TERRITORIAL ECONOMIC IMPACTS OF CLIMATE ANOMALIES IN BRAZIL

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Abstract. This paper evaluates the systemic impact of climate anomalies in a regional perspective using an interregional CGE model integrated with a physical model estimated for agriculture in order to catch the effects of climate change. The climate anomalies are estimated for 2005 and represent deviations over the historic trend. The results of this paper suggest that the economic costs of climate anomalies can be significantly underestimated if only partial equilibrium effects (direct impact/damage) are accounted for. The results show that a general equilibrium approach can provide a better comprehension about the systemic impact of climate anomalies, suggesting the economic costs are higher than those that would be observed in a partial equilibrium analysis. In addition, intersectoral and interregional linkages as well price effects seem to be important transmission channels in the context of systemic impact of climate anomalies.

1. Introduction

Climate has relevant consequences to human health, water availability and quality, agricultural production (and productivity), rural development and poverty. When it comes to climate impacts on agriculture, long-term climate changes have the potential to modify agricultural land use patterns[2], but short-term climate conditions also directly affect crop yields and farmers' earnings. This study explores the short-term consequences of climate on agriculture.

Agriculture losses in the recent past are often associated to more frequent climate extreme events. Climate change is expected to modify the frequency, intensity and duration of extreme events in many regions (Christensen et al., 2007; IPCC AR4). In South America, significant changes in rainfall extremes and dry spells are projected, including increased intensity of extreme precipitation events in western Amazonia and significant changes in the frequency of consecutive dry days in northeast Brazil and eastern Amazonia (Marengo et al. 2009). As pointed out by Sena et al. (2012) in a study on extreme events in the Amazonia, modifications in precipitation patterns could be

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[2] Climate change is defined as the evolution in the climate distribution over time caused mainly by anthropogenic emissions of greenhouse gases. Therefore, climate change refers to long-term changes in climate.

expected in the region, as changes in temperature can lead to several modifications of the environment, amongst them, alteration in the global hydrologic cycle, provoking impact on water resources at the regional level. In such scenarios, Brazilian agriculture would be expected to face higher risk of crop failure due to climate variability. Climate variability is the main environmental cause of losses to the agricultural sector. In general, the direct effects of climate on agriculture are mainly related to lower crop yields or failure due to drought, frost, hail, severe storms, and floods; loss of livestock in harsh winter conditions and frosts; and other losses due to short-term extreme weather events.

Some of these effects of climate on agriculture have already been studied in Latin American and Caribbean countries. However, there are not many studies exploring the systemic economic costs of the impacts of climate anomalies on the agriculture sector within a country. This broad territorial view is essential within a context of an integrated approach of production chain – the agribusiness.[3]

Existing studies usually focuses on the partial equilibrium effects of climate variables on different types of crops located within the geographical limits of the study areas. However, backward and forward linkages affect, to different extents, local demand by the various economic agents. Especially for the agribusiness complex, spatial and sectoral linkages play an important role. In any given region, firms exchange goods and services with each other; this phenomenon is usually captured in input-output tables [Hewings, 1999; p. 2]. With this formulation in place, it is possible to trace the consequences on other sectors of the economy of an expansion or contraction in any one sector or set of sectors. However, regional economies are, by their very nature, open and subject to the economic vicissitudes of demand and supply interactions in other parts of the country and other parts of the world. Hence, in parallel to the economic linkages between sectors within a region, there is a parallel set of linkages between regions. The growth or decline of one region's economy will have potential impacts on the economies of other regions; the nature and extent of this impact will depend on the

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[3] While the agriculture share in Brazilian GDP was 7.5% in 1999, the contribution of agribusiness, which takes into account the entire production chain related to agriculture, was 26.6% of national GDP. This picture varies by region: for instance, the figures for the South were 12.8% (share of agriculture in regional GDP) and 41.4% (share of agribusiness in regional GDP), and for the Southeast region 4.7% and 21.2%, respectively (Furtuoso and Guilhoto, 2003).

degree of exchange between the two regions – as well as exchange with other regions. Thus, there is a need to address these issues in a general equilibrium context.

There is an extent literature dealing with the systemic effects of climate change on agriculture in the context of computable general equilibrium (CGE) models.[4] Modeling strategies attempt to either include more details in the agriculture sectors within CGE model structures (e.g. modeling of land use and land classes) or to integrate stand-alone models of agriculture land use with CGE models, usually through soft links using semi-iterative approaches (Palatnik and Roson, 2012). Most of such CGE applications are global in nature, providing economic impacts only at the level of world regions or countries. The detailed spatially disaggregated information on land characteristics that may be present in the land use models is lost in aggregation procedures to run the global CGE models, providing few insights on the differential impacts within national borders.

In 2005, several regions in Brazil experienced expressive declines in precipitation compared to the historic averages. A symbolic case about extreme precipitation event in Amazonian Basin is the drought occurred in that year (Sena et al., 2012), which hit more severely the southwest of Amazonia and the state of Pará. In the same year, Brazil's northeast Sertao, encompassing the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco, and the South of the country also faced droughts during the main harvest season. As the agriculture sector has important forward linkages in the Brazilian economic structure and specific location patterns, those climate anomalies, even spatially concentrated, may imply in important economic losses for the whole country with distinct regional impacts.

Within this context, the objective of this study is to analyze the susceptibility of agricultural outputs to climate variations and the extent to which it propagates to the economic system as a whole. For this analysis, the definition for climate variability is related to a short-term approach (climate anomaly). We use a methodological framework in which physical and economic models are integrated for evaluating the economic impacts of observed climate anomalies in 2005. While physical models of agriculture productivity can provide estimates of the direct impact of climate variability

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[4] CGE models are based on systems of disaggregated data, consistent and comprehensive, that capture the existing interdependence within the economy (flow of income).

on the quantum of agriculture production, spatial general equilibrium models can take into account the systemic impact of climate anomalies considering the linkages of the agriculture sector with other sectors of the economy and the locational impacts that emerge.

2. Methodology

2.1. Direct effects

In this study, we first analyze how the production of different cultures is affected by climate variables by using a profit function approach (Lau, 1978; Jehle and Reny, 2000; Mas-Colell et al, 2006). This approach allows the measurement of the crop production variation (direct effects), which will be used as the physical measure of output change. Appendix A provides more details on the approach.

It is assumed that farmers allocate inputs (i.e. land, labor, fertilizers and energy) for the production of temporary crops and permanent crops. Allocation decision is based on a profit maximization problem in competitive markets. Climate variables are considered as exogenous fixed inputs to the profit function. Information on both long-term climate (seasonal pattern) and short-term climate variability (specific anomaly in the year) is introduced. Moreover, other fixed factors such as soil type, investments and farmer education are also considered.

Cross-section data were used as empirical support in this study. Panel data, which can potentially generate more accurate results, was not used because of data incompatibility between the last two agricultural censuses carried out in Brazil. The unit of analysis was Brazilian municipalities. The agricultural data were obtained from the Brazilian Agricultural Census of 2006, produced by the Brazilian Institute of Geography and Statistics (IBGE).[5] The climate data were obtained from different sources: historical temperature information was obtained from the National Meteorology Institute

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[5] The Brazilian Institute of Geography and Statistics (IBGE) conducts the Brazilian Agricultural Census 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 the agricultural companies. The last one employed technological refinements, mainly related to the introduction of new concepts to encompass the transformations that occurred in agricultural activities and in the countryside since the previous census.

(INMET); historical rainfall data was collected from CPC Morphing/NOAA.[6] Climate anomaly was defined as the difference between the observed values and the long-term averages (for rainfall) divided by the respective standard deviations over the period. Figure 1 presents the spatial pattern of climate anomalies among Brazilian municipalities for 2005. Comparing to the historic average, it can be observed an expressive reduction in precipitations on this year, mainly in some areas of North, Northeast and South of Brazil.

**Figure 1. Climate (Rainfall) Anomalies: Brazilian Municipalities, 2005**
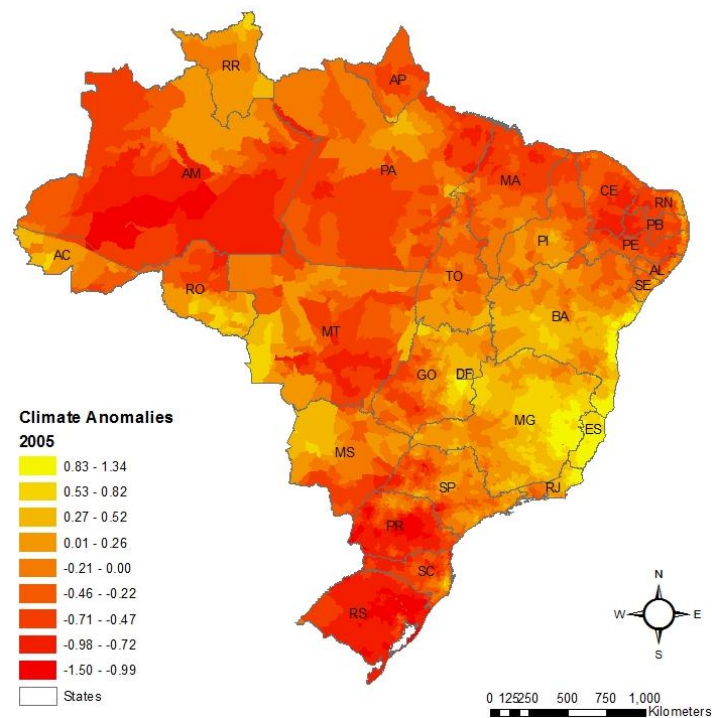
The profit model was estimated to predict the physical impact of climate anomalies for permanent and temporary crops in the year of 2005. The total direct impact on the agriculture sector in each Brazilian state was then calculated using Laspeyres indices whose weights were given by the shares of both permanent and temporary crops outputs for each municipality that were further aggregated to obtain a measure of the physical change in agriculture production at the state level.[7]

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[6] Rainfall data were calculated from CMORPH (CPC Morphing technique) for the production of global precipitation estimates (Joyce et al., 2004).
[7] Appendix B shows the estimated coefficients. It is worth nothing these coefficients were estimated using data for 2006, but climate anomalies were structurally estimated using rainfall data for 2005.

Such results were translated into productivity shocks changing the production functions of the agriculture sector in each state (Figure 2). As expected, the spatial distribution of these shocks is correlated to the climate anomalies showed in Figure 1, that is, the higher the reduction in precipitation the higher the negative impact on agriculture productivity. However, these productivity shocks only account for the direct impact of climate anomalies. As agriculture sector provides inputs for many other sectors in the economy, it is naturally expected that the effects of climate anomalies spread to the whole economic system. Thus, an interstate computable general equilibrium (CGE) model was used to simulate the systemic impacts of changes in agricultural yields by state due to climate variation.

Figure 2. Productivity Changes in the Agriculture Sector due to Climate (Rainfall) Anomalies: Brazilian States, 2005
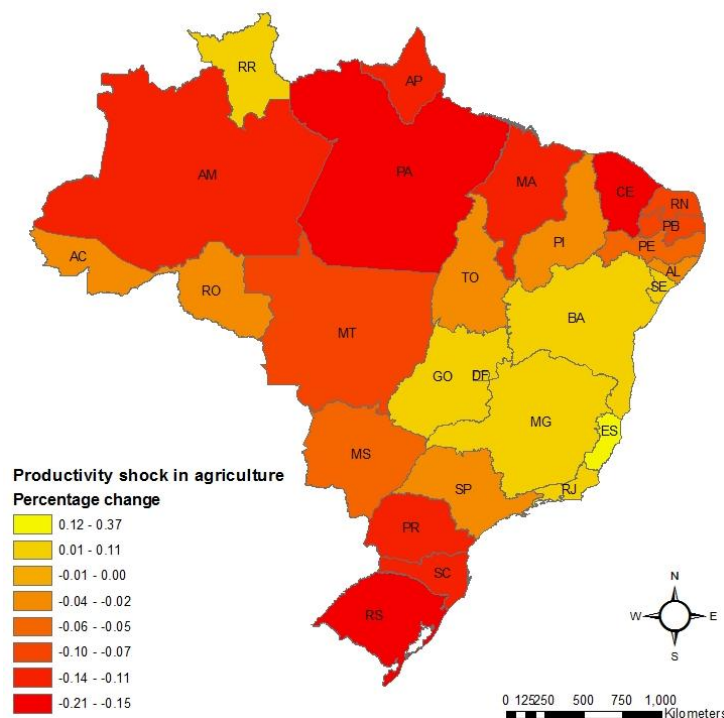
2.2. Modeling issue

Closely related to the policy implementations and results of CGE models is the specification of linkages between the national and regional economy. Two basic approaches are prevalent – top-down and bottom-up – and the choice between them

usually reflect a trade-off between theoretical sophistication and data requirements (Liew, 1984).

The top-down approach consists of the disaggregation of national results to regional levels, often on an ad hoc basis. The disaggregation can proceed in different steps (e.g. country-state → state-municipality), enhancing a very fine level of regional divisions. The desired adding-up property in a multi-step procedure is that, at each stage, the disaggregated projections have to be consistent with results at the immediately higher level (Adams and Dixon, 1994). The starting point of top-down models is economy-wide projections. The mapping to regional dimensions occurs without feedback from the regions. In this sense, effects of policies originating in the regions are precluded. In accordance with the lack of theoretical refinement in terms of modeling of behavior of regional agents, most top-down CGE models are not as data demanding as bottom-up models.

In the bottom-up approach, agents' behavior is modeled at the regional level. A fully interdependent system is specified in which national-regional feedbacks may occur in both directions. In this way, analysis of policies originating at the regional level is facilitated. The adding-up property is fully recognized, since national results are obtained from the aggregation of regional results. In order to make such highly sophisticated theoretical models operational, data requirements are very demanding. To start with, an interregional input-output/SAM database is required, with full specification of interregional flows. Data also include interregional trade elasticities and other regional variables, for which econometric estimates are rarely available in the literature.

2.3. Basic features of the interstate CGE model

Our departure point is the B-MARIA model, developed by Haddad (1999). The B-MARIA model – and its extensions – has been widely used for assessing regional impacts of economic policies in Brazil. Since the publication of the reference text,

various studies have been undertaken using, as the basic analytical tool, variations of the original model.[8]

The theoretical structure of the B-MARIA model is well documented.[9] The model recognizes the economies of 27 Brazilian regions. Results are based on a bottom-up approach – i.e. national results are obtained from the aggregation of regional results. The model identifies 56 production/investment sectors in each region producing 110 commodities, one representative household in each region, regional governments and one Federal government, and a single foreign area that trades with each domestic region, through a network of ports of exit and ports of entry. Three local primary factors are used in the production process, according to regional endowments (land, capital and labour). The model is structurally calibrated for 2007; a rather complete data set is available for that period.

The B-MARIA framework includes explicitly some important elements from an interregional system, needed to better understand macro spatial phenomena, namely: interregional flows of goods and services, transportation costs based on origin-destination pairs, interregional movement of primary factors, regionalization of the transactions of the public sector, and regional labor markets segmentation. We have also introduced the possibility of (external) non-constant returns in the production process, following Haddad (2004). This extension is essential to adequately represent one of the functioning mechanisms of a spatial economy.

In order to capture the effects of climate anomalies on agriculture productivity, the simulations were carried out under a standard short run closure. Capital stocks were held fixed, as well as regional population and labor supply, regional wage differentials, and national real wage. Regional employment is driven by the assumptions on wage rates, which indirectly determine regional unemployment rates. On the demand side, investment expenditures are fixed exogenously – firms cannot re-evaluate their investment decisions in the short run. Household consumption follows household disposable income, and real government consumption, at both regional and federal

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[8] Critical reviews of the model can be found in the Journal of Regional Science (Polenske, 2002), Economic Systems Research (Siriwardana, 2001) and in Papers in Regional Science (Azzoni, 2001).
[9] See Haddad (1999), and Haddad and Hewings (2005).

levels, is fixed. Finally, preferences and technology variables are exogenous allowing for exogenous changes in the production functions of the state agriculture sectors, consistent with projection of the profit function estimates. Typical results must be understood in a comparative-static sense; in other words, they show the percentage change in the endogenous variables that would have been observed in the benchmark year had the climate anomalies occurred in the benchmark database.

The strategy for sequentially modeling integration is summarized in Figure 3. At the first stage, the profit model was used to project the physical change on the production of agriculture sector (permanent and temporary crops) conditioned by the climate anomalies observed in 2005. At the second stage, such a physical change in the agricultural production is translated as a technological productivity shock into the CGE model. This productivity shock is modeled as technical change in the primary factors used in the production function. For instance, if the climate anomalies imply in a reduction of 10% in the agriculture production, it is assumed that the primary factors requirements of the agricultural sector would increase also by 10% in order to achieve the same actual production. As a consequence, productivity decreases in the agricultural sector and causes a supply constraint (shock) from the agricultural sector to the other sectors in the economic system.

Figure 3. The Integrated Framework
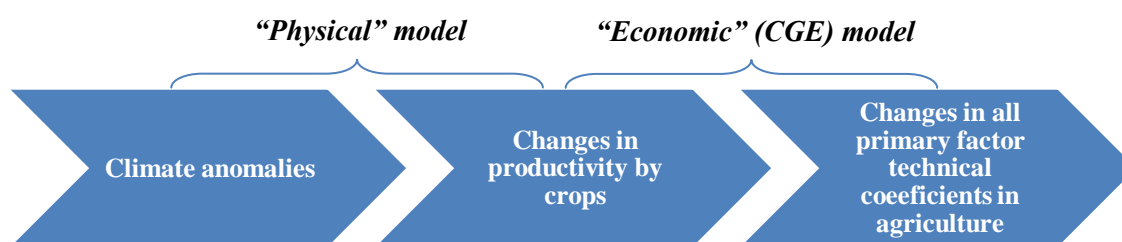
3. Simulation Results

Figure 4 presents the impact of climate anomalies, such as those observed in 2005, on the Gross Regional Product (GRP) of Brazilian states. As expected, the spatial distribution of these impacts is highly correlated with the shape of climate anomalies shown in Figure 2. The biggest reductions in GRP are concentrated in some states

located in the North (Pará, Amazonas and Amapá), Northeast (Maranhão, Paraíba and Ceará), Center-West (Mato Grosso) and South (Santa Catarina, Paraná and Rio Grande do Sul), especially in those where more severe droughts occurred in 2005.

These effects are determined by both the direct impacts of climate anomalies on the agricultural sector and by the indirect and induced impacts on other sectors, since agricultural goods are not only used as intermediate inputs to other sectors, but also part of the exports and household consumption. According to Figure 5, the sectors (indirectly) most affected by climate anomalies are those related to the agribusiness complex such as tobacco products, textiles and food products. Additionally, non tradable goods such as those in the service sectors are negatively affected by climate anomalies. This negative effect is mostly due to a reduction in real income caused by the general increase in prices led by the increase in the prices of agricultural products. Such effect on prices also hampers Brazilian competitiveness in foreign markets.

The extent to which climate anomalies affect short term regional economic growth is conditioned by the structural characteristics of each regional productive system, mainly the degree of specialization in agribusiness activities and their backward and forward linkages into the integrated interregional economic system. The evaluation of the importance of these structural characteristics for spreading climate shocks over the territory can be achieved by computing and comparing the direct economic costs to the total economic impact of climate shocks in terms of changes in the level of sectoral production. The direct impact, or damage, can be obtained through the changes in agricultural production caused by the productivity shock while the total impact is calculated by taking into account the general equilibrium effects on the activity level of all sectors of the state economies.
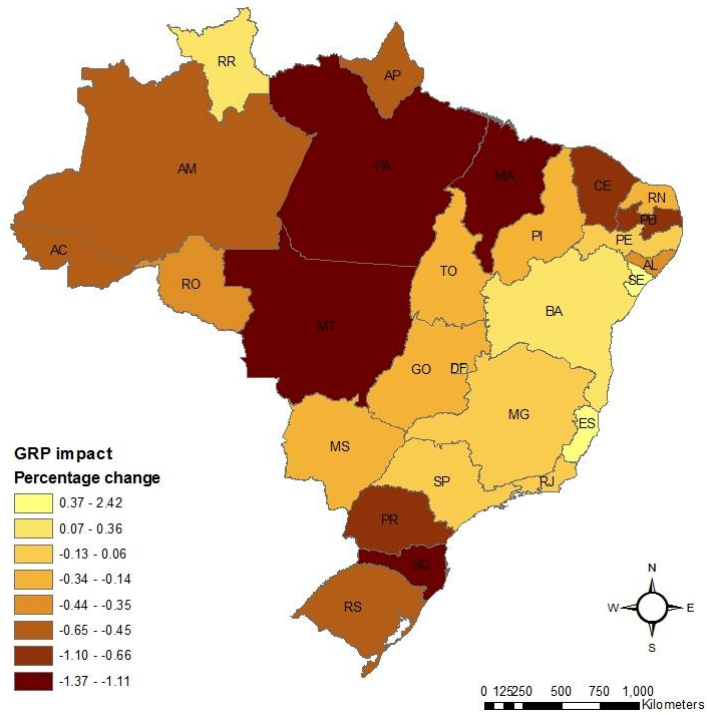
Figure 4. Impacts on GRP

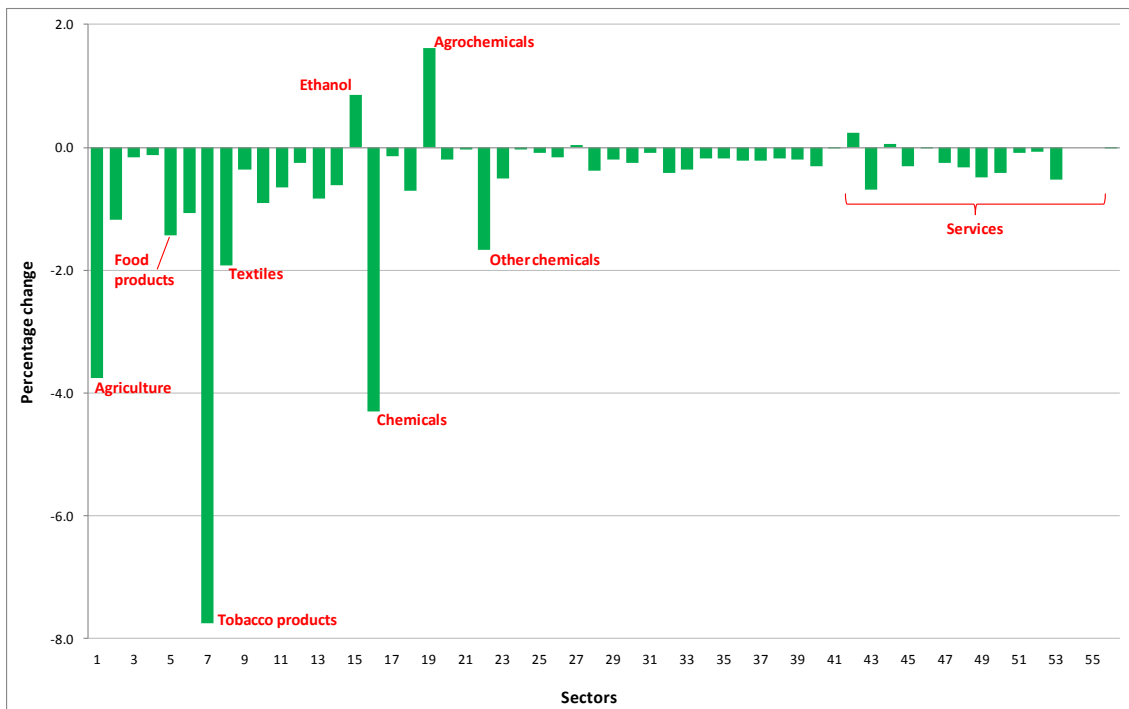# Figure 5. Impacts on Sectoral Value Added

Table 1 shows these economic costs calculated in terms of monetary changes in the sectoral production, in BRL 2011 values, and the total impact-damage ratio which represents the multiplier effect associated with each specific economic system. For the whole country, the loss of BRL 1.00 in the agricultural production caused by climate anomalies implied additional losses of BRL 3.25 in the economy as a whole. Considering the macro-regions with negative direct and indirect impacts, the North and South presented indirect economic costs relatively higher than the Center-West and Northeast. For the Southeast, the total impact was also negative despite the fact that this macro-region presented positive direct effects due to more favorable climate conditions to the agriculture production in 2005; this can be explained by the indirect and induced negative impacts on Sao Paulo and Rio de Janeiro. This result is heavily influenced by the structure of backward and forward linkages in the Brazilian interregional productive structure, in which these states play a central role, leading to strong interdependence between the core and the more peripheral regions in the North, Northeast and Center-West. The reduction in the demand originated in the more affected states causes a decrease in the demand for goods produced in the more economically developed states in the center-south of the country.

Table 1. Total Costs of Climate Anomalies (BRL millions 2011)

	Direct damage	Total impact	Total impact-damage ratio
North	*-921*	*-2103*	*2,28*
RO	-31	-105	3,36
AC	-18	-36	1,98
AM	-80	-393	4,88
RR	6	4	0,65
PA	-757	-1519	2,01
AP	-18	-23	1,26
TO	-22	-32	1,47
Northeast	*-437*	*-713*	*1,63*
MA	-233	-145	0,62
PI	-19	-38	2,01
CE	-326	-778	2,39
RN	-115	-198	1,72
PB	-176	104	-0,59
PE	-399	-626	1,57
AL	-109	-141	1,29
SE	9	65	7,07
BA	930	1045	1,12
Southeast	*3178*	*-6029*	*-1,90*
MG	1568	938	0,60
ES	2162	1719	0,79
RJ	127	-1725	-13,54
SP	-680	-6961	10,24
South	*-6453*	*-14032*	*2,17*
PR	-2948	-4379	1,49
SC	-804	-1017	1,26
RS	-2701	-8636	3,20
Center-West	*-1303*	*-2336*	*1,79*
MS	-208	-430	2,07
MT	-1179	-1592	1,35
GO	93	-192	-2,07
DF	-9	-122	14,14
BRAZIL	*-5936*	*-25212*	*4,25*

4. Concluding Remarks

The results of this paper suggest that the economic costs of climate anomalies can be significantly underestimated if only partial equilibrium effects (direct impact/damage) are accounted for. Thus, a general equilibrium approach can provide a better comprehension about the systemic impact of climate anomalies, contributing to formulate more consistent public policies in order to mitigate the potential impact of extreme climate events. In addition, our results suggest that intersectoral and interregional linkages as well price effects are important channels for spreading the economic effects of climate changes.

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Appendix A. Profit Function Approach

Profit function model

In order to measure the short- and long-terms impacts of climate change on agricultural production, a partial equilibrium model based on the microeconomics production theory was used. By specifying a profit function, it was possible to obtain the optimal input-output allocation for each type of crop or farm product.

It is assumed that producers allocate their k inputs for 2 types of production: temporary crops; and permanent crops. The total output plus the total input represent the m products considered in the analysis. The producers decide how to allocate their inputs by solving a profit maximization problem in a competitive market. Thus, prices are considered as taken/exogenous. Besides the historical input and output prices, $p = (p_1,...,p_m)'$, each producer faces a vector of h exogenous climate variables, $z = (z_1,...,z_h)'$, which affects the production and the farmers' profits. Other variables, such as soil type; farmer's schooling (Huffman and Evenson, 1989)[10] and other r fixed factors, represented by $X = (X_{1, ..., } Xr)'$, also significantly affect the production decision (q). The farmer's optimization problem can be described by the following expression:

$$\underset{q_1,q_2,...q_m}{Max}\left(\sum_{i=1}^{m}\Pi_i(p,z,X,q) \right) i = 1,...,m \tag{A.1}$$

The first-order condition is:

$$\frac{\partial \Pi_i}{\partial q_i} = 0, \ i = 1,...,m \tag{A.2}$$

Solving equation (A.2) leads to the optimal allocation for the supply outputs and demand (q_i), which depend on prices, climate, environmental variables, investments and other factors.

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[10] An increase in the level of farmer education, all else equal, increases the use of more advanced techniques. Thus, better education can spur the spread of technical change.

$$q_i^*(p_i, z, X), \quad i = 1,...,m \tag{A.3}$$

The chosen functional form for the supply/demand equations is the log-linear function. The m equations, obtained from deriving the profit equations in respect to the s outputs and k inputs, are described below.

$$\ln(q_i^*) = \beta_0^i + \sum_{f=1}^{m} \beta_{1f}^i p_f + \beta_2^i z + \beta_3^i X + \varepsilon_i, \quad i = 1,...,m \tag{A.4}$$

Climate variables in the model

The climate variables of the model (vector z) are represented by temperature and precipitation measures. For both variables, we considered:

- z_{mean}: The 15-year average of historical data, to compute the 2006 current climate pattern in each municipality[11]. The mean was calculated for the seasons, giving the long-term seasonal mean.

- z_{var}: The 2006 anomalies in temperature and precipitation by municipality and season. Anomaly is defined as the difference between the observed value in 2006 and the long-term average mentioned above.

After including these definitions of climate variables, the model is specified as:

$$\ln(q_i^*) = \beta_0^i + \sum_{f=1}^{m} \beta_{1f}^i p_f + \beta_{2.1}^i z_{mean} + \beta_{2.2*}^i z_{var} + \beta_3^i X + \varepsilon_i, \quad i = 1,...,m \tag{A.4'}$$

where $z_{mean,j} = (z_{mean,j}^{Temp}, z_{mean,j}^{Rain})$; $z_{var,j} = (z_{annom\,j}^{Temp}, z_{annom\,j}^{Rain})$ for each j season, and βs are the vectors of parameters to be estimated.

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[11] Fifteen years were used due to lack of historical information. The municipality is the local political division in Brazil and is similar to a county, except there is a single mayor and municipal council.

Appendix B. Partial Equilibrium Model: Results

Table B.1 summarizes the results from the supply equations estimation. The results indicate that the summer and spring seasons are the most sensitive seasons when it comes to the drought risks. During those seasons, the coefficients estimated suggest that production might be more affected to negative deviations from the normal rain conditions:

Table B.1. Total Costs of Climate Anomalies (BRL millions 2011)

Variables	(1) Permanent Crops Model *lnqt_permanentes*	(2) Temporary Crops Model *lnqt_temporarias*
price_maize	-0.640***	-1.302***
price_soybean	-0.124	0.336
price_ot_temp	-0.00174***	-0.00410***
price_coffe	0.000184	-0.00156
price_ot_perm	-0.00321**	0.000550
price_milk	1.088***	0.0982
price_cattle	0.333	-0.0323
price_wood	0.0128**	0.00322
price_ot_for	0.00375	-0.00375**
price_land	0.0174	0.00172
price_labor	0.0101	0.0246***
price_fuel	-0.0527	-0.312**
price_fert	0.0932***	0.0370*
rdi_stock_2006	0.000181***	0.000318***
degr_tot_areas	0.920	-2.233
agri_tot_areas	0.143	2.071***
tam_medio	-0.00489***	-0.000129
AMAZON	2.165***	3.277***
CAATINGA	1.390***	2.104**
CERRADO	0.970***	3.030***
MATA_ATL	1.969***	2.705***
PANTANAL	0.468	1.929*
alfab_temp	-0.377	-1.536***
ensfun_inc_temp	0.338	-1.070***
ensfun_comp_temp	1.178**	0.360
ensmed_comp_temp	0.298	0.113
enssup_temp	2.974***	4.089***
temp_fall_mean	0.449***	-0.157
temp_winter_mean	0.0824	-0.400***
temp_spring_mean	0.0135	0.523***
temp_summer_mean	-0.585***	0.0246
temp_fall_var	0.221*	0.000933
temp_winter_var	0.00636	0.476***
temp_spring_var	-0.812***	-0.312**
temp_summer_var	-0.0216	0.520***
rain_summer_mean	-0.000872	-0.00480***
rain_fall_mean	0.00259	-0.00157
rain_winter_mean	-0.00363*	0.00196
rain_spring_mean	-0.00793***	-0.00471***
rain_summer_diff	**0.00474***	**0.00259**
rain_fall_diff	**-0.00527***	**-0.00745***
rain_winter_diff	**-0.000522**	**-0.0146***
rain_spring_diff	**0.00576***	**0.00545***
Constant	5.067***	5.753***
Observations	**4,770**	**5,361**
R-squared	**17%**	**32%**

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.