	160.6	105.5
Wood	*n/a*	*n/a*
R&D Stock Average in 2006	**850.1**	**850.1**
R&D Investment in 2010	**194.5**	**194.5**

n/a: Not affected, or positively affected, by climate change

The numbers above show average R&D investment compensation for climate change by year and municipality. The only crops that will not be affected by climate change are coffee and wood. All the other crops analyzed will be negatively impacted by the expected change in climate trends in temperature and rainfall. The highest increases in R&D investments, in order of importance, are for other permanent crops, other temporary crops, soybeans, cattle, maize, and milk. For soybeans, maize and cattle, for example, R&D investment must increase between 70 and 90 percent over Embrapa's peak investments in 2010 to compensate for the impacts of climate change on farmers' production and profits.

7. Concluding Remarks

This study's objective is to analyze the effects of climate change and climate variation on agricultural outputs. Two definitions for climate variation were developed: a long-term approach, in order to analyze climate change impacts and compensation measures; and a short-term approach, which developed a weather index approach in order to estimate the amount of insurance needed by farmers based on expected loss of profits.

We believe that governments should be prepared for changes in land use and agricultural production due to climatic deviations in both the long and short term. Climate change effects on agriculture can be smoothed by new investments in crop modification and in productivity improvements. Due to the time lag of such changes, these long-term measures are very effective in mitigating the problem.

An investment approach, however, cannot be used for weather shocks. For this reason, this study formulated a weather index approach, which has assumed increasing importance in the recent literature, to model the average insurance needed based on the occurrence of weather shocks in Brazilian agriculture.

The contribution of the study is to incorporate the policy instruments mentioned above into an empirical analysis derived from a theoretical model.

The estimated results showed that in, the short term, a drought index and heat/cold stress index are the most relevant climate indicators for avoiding profit losses. The use of an insurance mechanism in a scenario where actual droughts deviate from normal conditions by one standard deviation nationwide could have mitigated agricultural losses of more than US$ 1 billion in

2006. The negative impact of cold waves in Brazil is even worse, with damage of over US$ 2 billion.

It is important to note that those numbers reflect a shock across all Brazilian municipalities. While such an occurrence is not foreseen, even from the most pessimistic standpoint, it provides an idea of potential losses and the amount of insurance required to offset them. The same idea can be applied to a specific region or municipality of Brazil, where the occurrence of a shock is more likely. The same analysis can be performed to estimate the insurance premium required to offset the losses from a weather extreme event.

In regard to long-run changes in climate, the results indicate that the only crops that will not be affected by climate change are coffee and wood. All the other crops analyzed will be impacted by variation in climate trends in temperature and rainfall. The greatest increases in R&D investments will be needed for, in order of importance, other permanent crops, other temporary crops, soybean, cattle, maize and milk. For soybeans, maize and cattle, for example, R&D investment must increase between 70 and 90 percent over Embrapa's peak investments in 2010 to compensate for the impacts of climate change on farmers' production and profits.

The findings presented for climate change impacts on Brazilian agriculture are in line with those of the previous literature. In this study we went a step forward by estimating the required value of R & D investments to adapt to or reduce possible negative impacts of climate change in the long run.

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Appendix A. Program (Climate Data)

A.1 Commands in R for Kriging the Climate Variables

```
## Reading dataframe for the weather stations data:
setwd("C:\Users\paula\Documents\IADB\\Data\Climate Data")
data1 <- read.table("Dados Climaticos.csv", header = TRUE, sep = ",")
attach(data1)
x=cbind(longitude,latitude)

## Shape-file for the municipalities (polygons):
mapa<-readShapePoly("Br_mun05")
z<-cbind(as.numeric(as.vector(mapa$LONGITUDE)),as.numeric(as.vector(mapa$LATITUDE)))

## Kriging the climatic data:
# Insolation (hours)
insol<-as.vector(data1[,seq(4,723,6)])
INSOL<-matrix(NA,5564,120)

for (i in 1:120) {
fit = Krig(x,insol[,i])
pred<-predict( fit,z)
INSOL[,i]<-pred
}
write.table(INSOL,"Insolacao")

# AverageTemperature
temp_media<-as.vector(data1[,seq(9,723,6)])
AVG_TEMP<-matrix(NA,5564,120)

for (i in 1:120) {
fit = Krig(x,temp_media[,i])
pred<-predict( fit,z)
AVG_TEMP[,i]<-pred
}
write.table(AVG_TEMP,"AVG_TEMPERATURE")

# MinimumTemperature
temp_min<-as.vector(data1[,seq(8,723,6)])
MIN_TEMP<-matrix(NA,5564,120)

for (i in 1:120) {
fit = Krig(x,temp_min[,i])
pred<-predict( fit,z)
MIN_TEMP[,i]<-pred
}

write.table(MIN_TEMP,"MIN_TEMPERATURE")

# MaximumTemperature
temp_max<-as.vector(data1[,seq(6,723,6)])
MAX_TEMP<-matrix(NA,5564,120)

for (i in 1:120) {
fit = Krig(x,temp_max[,i])
pred<-predict( fit,z)
MAX_TEMP[,i]<-pred
}

write.table(MAX_TEMP,"MAX_TEMPERATURE.xls")
```

```
# Relative Humidity:
umid_relat<-as.vector(data1[,seq(7,723,6)])
UMID_REL<-matrix(NA,5564,120)

for (i in 1:120) {
fit = Krig(x,umid_relat[,i])
pred<-predict( fit,z)
UMID_REL[,i]<-pred
}

write.table(UMID_REL,"UMID_REL.xls")
```

A.2 Commands in Data Library

```
### NOAA NCEP CPC CMORPH: CPC Morphingtechnique for the production of global precipitationestimates.

# In Data Library - http://iridl.ldeo.columbia.edu/ - write in the "ExpertMode":

expert
SOURCES .NOAA .NCEP .CPC .CMORPH .daily_calculated .mean .morphed .cmorph
T monthlyAverage
home .pcarvalho .GISupload .br_mun05 .geometry .the_geom
[X Y]weighted-average

where:
home .pcarvalho .GISupload .br_mun05 .geometry .the_geom: represent the SHape-file of the Brazilianmunicipalities, uploadedunder the user "pcarvalho".
```

A.3 Stata Commands for the Restricted ISUR

```
set memo 400m
set more off
set matsize 3000

useData (all databases).dta

** Generating UF variable (province code):
tostring code, replace
gen code_uf=substr(code,1,2)
destring code, replace
destring code_uf, replace

** Generating prices:
sort code_uf
by code_uf: egen med_maize=median(price_maize)
by code_uf: egen med_soybean=median(price_soybean)
sum med_soybean if code_uf==11
replace med_soybean=.3515325 if code_uf==12 | code_uf==13
sum med_soybean if code_uf==15
replace med_soybean=.4189082 if code_uf==16
sum med_soybean if code_uf==29
replace med_soybean=(.3974279+.291667)/2 if code_uf==23 | code_uf==24| code_uf==25 |
code_uf==27 | code_uf==28
sum med_soybean if code_uf==31
replace med_soybean=.4364524 if code_uf==32 | code_uf==33
by code_uf: egen med_ot_temp=median(price_ot_temp)
by code_uf: egen med_coffe=median(price_coffe)
sum med_coffe if code_uf==15
replace med_coffe=(1+1.3333)/2 if code_uf==17
sum med_coffe if code_uf==27
```

```
replace med_coffe=(1.304878) if code_uf==28
by code_uf: egen med_ot_perm=median(price_ot_perm)
by code_uf: egen med_milk=median(price_milk)
by code_uf: egen med_cattle=median(price_cattle)
by code_uf: egen med_wood=median(price_wood)
by code_uf: egen med_ot_for=median(price_ot_for)
sum med_ot_for if code_uf==29
replace med_ot_for=(.6923077) if code_uf==32
by code_uf: egen med_land=median(price_land)
sum med_land if code_uf==15
replace med_land=(.0753982) if code_uf==16
by code_uf: egen med_labor=median(price_labor)
by code_uf: egen med_fuel=median(price_fuel)
by code_uf: egen med_fert=median(price_fert)
replace price_maize=med_maize if price_maize==.
replace price_soybean=med_soybean if price_soybean==.
replace price_ot_temp=med_ot_temp if price_ot_temp==.
replace price_coffe=med_coffe if price_coffe==.
replace price_ot_perm=med_ot_perm if price_ot_perm==.
replace price_milk=med_milk if price_milk==.
replace price_cattle=med_cattle if price_cattle==.
replace price_wood=med_wood if price_wood==.
replace price_ot_for=med_ot_for if price_ot_for==.
replace price_land=med_land if price_land==.
replace price_labor=med_labor if price_labor==.
replace price_fuel=med_fuel if price_fuel==.
replace price_fert=med_fert if price_fert==.

drop med_maize- med_fert


** Generating total investments and standardized variables:

gen inv_total= inv_total_temp+ inv_total_perm+ inv_total_livs+ inv_total_for

foreach var in  qt_maize qt_soybean qt_ot_temp qt_coffe qt_ot_perm qt_milk qt_cattle
qt_wood qt_ot_for qt_land qt_labor qt_fuel qt_fert price_maize price_soybean
price_ot_temp price_coffe price_ot_perm price_milk price_cattle price_wood
price_ot_for price_land price_labor price_fuel price_fert inv_total_temp
inv_total_perm inv_total_livs inv_total_for analf_temp alfab_temp ensfun_inc_temp
ensfun_comp_temp ensmed_comp_temp enssup_temp analf_perm alfab_perm ensfun_inc_perm
ensfun_comp_perm ensmed_comp_perm enssup_perm analf_livs alfab_livs ensfun_inc_livs
ensfun_comp_livs ensmed_comp_livs enssup_livs analf_for alfab_for ensfun_inc_for
ensfun_comp_for ensmed_comp_for enssup_for degr_tot_areas agri_tot_areas
inapr_tot_areas tam_medio rain_jan_m rain_feb_m rain_mar_m rain_apr_m rain_may_m
rain_jun_m rain_jul_m rain_ago_m rain_sep_m rain_oct_m rain_nov_m rain_dec_m
rain_jan_var rain_feb_var rain_mar_var rain_apr_var rain_may_var rain_jun_var
rain_jul_var rain_ago_var rain_sep_var rain_oct_var rain_nov_var rain_dec_var
temp_jan_m temp_feb_m temp_mar_m temp_apr_m temp_may_m temp_jun_m temp_jul_m
temp_ago_m temp_sep_m temp_oct_m temp_nov_m temp_dec_m temp_jan_var temp_feb_var
temp_mar_var temp_apr_var temp_may_var temp_jun_var temp_jul_var temp_ago_var
temp_sep_var temp_oct_var temp_nov_var temp_dec_var inv_total rdi_stock_2006
{
egen `var'_s=std(`var')
}


**** SURE Regressions (standardized variables):

*Setting the Constrains:

constraint 1 [qt_maize_s]price_soybean_s=[qt_soybean_s]price_maize_s
constraint 2 [qt_maize_s]price_ot_temp_s=[qt_ot_temp_s]price_maize_s
```

```
constraint 3 [qt_maize_s]price_coffe_s=[qt_coffe_s]price_maize_s
constraint 4 [qt_maize_s]price_ot_perm_s=[qt_ot_perm_s]price_maize_s
constraint 5 [qt_maize_s]price_milk_s=[qt_milk_s]price_maize_s
constraint 6 [qt_maize_s]price_cattle_s=[qt_cattle_s]price_maize_s
constraint 7 [qt_maize_s]price_wood_s=[qt_wood_s]price_maize_s
constraint 8 [qt_maize_s]price_land_s=[qt_land_s]price_maize_s
constraint 9 [qt_maize_s]price_labor_s=[qt_labor_s]price_maize_s
constraint 10 [qt_maize_s]price_fuel_s=[qt_fuel_s]price_maize_s
constraint 11 [qt_maize_s]price_fert_s=[qt_fert_s]price_maize_s
constraint 12 [qt_soybean_s]price_ot_temp_s=[qt_ot_temp_s]price_soybean_s
constraint 13 [qt_soybean_s]price_coffe_s=[qt_coffe_s]price_soybean_s
constraint 14 [qt_soybean_s]price_ot_perm_s=[qt_ot_perm_s]price_soybean_s
constraint 15 [qt_soybean_s]price_milk_s=[qt_milk_s]price_soybean_s
constraint 16 [qt_soybean_s]price_cattle_s=[qt_cattle_s]price_soybean_s
constraint 17 [qt_soybean_s]price_wood_s=[qt_wood_s]price_soybean_s
constraint 18 [qt_soybean_s]price_land_s=[qt_land_s]price_soybean_s
constraint 19 [qt_soybean_s]price_labor_s=[qt_labor_s]price_soybean_s
constraint 20 [qt_soybean_s]price_fuel_s=[qt_fuel_s]price_soybean_s
constraint 21 [qt_soybean_s]price_fert_s=[qt_fert_s]price_soybean_s
constraint 22 [qt_ot_temp_s]price_coffe_s=[qt_coffe_s]price_ot_temp_s
constraint 23 [qt_ot_temp_s]price_ot_perm_s=[qt_ot_perm_s]price_ot_temp_s
constraint 24 [qt_ot_temp_s]price_milk_s=[qt_milk_s]price_ot_temp_s
constraint 25 [qt_ot_temp_s]price_cattle_s=[qt_cattle_s]price_ot_temp_s
constraint 26 [qt_ot_temp_s]price_wood_s=[qt_wood_s]price_ot_temp_s
constraint 27 [qt_ot_temp_s]price_land_s=[qt_land_s]price_ot_temp_s
constraint 28 [qt_ot_temp_s]price_labor_s=[qt_labor_s]price_ot_temp_s
constraint 29 [qt_ot_temp_s]price_fuel_s=[qt_fuel_s]price_ot_temp_s
constraint 30 [qt_ot_temp_s]price_fert_s=[qt_fert_s]price_ot_temp_s
constraint 31 [qt_coffe_s]price_ot_perm_s=[qt_ot_perm_s]price_coffe_s
constraint 32 [qt_coffe_s]price_milk_s=[qt_milk_s]price_coffe_s
constraint 33 [qt_coffe_s]price_cattle_s=[qt_cattle_s]price_coffe_s
constraint 34 [qt_coffe_s]price_wood_s=[qt_wood_s]price_coffe_s
constraint 35 [qt_coffe_s]price_land_s=[qt_land_s]price_coffe_s
constraint 36 [qt_coffe_s]price_labor_s=[qt_labor_s]price_coffe_s
constraint 37 [qt_coffe_s]price_fuel_s=[qt_fuel_s]price_coffe_s
constraint 38 [qt_coffe_s]price_fert_s=[qt_fert_s]price_coffe_s
constraint 39 [qt_ot_perm_s]price_milk_s=[qt_milk_s]price_ot_perm_s
constraint 40 [qt_ot_perm_s]price_cattle_s=[qt_cattle_s]price_ot_perm_s
constraint 41 [qt_ot_perm_s]price_wood_s=[qt_wood_s]price_ot_perm_s
constraint 42 [qt_ot_perm_s]price_land_s=[qt_land_s]price_ot_perm_s
constraint 43 [qt_ot_perm_s]price_labor_s=[qt_labor_s]price_ot_perm_s
constraint 44 [qt_ot_perm_s]price_fuel_s=[qt_fuel_s]price_ot_perm_s
constraint 45 [qt_ot_perm_s]price_fert_s=[qt_fert_s]price_ot_perm_s
constraint 46 [qt_milk_s]price_cattle_s=[qt_cattle_s]price_milk_s
constraint 47 [qt_milk_s]price_wood_s=[qt_wood_s]price_milk_s
constraint 48 [qt_milk_s]price_land_s=[qt_land_s]price_milk_s
constraint 49 [qt_milk_s]price_labor_s=[qt_labor_s]price_milk_s
constraint 50 [qt_milk_s]price_fuel_s=[qt_fuel_s]price_milk_s
constraint 51 [qt_milk_s]price_fert_s=[qt_fert_s]price_milk_s
constraint 52 [qt_cattle_s]price_wood_s=[qt_wood_s]price_cattle_s
constraint 53 [qt_cattle_s]price_land_s=[qt_land_s]price_cattle_s
constraint 54 [qt_cattle_s]price_labor_s=[qt_labor_s]price_cattle_s
constraint 55 [qt_cattle_s]price_fuel_s=[qt_fuel_s]price_cattle_s
constraint 56 [qt_cattle_s]price_fert_s=[qt_fert_s]price_cattle_s
constraint 57 [qt_wood_s]price_land_s=[qt_land_s]price_wood_s
constraint 58 [qt_wood_s]price_labor_s=[qt_labor_s]price_wood_s
constraint 59 [qt_wood_s]price_fuel_s=[qt_fuel_s]price_wood_s
constraint 60 [qt_wood_s]price_fert_s=[qt_fert_s]price_wood_s
constraint 61 [qt_land_s]price_labor_s=[qt_labor_s]price_land_s
constraint 62 [qt_land_s]price_fuel_s=[qt_fuel_s]price_land_s
constraint 63 [qt_land_s]price_fert_s=[qt_fert_s]price_land_s
constraint 64 [qt_labor_s]price_fuel_s=[qt_fuel_s]price_labor_s
constraint 65 [qt_labor_s]price_fert_s=[qt_fert_s]price_labor_s
```

```
constraint 66 [qt_fuel_s]price_fert_s=[qt_fert_s]price_fuel_s


sureg (qt_maize_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s-
enssup_temp_s degr_tot_areas_s agri_tot_areas_s tam_medio_s rain_mar_m_s rain_jun_m_s
rain_sep_m_s rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s
temp_mar_m_s temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s
temp_sep_var_s temp_dec_var_s)
 (qt_soybean_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s-
enssup_temp_s degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s
rain_sep_m_s rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s
temp_mar_m_s temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s
temp_sep_var_s temp_dec_var_s)
 (qt_ot_temp_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s-
enssup_temp_s degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s
rain_sep_m_s rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s
temp_mar_m_s temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s
temp_sep_var_s temp_dec_var_s)
 (qt_coffe_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_perm_s- enssup_perm_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_ot_perm_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_perm_s-
enssup_perm_s degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s
rain_sep_m_s rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s
temp_mar_m_s temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s
temp_sep_var_s temp_dec_var_s)
 (qt_milk_s price_maize_s-price_fert_s rdi_stock_2006_s alfab_livs_s- enssup_livs_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_cattle_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_livs_s- enssup_livs_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_wood_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_for_s- enssup_for_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_land_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s- enssup_temp_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_labor_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s- enssup_temp_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_fuel_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s- enssup_temp_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s)
 (qt_fert_s price_maize_s- price_fert_s rdi_stock_2006_s alfab_temp_s- enssup_temp_s
degr_tot_areas_s agri_tot_areas_s tam_medio_s  rain_mar_m_s rain_jun_m_s rain_sep_m_s
rain_dec_m_s rain_mar_var_s rain_jun_var_s rain_sep_var_s rain_dec_var_s temp_mar_m_s
temp_jun_m_s temp_sep_m_s temp_dec_m_s temp_mar_var_s temp_jun_var_s temp_sep_var_s
temp_dec_var_s), const(1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
```

```
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53
54 55 56 57 58 59 60 61 62 63 64 65 66) i;

estimates store SUR_restricted;

outreg2 [SUR_restricted] using sur_results, excel;
```

Appendix B. Climate/Agriculture Description in Brazil

B.1 Brazilian Geographical Division

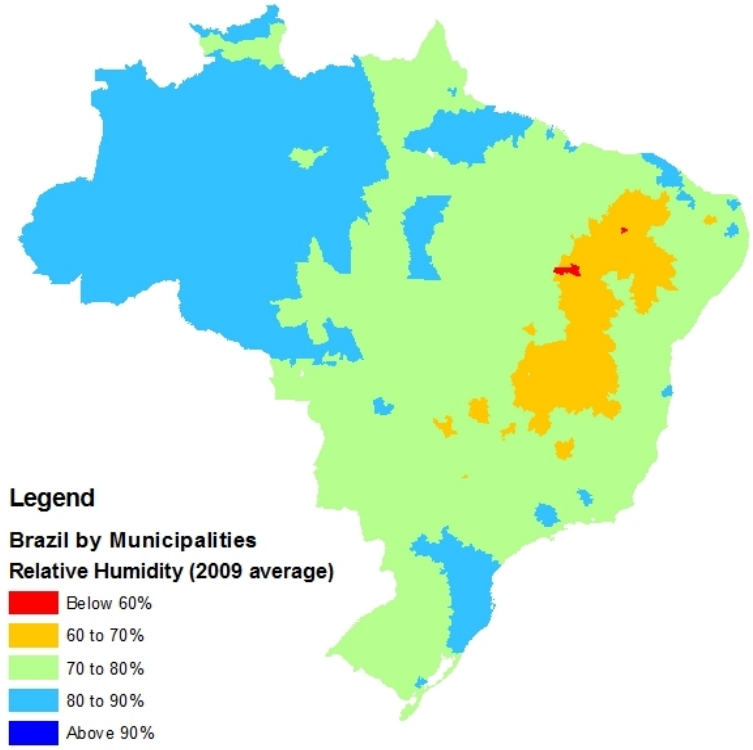
Brazil is geographically divided into five regions, which share common socio-economic and cultural characteristics. The following map shows the country's division into regions.

Map B.1. Brazilian Regions

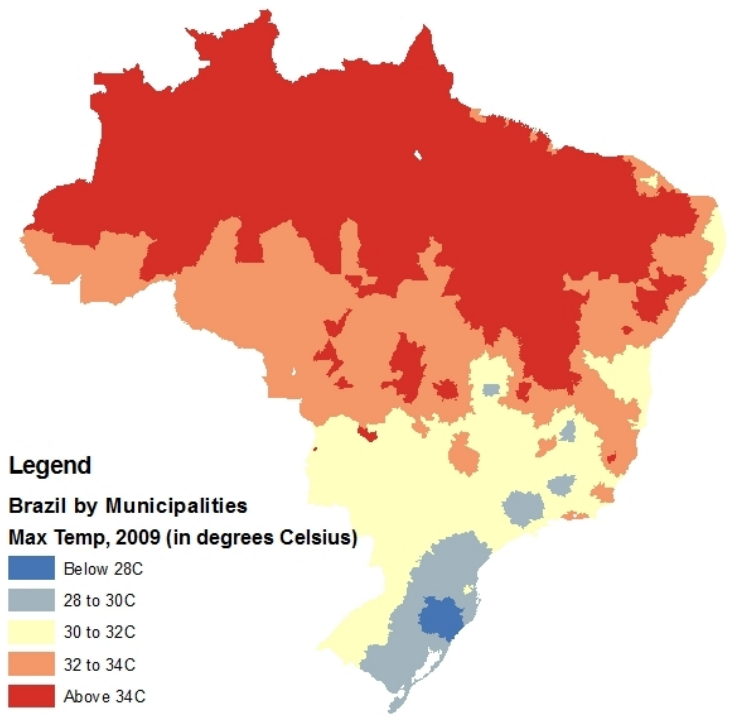
1: Central West
2: North East
3: North
4: South East
5: South

B.2 Brazilian Climate Patterns

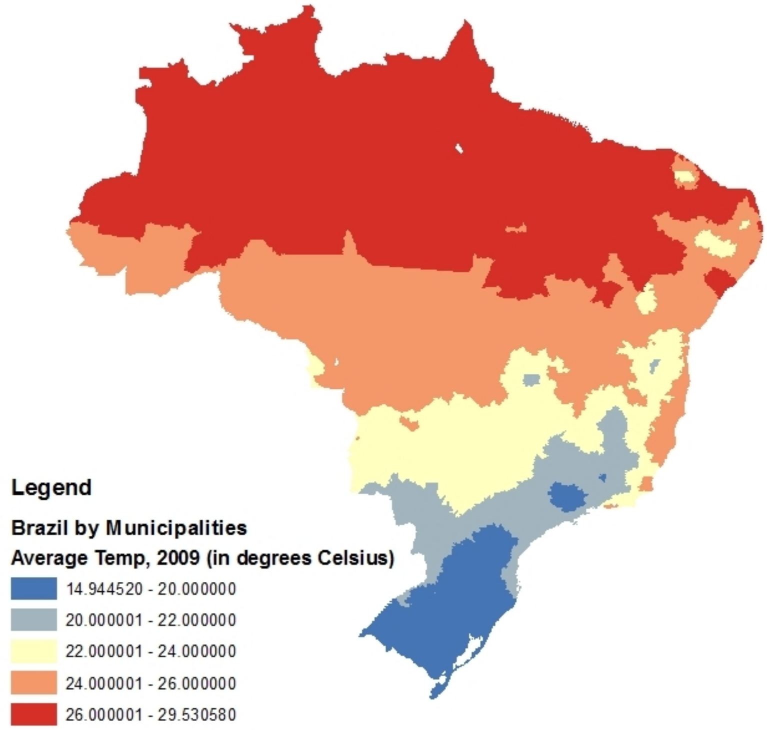
Map B.2. Average Humidity (in %) in Brazil, 2009



Map B.3. Maximum Temperature in Brazil in Degrees Celsius, 2009



Map B.4. Average Temperature in Brazil in Degrees Celsius, 2009



Map B.5. Accumulated Rainfall in Brazil in mm, 2009

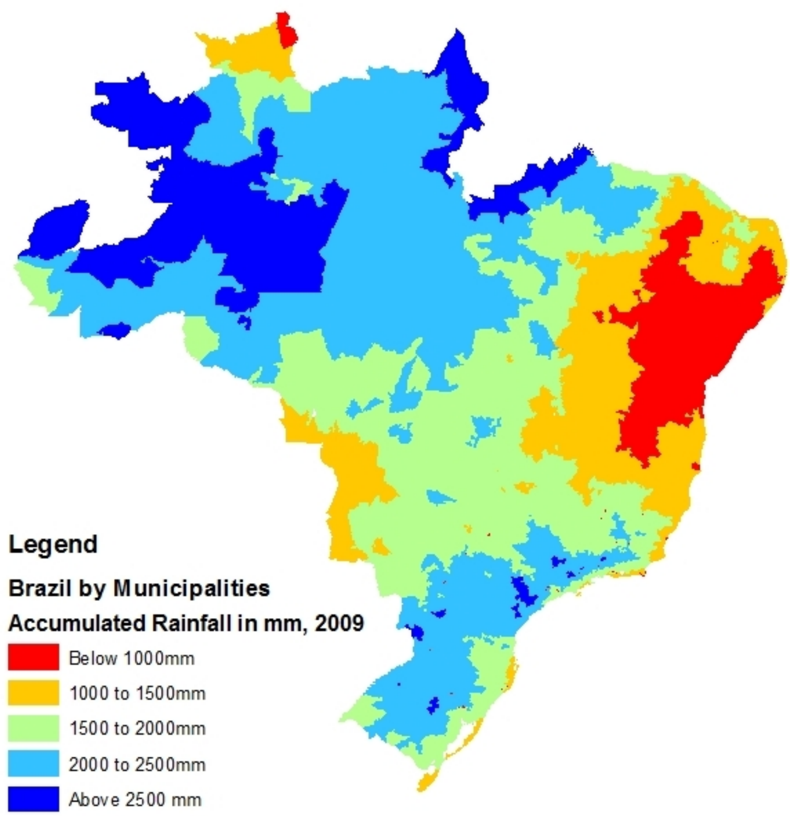


Figure B.1. Monthly Average from 2001-2009: Rainfall in mm, South East and Central West

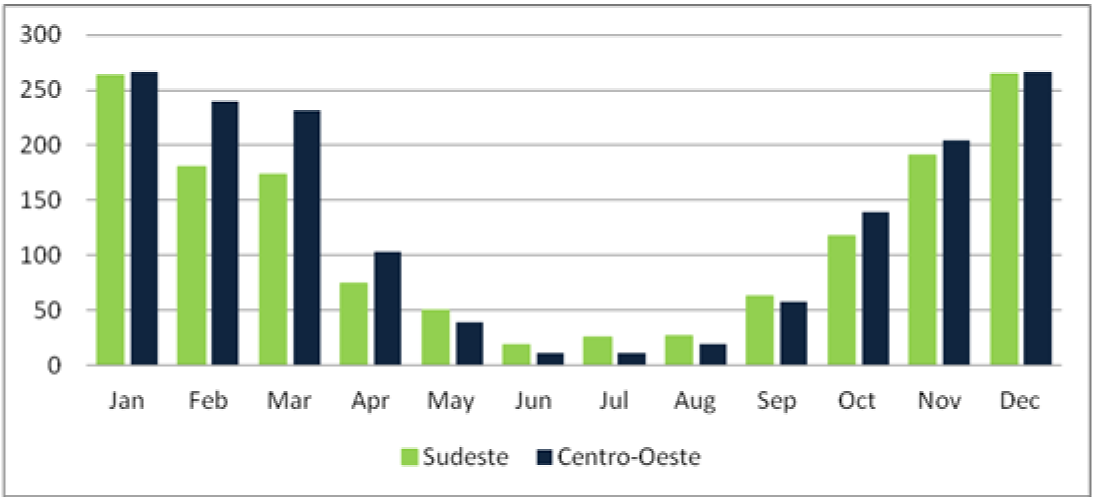


Figure B.2 - Monthly Average - Precipitation North and South Regions

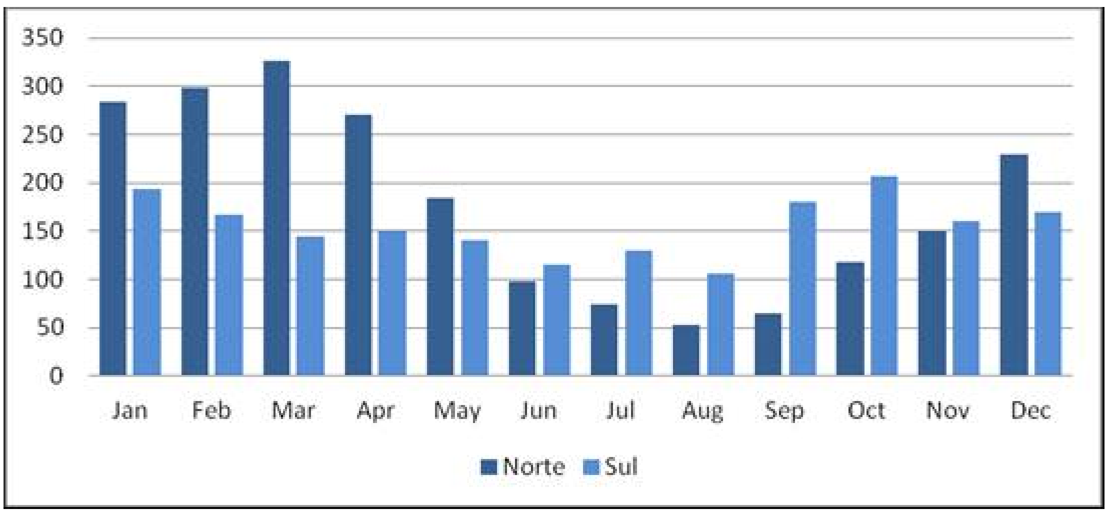
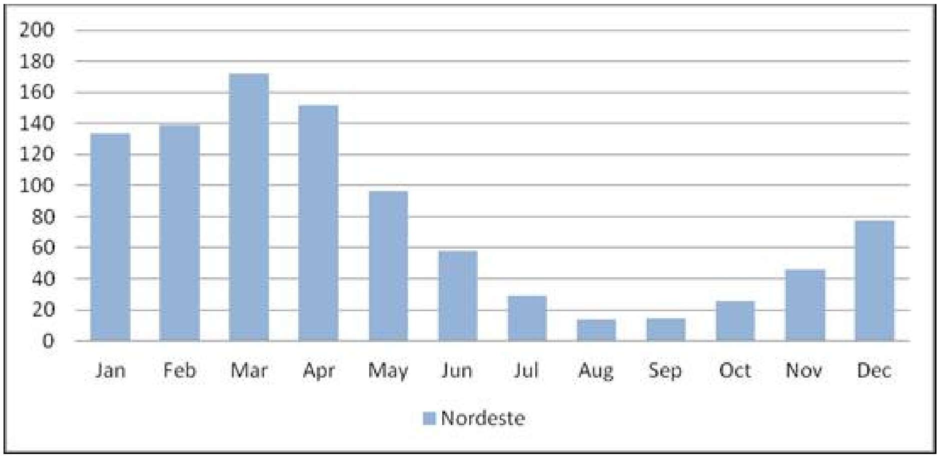


Figure B.3. Monthly Average Precipitation, Northeast Region



B.3 Brazilian Agriculture Patterns

Table B.1. Number of Establishments, 2006

Land use (types)	Number of Rural Establishments	% of Establishments
Livestock	1,511,785	41.8%
Temporary crops	1,351,364	37.3%
Permanent crops	473,062	13.1%
Forest (planted and native)	128,229	3.5%
Others	156,230	4.3%
Total	**3,620,670**	**100.0%**

Figure B.4. Total Revenues by Crop in Millions BRL, Brazil, 2006

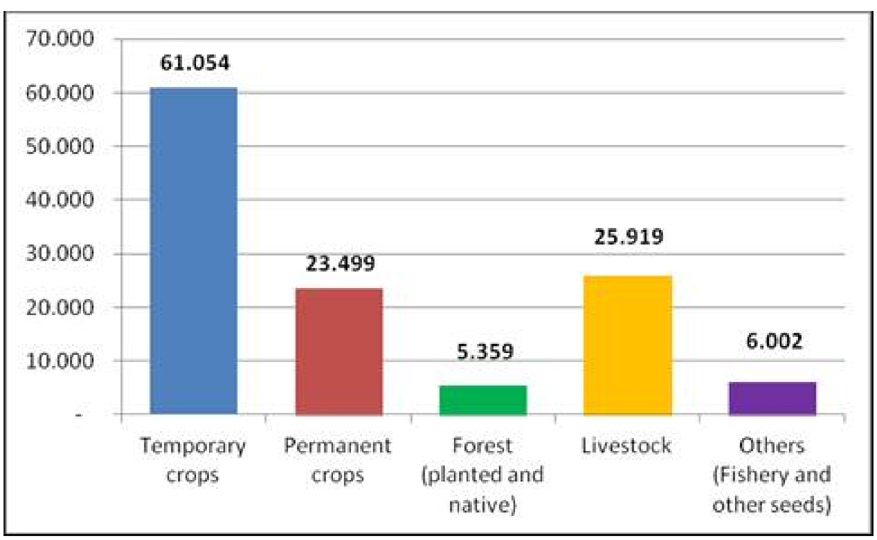


Figure B.5. Temporary vs. Permanent Crops, Planted Area

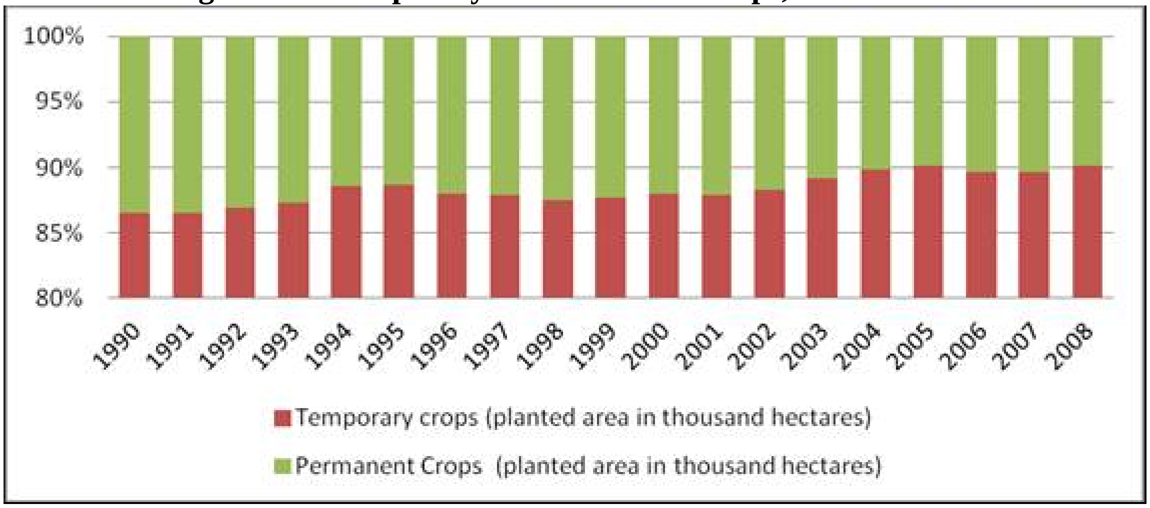


Figure B.6. Temporary Crops, Planted Area, 1990-2009

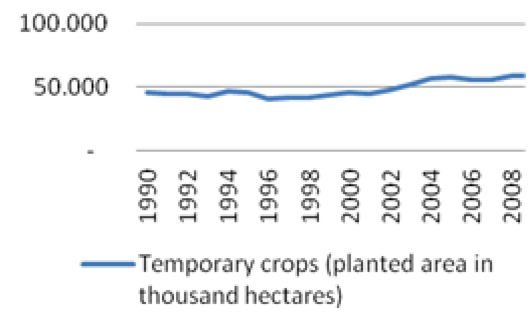


Figure B.7. Permanent Crops, Planted Area, 1990-2008

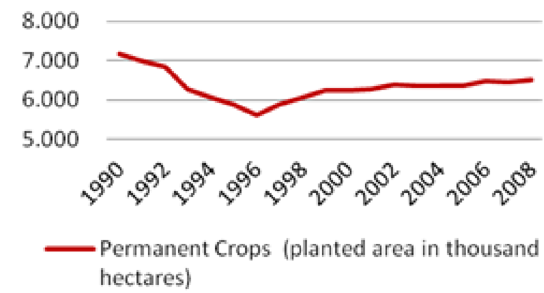


Figure B.8.Temporary vs. Permanent Crops, Production, 1994-2008

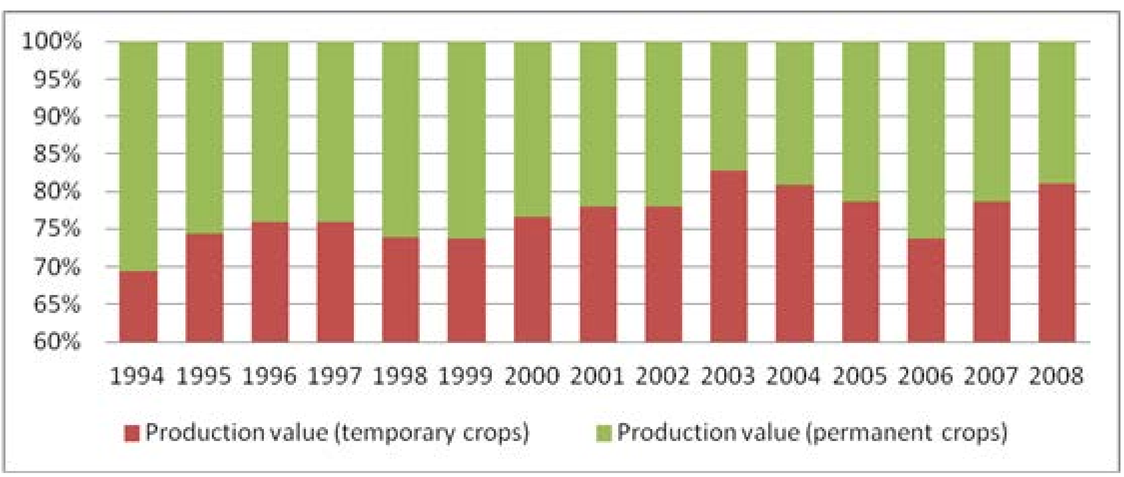


Figure B.9 - Temporary Crops, Production in thousand BRL, 1994-2009

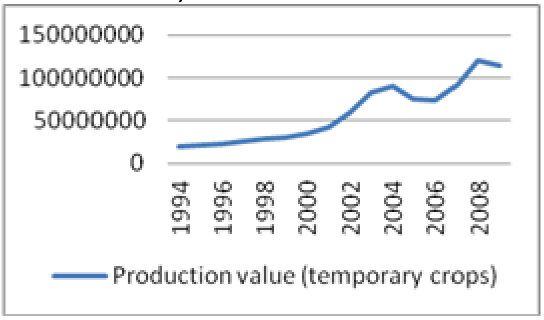


Figure B.10 - Permanent Crops, Production in thousand BRL, 1994-2009

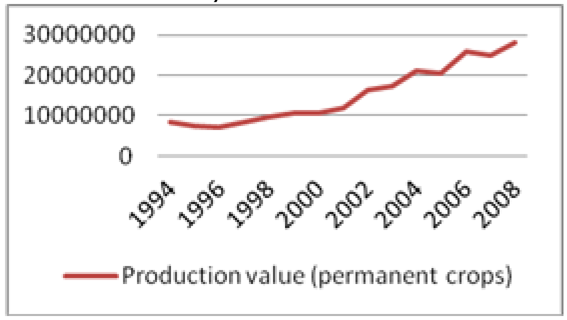


Table B.2. Planted and Harvested Area and Production (in BRL) of the Main Temporary Crops in Brazil, 2009

Crop	Planted Area		Harvested Area		Production Value	
	Hectares	%	Hectares	%	Thousand BRL	%
Soybean (grain)	21,761,782	36.67%	21,750,468	37.29%	37,988,045	33.29%
Maize (grain)	14,144,321	23.84%	13,654,715	23.41%	15,032,484	13.18%
Sugarcane	8,756,576	14.76%	8,523,415	14.61%	23,990,924	21.03%
Beans (grain)	4,277,674	7.21%	4,099,991	7.03%	4,436,430	3.89%
Rice (paddy)	2,905,202	4.90%	2,872,036	4.92%	7,070,978	6.20%
Wheat (grain)	2,438,778	4.11%	2,430,253	4.17%	2,026,868	1.78%
Cassava	1,796,966	3.03%	1,760,578	3.02%	5,575,307	4.89%
Cotton (seed)	814,696	1.37%	811,686	1.39%	3,458,444	3.03%
Sorghum (grain)	808,333	1.36%	793,027	1.36%	363,229	0.32%
Tobacco (leaf)	443,239	0.75%	442,397	0.76%	4,343,982	3.81%
Tomato	67,690	0.11%	67,605	0.12%	2,759,002	2.42%
Potato	138,881	0.23%	138,692	0.24%	2,673,617	2.34%
Other temporary crops*	988,315	1.67%	976,908	1.68%	4,377,049	3.84%
Total	**59,342,453**	**100%**	**58,321,771**	**100%**	**114,096,359**	**100%**

* Castor oil plant, oats, groundnut, watermelon, sunflower, barley, onion, triticale, pineapple, fava, sweet potato, melon, linseed, garlic, malva, rye, pea, jute, and rami.
Source: IBGE - 2009 Municipal Agricultural Production (*Produção Agrícola Municipal*)

Table B.3. Planted and Harvested Area and Production (in BRL) of the Main Permanent Crops in Brazil, 2008

Crop	Planted Area		Harvested Area		Production Value	
	Hectares	%	Hectares	%	Thousand BRL	%
Coffee (grain)	2,250,491	34.65%	2,222,224	35.05%	10,468,475	37.07%
Orange	837,031	12.89%	836,602	13.20%	5,100,062	18.06%
Cashew nut	748,448	11.52%	747,434	11.79%	213,299	0.76%
Cocoa (beans)	686,206	10.56%	641,337	10.12%	822,139	2.91%
Bananas (bunch)	522,867	8.05%	513,097	8.09%	3,165,312	11.21%
Coconut	288,559	4.44%	287,016	4.53%	799,744	2.83%
Grape	81,286	1.25%	79,946	1.26%	1,527,395	5.41%
Papaya	37,030	0.57%	36,585	0.58%	1,021,821	3.62%
Apple	38,072	0.59%	38,072	0.60%	872,625	3.09%
Other permanent crops*	1,005,573	15.48%	937,027	14.78%	4,250,397	15.05%
Total	**6,495,563**	**100%**	**6,339,340**	**100%**	**28,241,269**	**100%**

* Mango, passion fruit, tangerine, rubber, lemon, peach, pepper, sisal, guava, palm, yerba, palmetto, khaki, avocado, fig, annatto, guarana, pear, tea, nut, quince, cotton tree, tung, and olive.
Source: IBGE, 2009 Municipal Agricultural Production (*Produção Agrícola Municipal*).

Figure B.11. Percentage of Farmers that Financed Production by Farm Size (in Hectares), Brazil, 2006

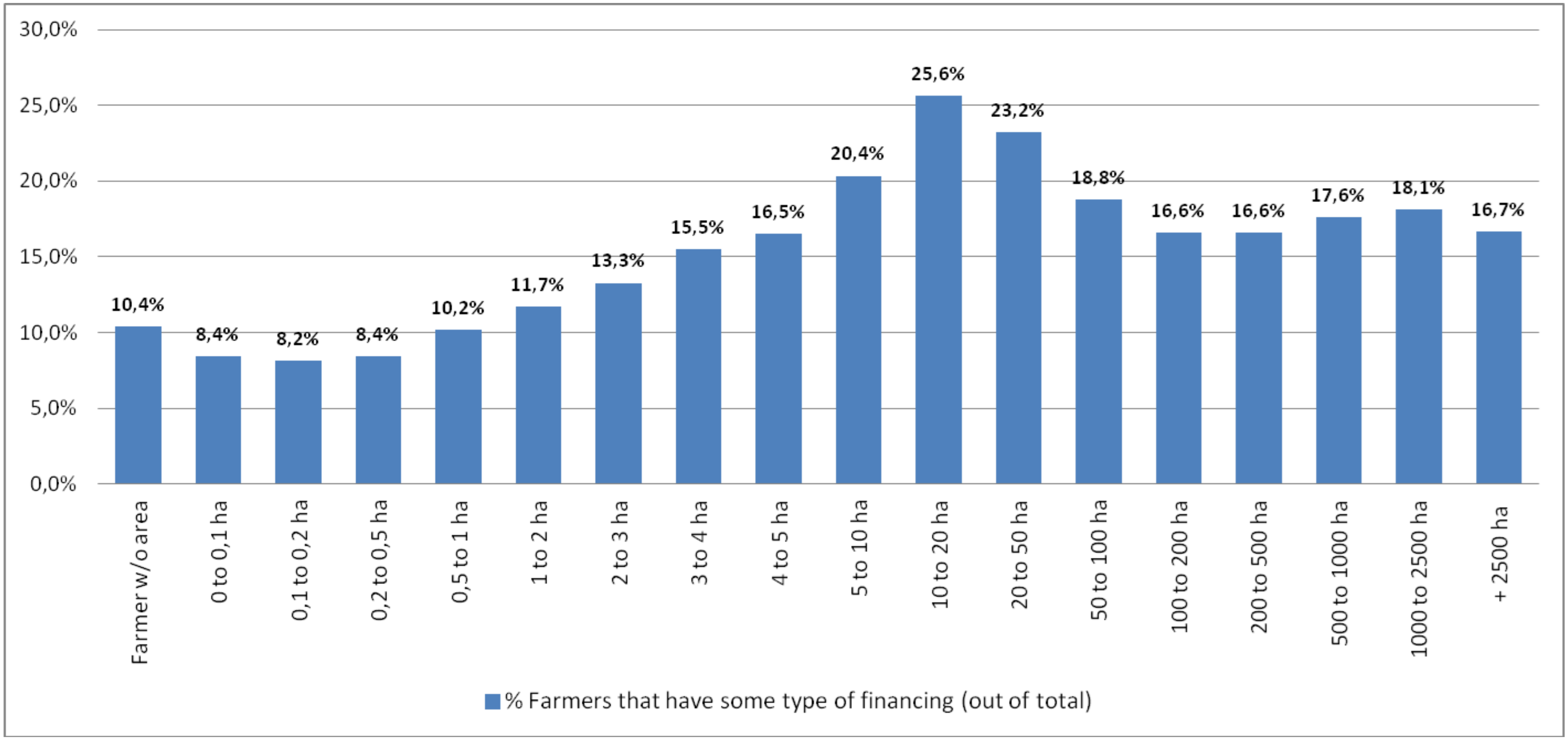
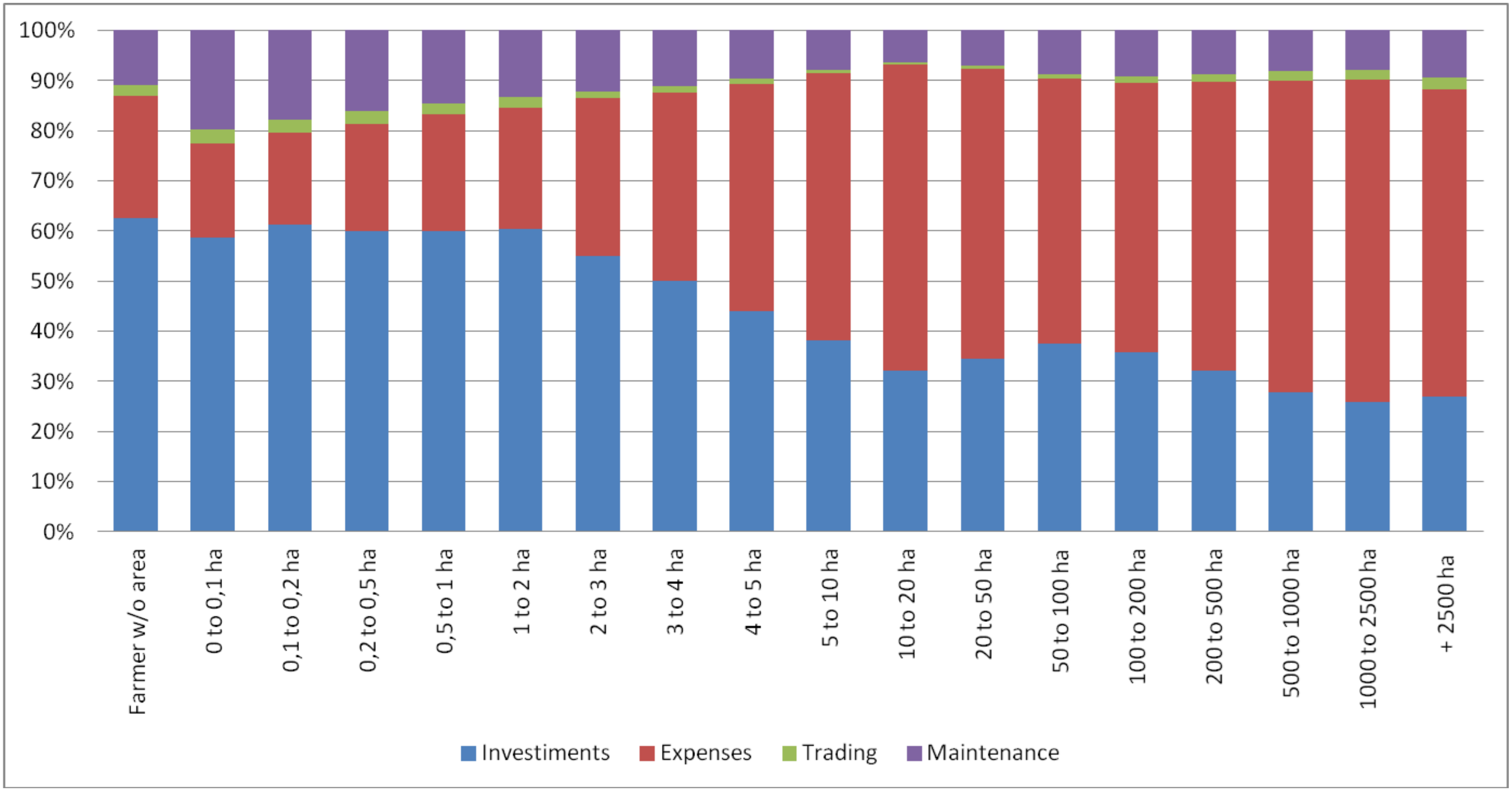


Figure B.12. Loan Purpose by Farm Size (in Hectares), Brazil, 2006



Appendix C. Data Sources (Climate)

Section C.1 describes the collection and organization of the agricultural data for the analysis, followed by a section describing the organization of the climate data.

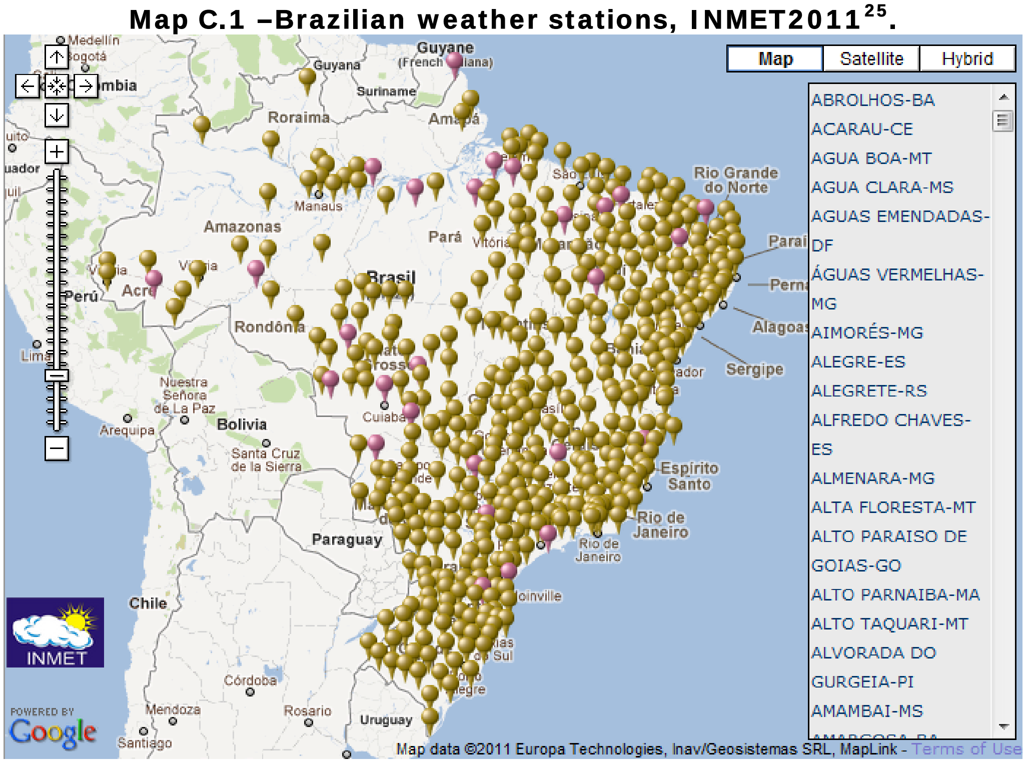
C.1 Weather Stations

In relation to climate data, Brazil has a network of weather stations covering the whole country. These data are processed by the National Meteorology Institute (INMET) per station, including the following climate data:

- Average temperature per month;
- Minimum temperature of the month;
- Maximum temperature of the month;
- Days of precipitation out of the month; and
- Average relative humidity of the month.

The weather stations distribution is presented below (yellow bullets):

Map C.1 –Brazilian weather stations, INMET2011[25].



[25]Website: http://www.inmet.gov.br/sonabra/maps/automaticas.php. Consulted on September, 21, 2011.

To transform the data from the weather stations into municipal data, we used the Kriging method of interpolation (Haas, 1990). This method assumes that each geographical coordinate is a realization of a spatial random process, and it allows for interpolation of data with flexibility in specifying the covariance between the outputs. Appendix A shows the code used in R to apply the Kriging algorithm.

Rainfall data were calculated from CMORPH (CPC Morphing technique) for the production of global precipitation estimates (Joyce et al., 2004). The source from the data is the Climate Prediction Center (CPC), part of the National Centers for Environmental Prediction (NCEP) in the National Oceanic and Atmospheric Administration (NOAA). CMORPH produces global precipitation estimates at high spatial and temporal resolution.[26]

C.2 Climate Forecast and Climate Change Forecast

Climate change information in Brazil is produced by CPTEC/INPE (the department of weather forecasting and climate studies from the National Institute for Space Research). The forecasts are based on the ETA Regional Model for the South American region. This model is an atmospheric model based on surface pressure, horizontal wind components, temperature, specific humidity, turbulent kinetic energy, and cloud hydrometeors. According to CPTEC/INPE, the conditions to run the model come from the Global Model from Hadley Center (Met Office, UK). This type of

[26] According to the CPC website (consulted on September 15, 2011): http://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html : "This technique uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. At present we incorporate precipitation estimates derived from the passive microwaves aboard the DMSP 13, 14 & 15 (SSM/I), the NOAA-15, 16, 17 & 18 (AMSU-B), and AMSR-E and TMI aboard NASA's Aqua and TRMM spacecraft, respectively. These estimates are generated by algorithms of Ferraro (1997) for SSM/I, Ferraro et al. (2000) for AMSU-B and Kummerow et al. (2001) for TMI. Note that this technique is not a precipitation estimation algorithm but a means by which estimates from existing microwave rainfall algorithms can be combined. Therefore, this method is extremely flexible such that any precipitation estimates from any microwave satellite source can be incorporated. With regard to spatial resolution, although the precipitation estimates are available on a grid with a spacing of 8 km (at the equator), the resolution of the individual satellite-derived estimates is coarser than that - more on the order of 12 x 15 km or so. The finer 'resolution' is obtained via interpolation. In effect, IR data are used as a means to transport the microwave-derived precipitation features during periods when microwave data are not available at a location. Propagation vector matrices are produced by computing spatial lag correlations on successive images of geostationary satellite IR which are then used to propagate the microwave derived precipitation estimates. This process governs the movement of the precipitation features only. At a given location, the shape and intensity of the precipitation features in the intervening half hour periods between microwave scans are determined by performing a time-weighting interpolation between microwave-derived features that have been propagated forward in time from the previous microwave observation and those that have been propagated backward in time from the following microwave scan. We refer to this latter step as 'morphing' of the features."

model aims at identifying changes in climatic patters and trends.[27] The data used were generated by region in Brazil and the average changes by region are summarized below:[28]

North East

Scenario A2: Three Celsius degrees increase and 17.5 percent rainfall decrease;

Scenario B2: Two Celsius degrees increase and 12.5 percent rainfall decrease.

North

Scenario A2: Six Celsius degrees increase and 17.5 percent rainfall decrease;

Scenario B2: Four Celsius degrees increase and 10 percent rainfall decrease.

Central West

Scenario A2: 4.5 Celsius degrees increase and uncertainty regarding rainfall predictions;

Scenario B2: Two Celsius degrees increase and uncertainty regarding rainfall predictions.

South East

Scenario A2: 3.5 Celsius degrees increase and uncertainty regarding rainfall predictions;

Scenario B2: 2.5 Celsius degrees increase and uncertainty regarding rainfall predictions.

South

Scenario A2: Three Celsius degrees increase and 7.5 percent rainfall increase;

Scenario B2: Two Celsius degrees increase and 2.5 percent rainfall increase

[27]See http://etamodel.cptec.inpe.br/index.shtml. Consulted on August 29, 2011.

[28] The INPE information that motivates those results can be accessed at http://mudancasclimaticas.cptec.inpe.br. Consulted on December 10, 2011.

Appendix D. Index Insurance Implementation

A contract based on index insurance can be used by many actors in the agricultural sector. They include, among others, small farmers and agricultural laborers, suppliers and financers, institutions within the agricultural supply chain, and non-governmental organizations.

The index insurance mechanism must have a threshold defined in order to limit the range of values over which the payout will be made. When the threshold is reached, the payout increases proportionately as the value reaches the limit (Skees, 2008). Moreover, the amount of the payout will also depend on the amount of insurance purchased. The author presents an illustrative example for the calculation of an index insurance for droughts that begins payouts when rainfall is below a threshold:

Index: Total accumulated rainfall (R) measured at a weather station i, in millimeters (mm) = R_i

Threshold: R_i^T

Limit: R_i^L, where $R_i^L < R_i^T$

Insurance Purchased (I): $ I

Payment rate (PR): Based on the difference between the actual value (R_i^A) and the threshold and limit:

$$PR = \frac{(R_i^T - R_i^A)}{(R_i^T - R_i^L)} \quad \text{(D.1)}$$

Payout (PO): Payment Rate multiplied by the Insurance Purchased:

$$PO = \frac{(R_i^T - R_i^A)}{(R_i^T - R_i^L)} * I \quad \text{(D.2)}$$

According to Skees (2008), besides its simplicity, this type of index insurance can be effective in preventing all the problems mentioned in Section 3.1, such as moral hazard, transaction costs, adverse selection, lack of transparency and delay in receiving payouts, among others.

Appendix E. Descriptive Statistics

Table E.1 – Variables Names and Description

Variable	Description
Agricultural Variables	
qt_maize	Tons of maize produced by municipality
qt_soybean	Tons of soybean produced by municipality
qt_ot_temp	Tons of other temporary crops (other than soybean and maize) produced by municipality
qt_coffe	Tons of coffee (Arabic and green) produced by municipality
qt_ot_perm	Tons of other permanent crops (other than coffee) produced by municipality
qt_milk	Thousands of liters of milk produced by municipality
qt_cattle	Stock of cattle by municipality
qt_wood	Thousands of cubic meters of wood produced by municipality
qt_ot_for	Tons of other forest products (other than wood) produced by municipality
qt_land	Total area used by crops, livestock and planted forest in the municipality (in hectares)
qt_labor	Number of rural workers (employees and family) by municipality
qt_fuel	Thousand kcal used by municipality
qt_fert	Fertilized area, in hectares, in the municipality
price_maize	Price, in thousand BRL, of the maize tons*
price_soybean	Price, in thousand BRL, of the soybean tons*
price_ot_temp	Price, in thousand BRL, of other temp. crops tons*
price_coffe	Price, in thousand BRL, of the coffee tons*
price_ot_perm	Price, in thousand BRL, of other perm. crops tons*
price_milk	Price, in thousand BRL, of thousand milk liters*
price_cattle	Price, in thousand BRL, of one livestock*
price_wood	Price, in thousand BRL, of thousand cubic meter of wood*
price_ot_for	Price, in thousand BRL, of other forest products tons*
price_land	Rental price, in thousand BRL, of the hectare*
price_labor	Average salary , in thousand BRL, of each employee/family member*
price_fuel	Price, in thousand BRL, of the thousand Kcal of fuel*
price_fert	Price, in thousand BRL, per fertilized hectare*
degr_tot_areas	Percentage of the municipality area which is degraded
agri_tot_areas	Percentage of the municipality area which is agricultural
inapr_tot_areas	Percentage of the municipality area which is innapropriate
tam_medio	Average size, in hectares, of the farmer in the municipality
Variables calculated by land use: temporary crops/permanent crops/livestock/planted forests	
rd_stock2006	Total R&D stock of investments in the past 20 years, such as Section 3.3 describes.
analf	Illiteracy rate, out of the total farm managers of the municipality
alfab	Percentage of farm managers that can read, but did not attend school (municipality level)

Variable	Description
ensfun_inc	Percentage of farm managers with incomplete primary education (municipality level)
ensfun_comp	Percentage of farm managers that completed primary education (municipality level)
ensmed_comp	Percentage of farm managers that completed secondary education (municipality level)
enssup	Percentage of farm managers that finished college (municipality level)
Climate Variables	
rain_jan_m to rain_dec_m	Monthly average rainfall for the last 15 years, in milimeters, from Jan. to Dec.
rain_jan_var to rain_dec_var	Difference between the 2006 observation and the monthly average rainfall, in milimeters, from Jan to Dec.
temp_jan_m to temp_dec_m	Monthly average temperature for the last 15 years, in Celsius degrees, from Jan. to Dec.
temp_jan_var to temp_dec_var	Difference between the 2006 observation and the monthly average temperature, Celsius degrees, from Jan. to Dec.

* The procedure for generating prices is described in Section 4.1.

Table E.2. Agricultural Variables: Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
qt_maize	5548	6,827	25,470	-	596,645
qt_soybean	5548	7,058	37,723	-	1,360,187
qt_ot_temp	5548	75,534	343,188	-	7,330,239
qt_coffe	5548	463	2,244	-	67,361
qt_ot_perm	5548	3,855	18,816	-	479,138
qt_milk	5548	3,058	5,776	-	125,104
qt_cattle	5548	4,132	12,459	-	298,957
qt_wood	5548	7	54	-	1,675
qt_ot_for	5548	161	2,148	-	131,572
qt_land	5548	41,602	86,862	-	3,719,038
qt_labor	5548	4,698	7,761	-	306,279
qt_fuel	5548	4,715	9,715	-	233,783
qt_fert	5548	7,240	21,934	-	595,488
price_maize	5570	0	0	0	4
price_soybean	5565	0	0	0	4
price_ot_temp	5570	4	58	0	2,600
price_coffe	5565	2	7	0	446
price_ot_perm	5570	4	41	0	2,151
price_milk	5570	1	0	0	1
price_cattle	5570	1	0	0	4
price_wood	5565	15	9	0	97
price_ot_for	5570	1	9	0	604
price_land	5570	0	3	0	136
price_labor	5570	1	5	0	142
price_fuel	5570	0	0	0	20
price_fert	5570	0	1	0	59
degr_tot_areas	5548	0	0	-	0
agri_tot_areas	5548	1	0	-	1
inapr_tot_areas	5548	0	0	-	1
tam_medio	5548	34	80	-	1,562
rd_stock2006	5543	850.1	1,499	-	42,910

Table E.3. Climate Variables: Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Rainfall Variables					
rain_mar_m	5514	184	76	48	610
rain_jun_m	5514	58	62	0	349
rain_sep_m	5514	72	65	0	237
rain_dec_m	5514	181	92	13	359
rain_mar_var	5514	30	61	(114)	269
rain_jun_var	5514	(13)	30	(149)	265
rain_sep_var	5514	(1)	40	(158)	155
rain_dec_var	5514	(3)	60	(165)	257
Temperature Variables					
temp_mar_m	5565	25	2	18	29
temp_jun_m	5565	20	4	11	30
temp_sep_m	5565	23	4	12	31
temp_dec_m	5565	25	2	17	29
temp_mar_var	5565	0	0	(2)	5
temp_jun_var	5565	(0)	1	(3)	2
temp_sep_var	5565	(0)	1	(2)	3
temp_dec_var	5565	0	1	(1)	4

Appendix F. Other General Results

Table F.1. Estimation Output for the Secondary Variables

SUR - Restricted	qt_maize_s	qt_soybean_s	qt_ot_temp_s	qt_coffe_s	qt_ot_perm_s	qt_milk_s	qt_cattle_s	qt_wood_s	qt_land_s	qt_labor_s	qt_fuel_s	qt_fert_s
Other Regressors:												
price_maize_s	-0.0487***	-0.0260***	-0.00238	-0.00298	0.00994	-0.0228***	-0.00750	-0.00151	-0.00401	-0.00841	-0.00630	-0.0270***
	(0.0104)	(0.00774)	(0.00783)	(0.00803)	(0.00811)	(0.00857)	(0.00716)	(0.00937)	(0.00673)	(0.00807)	(0.00752)	(0.00736)
price_soybean_s	-0.0260***	-0.0198**	-0.00378	0.000325	0.0423***	0.0135*	0.00129	-0.00967	-0.00160	0.000277	0.00283	-0.0196**
	(0.00774)	(0.00897)	(0.00725)	(0.00742)	(0.00752)	(0.00776)	(0.00657)	(0.00850)	(0.00618)	(0.00744)	(0.00708)	(0.00763)
price_ot_temp_s	-0.00238	-0.00378	-0.0373***	0.0141	-0.0127	0.00612	-0.00338	0.0220**	0.00103	0.0371***	0.00505	-0.00111
	(0.00783)	(0.00725)	(0.0121)	(0.00881)	(0.00896)	(0.00925)	(0.00770)	(0.0102)	(0.00724)	(0.00884)	(0.00804)	(0.00682)
price_coffe_s	-0.00298	0.000325	0.0141	0.0142	0.0220**	0.00799	0.00358	-0.0230**	0.0107	0.0472***	0.00339	0.00611
	(0.00803)	(0.00742)	(0.00881)	(0.0128)	(0.00916)	(0.00951)	(0.00791)	(0.0105)	(0.00745)	(0.00907)	(0.00816)	(0.00690)
price_ot_perm_s	0.00994	0.0423***	-0.0127	0.0220**	-0.0185	0.0220**	0.00445	0.0280***	0.0256***	0.0331***	0.00244	0.0456***
	(0.00811)	(0.00752)	(0.00896)	(0.00916)	(0.0131)	(0.00957)	(0.00798)	(0.0105)	(0.00751)	(0.00915)	(0.00825)	(0.00701)
price_milk_s	-0.0228***	0.0135*	0.00612	0.00799	0.0220**	-0.192***	-0.0594***	-0.0210*	-0.0200**	-0.0213**	-0.00369	0.00771
	(0.00857)	(0.00776)	(0.00925)	(0.00951)	(0.00957)	(0.0147)	(0.00859)	(0.0114)	(0.00805)	(0.00959)	(0.00871)	(0.00715)
price_cattle_s	-0.00750	0.00129	-0.00338	0.00358	0.00445	-0.0594***	-0.0174*	-0.0551***	-0.0201***	-0.0197**	-0.00689	-0.00273
	(0.00716)	(0.00657)	(0.00770)	(0.00791)	(0.00798)	(0.00859)	(0.00999)	(0.00932)	(0.00750)	(0.00794)	(0.00722)	(0.00610)
price_wood_s	-0.00151	-0.00967	0.0220**	-0.0230**	0.0280***	-0.0210*	-0.0551***	0.0141	-0.000843	-0.0101	0.00143	-0.0122
	(0.00937)	(0.00850)	(0.0102)	(0.0105)	(0.0105)	(0.0114)	(0.00932)	(0.0175)	(0.00876)	(0.0105)	(0.00953)	(0.00785)
price_ot_for_s	-0.00377	-0.00114	-0.00127	-0.00245	0.000547	0.00938	0.0119	-0.00133	0.00783	0.00400	0.00510	-0.00259
	(0.0125)	(0.0124)	(0.0125)	(0.0128)	(0.0132)	(0.0119)	(0.0107)	(0.0133)	(0.0102)	(0.0126)	(0.0120)	(0.0120)
price_land_s	-0.00401	-0.00160	0.00103	0.0107	0.0256***	-0.0200**	-0.0201***	-0.000843	-0.0132	-0.00602	-0.00565	-0.00247
	(0.00673)	(0.00618)	(0.00724)	(0.00745)	(0.00751)	(0.00805)	(0.00750)	(0.00876)	(0.00882)	(0.00751)	(0.00687)	(0.00574)
price_labor_s	-0.00841	0.000277	0.0371***	0.0472***	0.0331***	-0.0213**	-0.0197**	-0.0101	-0.00602	-0.0405***	0.0130	0.00566

Table F.1., continued

SUR - Restricted	qt_maize_s	qt_soybean_s	qt_ot_temp_s	qt_coffe_s	qt_ot_perm_s	qt_milk_s	qt_cattle_s	qt_wood_s	qt_land_s	qt_labor_s	qt_fuel_s	qt_fert_s
	(0.00807)	(0.00744)	(0.00884)	(0.00907)	(0.00915)	(0.00959)	(0.00794)	(0.0105)	(0.00751)	(0.0129)	(0.00822)	(0.00691)
price_fuel_s	-0.00630	0.00283	0.00505	0.00339	0.00244	-0.00369	-0.00689	0.00143	-0.00565	0.0130	-0.0172	0.00748
	(0.00752)	(0.00708)	(0.00804)	(0.00816)	(0.00825)	(0.00871)	(0.00722)	(0.00953)	(0.00687)	(0.00822)	(0.0105)	(0.00672)
price_fert_s	-0.0270***	-0.0196**	-0.00111	0.00611	0.0456***	0.00771	-0.00273	-0.0122	-0.00247	0.00566	0.00748	-0.0190**
	(0.00736)	(0.00763)	(0.00682)	(0.00690)	(0.00701)	(0.00715)	(0.00610)	(0.00785)	(0.00574)	(0.00691)	(0.00672)	(0.00792)
alfab_s	-0.00674	-0.0288	-0.00573	-0.00109	0.00325	0.0311	0.0264*	0.0221	0.0137	0.00223	-0.0262	-0.0281
	(0.0178)	(0.0178)	(0.0178)	(0.0143)	(0.0146)	(0.0195)	(0.0142)	(0.0141)	(0.0121)	(0.0180)	(0.0170)	(0.0172)
ensfun_inc_s	-0.00798	-0.0150	0.00867	0.0638***	0.0326**	0.0988***	0.0385**	-0.0130	0.00454	-0.0305	-0.00347	-0.00823
	(0.0224)	(0.0223)	(0.0223)	(0.0153)	(0.0156)	(0.0258)	(0.0186)	(0.0148)	(0.0151)	(0.0225)	(0.0213)	(0.0215)
ensfun_comp_s	0.0366**	0.0256*	0.0233	0.0160	0.0553***	0.0212	-0.0201*	-0.0122	-0.0172*	-0.0521***	0.0210	0.0337**
	(0.0152)	(0.0152)	(0.0152)	(0.0134)	(0.0137)	(0.0153)	(0.0107)	(0.0137)	(0.0100)	(0.0154)	(0.0145)	(0.0147)
ensmed_comp_s	0.0440***	0.0884***	0.0192	0.00206	0.0409***	0.00385	0.00614	-0.0219	-0.0410***	-0.0442**	0.0271*	0.0759***
	(0.0171)	(0.0170)	(0.0170)	(0.0138)	(0.0141)	(0.0164)	(0.0114)	(0.0140)	(0.0112)	(0.0172)	(0.0163)	(0.0164)
enssup_s	-0.0298*	-0.0435**	0.241***	-0.00694	0.0681***	-0.0386**	0.0332***	-0.0257*	-0.0565***	-0.0452***	0.0462***	0.0137
	(0.0172)	(0.0172)	(0.0171)	(0.0138)	(0.0142)	(0.0163)	(0.0114)	(0.0143)	(0.0113)	(0.0174)	(0.0164)	(0.0166)
degr_tot_areas_s	0.00239	0.00157	0.000332	-0.00501	-0.00246	0.000463	-0.00678	0.00403	-0.00475	-0.00720	0.000195	0.00246
	(0.0128)	(0.0128)	(0.0129)	(0.0131)	(0.0136)	(0.0123)	(0.0110)	(0.0136)	(0.0105)	(0.0130)	(0.0123)	(0.0124)
agri_tot_areas_s	0.0158	0.00671	0.0719***	0.0465***	0.0232	0.0969***	-0.0130	-0.0976***	-0.0146	0.0154	0.0365**	0.0416***
	(0.0151)	(0.0151)	(0.0152)	(0.0154)	(0.0159)	(0.0147)	(0.0129)	(0.0161)	(0.0124)	(0.0154)	(0.0145)	(0.0146)
tam_medio_s	0.128***	0.214***	0.0349**	-0.0495***	-0.0303**	-0.0597***	0.426***	-0.00245	0.546***	-0.0180	0.155***	0.191***
	(0.0139)	(0.0138)	(0.0139)	(0.0140)	(0.0145)	(0.0132)	(0.0117)	(0.0145)	(0.0113)	(0.0141)	(0.0133)	(0.0134)
Constant	0.000489	0.000563	0.00272	0.000679	0.00113	0.00151	0.00217	0.00150	0.00226	0.00374	0.00139	0.00142
	(0.0125)	(0.0125)	(0.0126)	(0.0128)	(0.0133)	(0.0120)	(0.0107)	(0.0133)	(0.0103)	(0.0127)	(0.0120)	(0.0121)
Observations	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**	**5,485**
R-squared	**0.146**	**0.153**	**0.142**	**0.107**	**0.045**	**0.219**	**0.375**	**0.036**	**0.427**	**0.124**	**0.212**	**0.206**

Standard errors in parentheses

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

Appendix G. Brazilian Agricultural Research System

The Brazilian research system for agriculture was consolidated in 1991 by the Ministry of Agriculture (Law n. 8171, 17th January of 1991). It is made up of the following institutions:

- **EMBRAPA** (Brazilian Agricultural Research Corporation): EMBRAPA's organization includes a large network, composed by a central unit, located in Brasilia, and decentralized research centers distributed among the several regions of Brazil;
- **Oepas** (State Agricultural Research Organizations): The Oepas are distributed all over Brazil, according to the following table:

Table G.1. Regional Distribution of Oepas

North EastRegion	North and Central West Regions	South EastRegion	South Region
EBDA	Agência Rural	Apta	Epagri
Emdagro	Empaer-MT	Epamig	Fepagro
Emepa	Idaterra-MS	Incaper	Iapar
Emparn	Unitins	Pesagro-Rio	
IPA			

- **Others**: Universities and other research institutes and research undertaken by private companies, among others.

Agriculture accounts for 10 to 11 percent of Brazil's R&D spending.

Table G.2. Brazilian R&D Spending, 2000 to 2009

in BRL million

Socioeconomic Objective	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009	
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
Total	**6,493.8**	**100.00**	**7,447.8**	**100.00**	**7,760.9**	**100.00**	**8,826.0**	**100.00**	**9,335.3**	**100.00**	**10,371.2**	**100.00**	**11,911.1**	**100.00**	**15,184.8**	**100.00**	**17,680.7**	**100.00**	**19,498.1**	**100.00**
Agriculture	783.2	12.06	851.0	11.43	832.7	10.73	922.5	10.45	1,055.8	11.31	1,188.2	11.46	1,265.1	10.62	1,509.6	9.94	1,779.6	10.07	2,336.1	11.98
Envioronment control and protection	37.5	0.58	81.3	1.09	42.5	0.55	110.1	1.25	64.4	0.69	102.4	0.99	109.9	0.92	123.2	0.81	116.2	0.66	137.0	0.70
Defense	102.5	1.58	118.0	1.59	88.8	1.14	90.8	1.03	110.8	1.19	123.7	1.19	73.3	0.62	82.5	0.54	110.4	0.62	168.1	0.86
Social development and services	3.3	0.05	9.3	0.12	5.0	0.06	29.6	0.34	10.4	0.11	107.7	1.04	60.0	0.50	54.6	0.36	191.6	1.08	66.8	0.34
Industrial and technologycal development	114.8	1.77	150.5	2.02	229.1	2.95	382.8	4.34	467.5	5.01	478.4	4.61	551.9	4.63	863.0	5.68	1,129.0	6.39	1,470.7	7.54
Expenses with universities / academic issues	3,924.8	60.44	4,262.4	57.23	4,779.6	61.59	5,261.3	59.61	5,411.5	57.97	5,814.2	56.06	6,689.5	56.16	8,844.5	58.25	10,272.2	58.10	10,797.7	55.38
Energy	138.3	2.13	165.3	2.22	103.6	1.33	151.6	1.72	150.4	1.61	164.2	1.58	215.5	1.81	212.1	1.40	200.7	1.14	168.0	0.86
Civil area	147.1	2.27	138.6	1.86	108.7	1.40	122.6	1.39	154.4	1.65	160.3	1.55	158.9	1.33	165.3	1.09	149.6	0.85	183.4	0.94
Land exploration and athmosphere	58.5	0.90	81.4	1.09	70.0	0.90	103.2	1.17	74.6	0.80	64.2	0.62	74.8	0.63	70.9	0.47	58.3	0.33	92.5	0.47
Infrastructure	27.1	0.42	163.8	2.20	215.4	2.78	311.0	3.52	278.2	2.98	319.7	3.08	412.7	3.46	582.6	3.84	514.9	2.91	491.2	2.52
Other researches	744.1	11.46	969.9	13.02	907.6	11.69	857.1	9.71	810.9	8.69	1,112.0	10.72	1,301.6	10.93	1,499.2	9.87	1,949.0	11.02	2,103.8	10.79
Health	410.1	6.31	454.0	6.10	370.5	4.77	448.0	5.08	693.1	7.42	669.0	6.45	893.3	7.50	1,059.4	6.98	1,066.3	6.03	1,270.2	6.51
Non-specified	2.6	0.04	2.2	0.03	7.5	0.10	35.5	0.40	53.2	0.57	67.3	0.65	104.7	0.88	117.9	0.78	142.9	0.81	212.6	1.09

Source: Coordenação-Geral de Indicadores (CGIN) - ASCAV/SEXEC - Ministério da Ciência e Tecnologia (MCT).

In this work, Embrapa's R&D spending was used as a proxy for Brazil's agricultural R&D spending. In addition to Embrapa's historical importance in adapting crops to Brazilian climate patterns since the 1970s, its strategic and political importance also justify the use of this institution's R&D spending as a proxy for Brazilian agricultural expenses.

From the 1970s now on, Embrapa is the institution that has created the most climate-resistant crop varieties. The cultivation of soybean and maize, which previously had only been possible in temperate South region, also became possible in the Cerrado.[29] Following the adoption of new technologies, the Cerrado now accounts for more than 40 percent of the country's grain production, and this but one example of Embrapa's historical importance for Brazilian agricultural development.

The strategic importance of the institution is demonstrated by the productivity growth resulting from its investments over the last three decades. According to the Ministério da Agricultura, Pecuária e Abastecimento (MAPA),[30] nearly of 60 percent[31] of agricultural productivity growth in the 2000s is the result of Embrapa-funded research. Embrapa figures show that from the 1970s to the 2000s the country's beef supply increased four times, the chicken supply increased nearly 18 times and the soybean production grew almost 30 times. Embrapa data further show that, from 1975 to 2006, milk production grew from 7.9 billion liters to 25.4 billion liter and the supply of vegetables supply increased from 9 million tons to 17.5 million tons. This growth generated spillover effects, leading to the creation of large-scale technical, business and trade activity that in turn produces more capital and jobs for other Brazilian agricultural activities.

The policy explanation for using Embrapa's R&D expenses as a proxy for agricultural research spending is that the Brazilian Federal Government, through the Programa de Aceleração do Crescimento (PAC),[32] granted Embrapa nearly R$ 1 billion to invest in agricultural research. Presumably some of that amount is being used to support research on of minimizing the effects of climate changes on agricultural activities.

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[29] The Cerrado is a vast tropical savanna ecoregion of Brazil, located mainly in the states of Goiás and Minas Gerais.
[30] MAPA means Ministry of Agriculture, Livestock and Food Supply.
[31] The other 40 percent of productivity growth is due to an increase in land under cultivation.
[32] PAC means "Growth Acceleration Program," a program created in 2007 by the Brazilian Federal Government that comprises a set of policy measures to accelerate the economic growth.