

Porsse, Alexandre; Haddad, Eduardo; Pereda, Paula

Conference Paper

Territorial Economic Impacts of Climate Anomalies in Brazil

53rd Congress of the European Regional Science Association: "Regional Integration: Europe, the Mediterranean and the World Economy", 27-31 August 2013, Palermo, Italy

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Porsse, Alexandre; Haddad, Eduardo; Pereda, Paula (2013) : Territorial Economic Impacts of Climate Anomalies in Brazil, 53rd Congress of the European Regional Science Association: "Regional Integration: Europe, the Mediterranean and the World Economy", 27-31 August 2013, Palermo, Italy, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

<https://hdl.handle.net/10419/124035>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Territorial Economic Impacts of Climate Anomalies in Brazil

Prof. Dr. Alexandre Alves Porsse (porsse@ufpr.br)

Associate Professor at the Federal University of Paraná, Brazil

Departamento de Economia

Av. Prefeito Lothário Meissner, 632 - térreo

80210-170 – Jardim Botânico, Curitiba, PR – BRAZIL

Prof. Dr. Eduardo Amaral Haddad (ehaddad@usp.br)

Full Professor at the Department of Economics at the University of Sao Paulo, Brazil

NEREUS – The University of Sao Paulo Regional and Urban Economics Lab

Departamento de Economia – FEA

Av. Prof. Luciano Gualberto, 908, FEA I

05508-900 – Cidade Universitária, São Paulo, SP – BRAZIL

Paula Carvalho Pereda (paulapereda@gmail.com)

PhD Student at the Department of Economics at the University of Sao Paulo, Brazil

NEREUS – The University of Sao Paulo Regional and Urban Economics Lab

Departamento de Economia – FEA

Av. Prof. Luciano Gualberto, 908, FEA I

05508-900 – Cidade Universitária, São Paulo, SP – BRAZIL

Abstract. Climate variability is one of the main environmental causes of losses to the agricultural sector. Most of the methodological tools applied to estimate its economic cost usually account only for the direct impact on agricultural activity. In this paper we use an alternative approach in which a physical model is integrated with an interregional CGE model in order to evaluate the systemic economic impacts of climate anomalies. The analysis is done for the Brazilian economy taking into account the phenomena observed in 2005. The economy-wide impacts are assessed considering both the indirect linkages of the agricultural sector with other sectors in the economic system and the regional interdependence among Brazilian states associated with interregional trade flows. The results show that the economic costs of climate anomalies can be significantly underestimated if only partial equilibrium effects (direct impact/damage) are accounted for. For the whole country, the loss of BRL 1.00 in the agricultural production caused by climate anomalies such as those occurred in 2005 implies additional losses of BRL 3.25 in the economy as a whole. It is also shown that intersectoral and interregional linkages as well as price effects are important channels for spreading the economic effects of located climate anomalies on other regions of the country.

Keywords: climate anomalies, economic impacts, agriculture, systemic approach, interregional CGE analysis, Brazil.

1. Introduction

While long-term changes in climate have the potential to modify agricultural land use patterns (e.g., Evenson and Alves, 1998, Gurgel et al., 2007; Matthews et al., 2007; Ronnenberger et al., 2009), short-term climate conditions directly affect crop yields and farmers' earnings (e.g., Moore and

Negri, 1992; Mendelsohn et al., 1994; Mendelsohn et al., 1999; Sands and Edmonds, 2005; Dêschenes and Greenstone, 2007). Agriculture losses in the recent past are often associated not only to climate variability but also to weather-related extreme events, such as droughts and floods (Ding et al., 2010).

Climate change is expected to modify the frequency, intensity, and duration of extreme events in many regions (Christensen et al., 2007). 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 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 a higher risk of crop failure owing to climate variability.

Climate variability is one of the main environmental causes of losses to the agriculture sector. In general, the direct effects of climate on agriculture are mainly related to lower crop yields or failure owing to drought, frost, hail, severe storms, and floods; loss of livestock in harsh winter conditions and frosts; and other losses owing to short-term extreme weather events. Some of these effects of climate on agriculture have already been studied in the Latin American countries (Magalhaes, 1992; Boyd and Ibararán, 2008). However, not many studies have explored the systemic economic costs of the impacts of climate anomalies on the agriculture sector within a country.¹ This broad regional view is essential in the context of an integrated approach of the production value chain – the agribusiness.²

Existing studies usually focus on the direct (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, the 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

¹ The pioneering study by Horridge et al. (2005) may be regarded as a milestone in the field.

² While the share of agriculture in the Brazilian GDP was 7.5% in 1999, the contribution of agribusiness, which takes into account the entire value chain related to agriculture, was 26.6% of the national GDP. This picture varies by region, for instance, the figures for the South region were 12.8% (share of agriculture in the regional GDP) and 41.4% (share of agribusiness in the regional GDP), and for the Southeast region were 4.7% and 21.2%, respectively (Furtuoso and Guilhoto, 2003).

phenomenon is usually captured in the input–output tables (Hewings, 1999; p. 2). With this formulation in place, it is possible to trace the consequences of an expansion or contraction in any one sector or set of sectors on other sectors of the economy. 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 the world. Hence, parallel to the economic linkages between sectors within a region, there is a parallel set of linkages between the regions. The growth or decline of one region’s economy will have potential impacts on the economies of the other regions. The nature and extent of this impact will depend on the degree of exchange between the two regions and the exchanges with the other regions. Thus, there is a need to address these issues in a general equilibrium context by including price effects.

Extensive literature on the systemic effects of climate change on agriculture in the context of computable general equilibrium (CGE) models³ is available. Modeling strategies attempt either to include more details in the agriculture sectors within the CGE-model structures (e.g., modeling of land use and land classes) or to integrate stand-alone models of agricultural land use with the CGE models, usually through soft links that use semi-iterative approaches (Palatnik and Roson, 2012). Most of such CGE applications are global in nature, providing economic impacts only at the level of regions of the world or countries. The detailed spatially disaggregated information on land characteristics that may be present in the land use models is lost in aggregation procedures that are used to run the global CGE models, providing few insights on the differential impacts within national borders.

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 of 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 assessing the wider economic impacts of climate anomalies observed in 2005 in Brazil.⁴ As the agriculture sector has important forward linkages in the Brazilian economic structure, as well as specific location patterns, these climate anomalies, even if spatially concentrated, may have implied important economic losses for the whole country with distinct

³ CGE models are based on systems of disaggregated data, consistent and comprehensive, that capture the existing interdependence within the economy (flow of income).

⁴ In 2005, several Brazilian regions experienced expressive declines in precipitation compared to the historic averages. A symbolic case of an extreme precipitation event in the Amazonian Basin is the drought that occurred in that year (Sena et al., 2012), which hit the southwest of Amazonia and the state of Pará severely. In the same year, Brazil’s northeast Sertão, 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.

regional impacts. While physical models of agricultural productivity can provide estimates of the direct impact of climate variability on the quantum of agricultural production, spatial general equilibrium models can take into account the systemic impact of climate anomalies by considering the linkages of the agriculture sector with other sectors of the economy and the locational impacts that emerge. Thus, assessing the economic contribution of a part of a country's economic sector requires some consideration of the likely paths of interactions that are a consequence of the direct effects of climate on agricultural output. Accordingly, the process adopted here is to extract the initial causality path and to estimate the initial reactions econometrically and then to feed the results back into the CGE model to capture the system-wide impacts.

The remaining of the paper is structured as follows. In the next section, we discuss the methodological approach and present the estimates of the direct effects of climate anomalies derived from a physical agronomic model. The next two sections provide an overview of the integrated approach to derive the economy-wide impacts of the 2005 climate anomalies, followed by the presentation of the results and a discussion.

2. Direct Effects: Methodology and Results

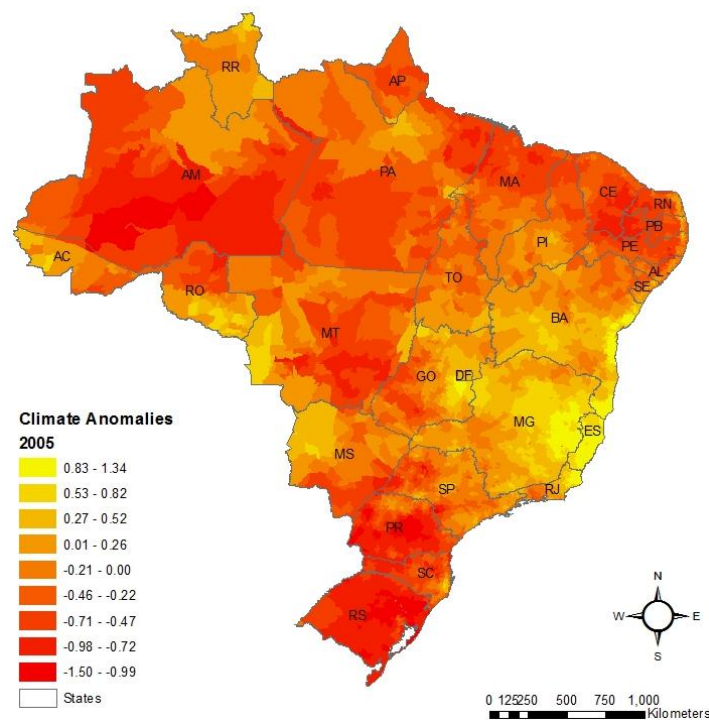
In this study, we first analyze how the production of different cultures is affected by climate variables by using a profit function approach (Lau, 1978; Jehle and Reny, 2000; Mas-Colell et al, 2006). This approach allows the measurement of crop production variation (direct effects), which will be used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

Cross-section data were used as empirical support in this study. The unit of analysis was the Brazilian municipalities. The agricultural data were obtained from the Brazilian Agricultural Census of 2006 that was produced by the Brazilian Institute of Geography and Statistics (IBGE).⁹

⁹ 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 census employed technological refinements,

The climate data were obtained from different sources: historical temperature information was obtained from the National Meteorology Institute (INMET) and historical rainfall data were collected from CPC Morphing/NOAA.¹⁰ 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 the Brazilian municipalities for 2005. By comparing with the historic average, an expressive reduction in precipitations, mainly in some areas of the North, Northeast, and South of Brazil can be observed.

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 2005. The total direct impact on the agriculture sector in each Brazilian state was then calculated by using Laspeyres indices whose weights were given by the shares of both permanent- and temporary-crop outputs for each municipality that were further aggregated to obtain a measure of the physical change in agricultural production at the state level.¹³

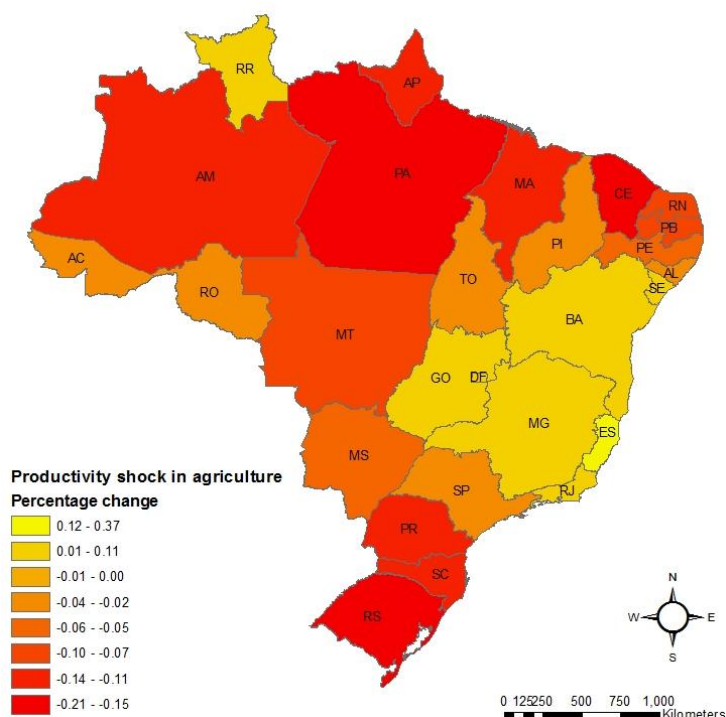
mainly related to the introduction of new concepts to encompass the transformations that occurred in agricultural activities and in the countryside since the previous census.

¹⁰ Rainfall data were calculated from CMORPH (CPC Morphing technique) for the production of global precipitation estimates (Joyce et al., 2004).

¹³ Appendix B shows the estimated coefficients of the profit model. It is worth mentioning that these coefficients were estimated by using data for 2006, but climate anomalies were structurally estimated by using rainfall data for 2005.

Such results were translated into productivity shocks that change the production functions of the agriculture sector in each state (Figure 2).¹⁴ As expected, the spatial distribution of these shocks is correlated to the climate anomalies shown in Figure 1, that is, the higher the reduction in precipitation, the higher is the negative impact on agricultural productivity. The states located mainly in the North (Amazonas, Para, and Amapa) and South (Parana, Santa Catarina, and Rio Grande do Sul) were the most directly affected by the climate anomalies in 2005. It is noteworthy that there are also states, located mainly in the Southeast (Minas Gerais, Rio de Janeiro, and Espirito Santo), with gains in productivity associated with more favorable climate conditions. These productivity shocks only account for the direct impact of climate anomalies. As the agriculture sector provides inputs for many other sectors in the economy, it is naturally expected that the effects of climate anomalies will spread to the entire economic system. The strategy adopted to calculate the wider economic impacts follows.

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



¹⁴ As the CGE model is calibrated based on an interstate input-output system, this bottom-up spatial aggregation procedure was necessary to define the linkages between the physical and the economic models.

3. Wider Economic Impacts: Methodological Approach

An interstate computable general equilibrium (CGE) model was used to simulate the systemic impacts of changes in agricultural yields by state owing to climate variation. The 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 were undertaken by using variations of the original model as the basic analytical tool.¹⁷

The theoretical structure of the B-MARIA model is well documented.¹⁸ The model recognizes the economies of 27 Brazilian regions. Results are based on a bottom-up approach, that is, national results are obtained from the aggregation of regional results. The model identifies 56 production/investment sectors in each region that produce 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 labor). The model is structurally calibrated for 2005–2007; a rather complete data set is available for that period.

The B-MARIA framework explicitly includes some important elements from an interregional system that is 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 market segmentation. We have also introduced the possibility of (external) non-constant returns in the production process, following Haddad and Hewings (2005). This extension is essential to adequately represent one of the functioning mechanisms of a spatial economy.

The simulations were carried out under a standard short-run closure in order to capture the economic effects of the 2005 climate anomalies in Brazil. 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

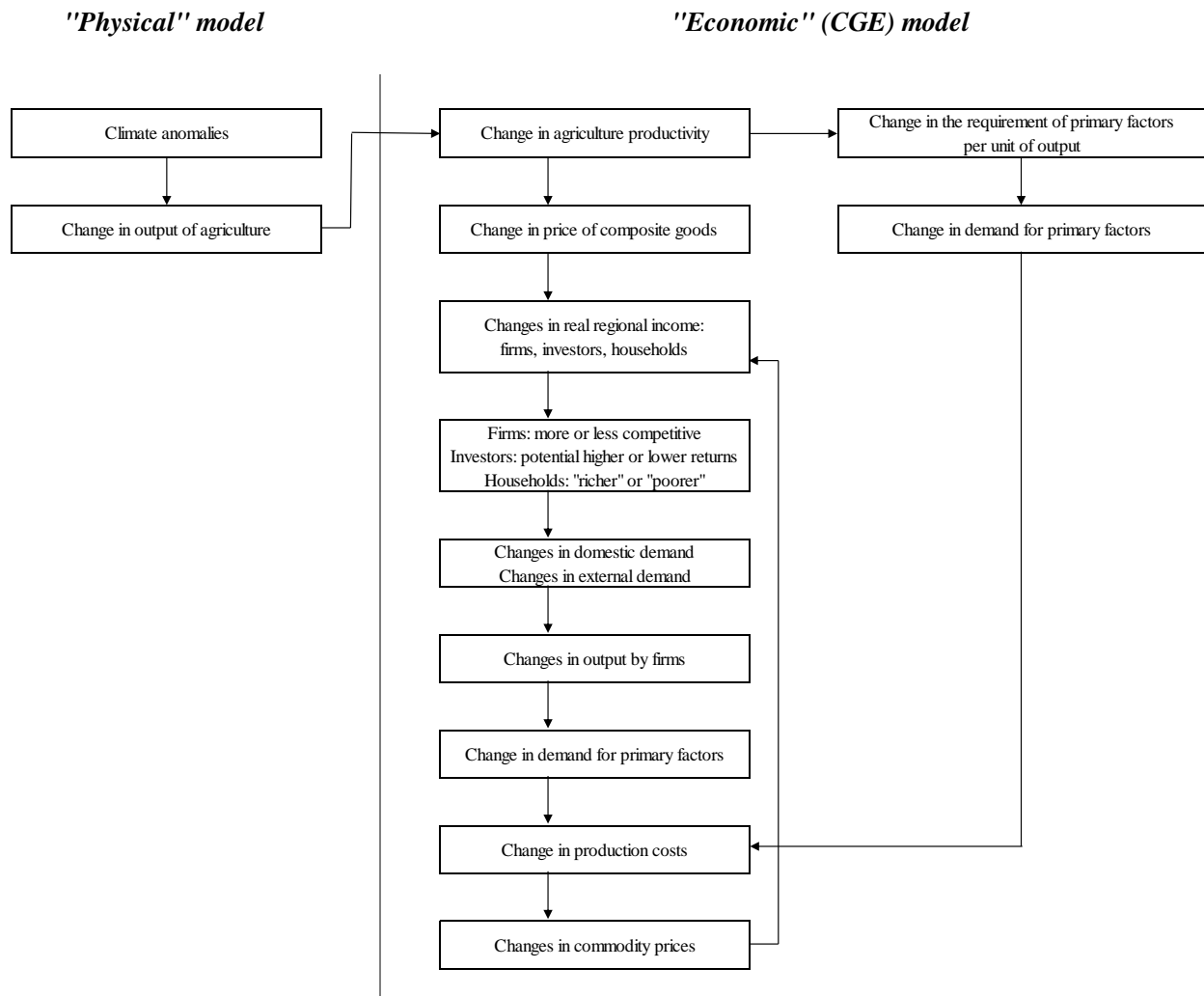
¹⁷ Critical reviews of the model can be found in the *Journal of Regional Science* (Polenske, 2002), *Economic Systems Research* (Siriwardana, 2001) and in *Papers in Regional Science* (Azzoni, 2001).

¹⁸ See Haddad (1999), and Haddad and Hewings (2005).

cannot reevaluate their investment decisions in the short run. Household consumption follows household disposable income, and real government consumption, at both regional and federal levels, is fixed. It is assumed that the public sector keeps its expenditure level through running short-term deficits (surpluses). 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 partial equilibrium model was used to project the physical change in the production of the agriculture sector (permanent and temporary crops) conditioned by the climate anomalies observed in 2005. At the second stage, such physical changes in the state agricultural output were translated as technological productivity shocks into the CGE model. The productivity shocks are modeled as technical changes in the requirements for primary factors that are used in the production function. For instance, if the climate anomalies implied a 10% reduction in the agricultural output, it was assumed that the primary factors' requirements of the agriculture sector would also have to increase by 10% in order to achieve the same current production. Therefore, productivity would decrease in the agriculture sector causing increases in the composite prices and decreases in the real income of economic agents. The main channels of propagation of the general equilibrium effects of climate anomalies through the economic system consist in supply constraints from the agriculture sector to other sectors, as well changes in prices of composite goods and primary factors, affecting firms' competitiveness and household welfare.

Figure 3. The Integrated Framework



4. Simulation Results and Conclusion

What would have happened if the climate in 2005 had followed historical trends in Brazil? What would be the difference in terms of value added (GRP/GDP) for the country and its regions? Results of the CGE simulations with the software GEMPAK were computed via a 1-2-4 Euler procedure with extrapolation (Harrison and Pearson, 1996, under a short-run closure (exogenous capital stocks). We focus our analysis on the national, sectoral, and regional activity effects in the following section.

Table 1 shows the results for the macroeconomic effects of the 2005 climate anomalies generated by the CGE simulation. It is expected that climate variability lowered the national GDP by 0.163% and employment by 0.403%. Despite the localized occurrence of droughts within the specific regional limits, they reduce output growth beyond the affected territories. They also contribute to a

decline in welfare of national residents (lower real-household consumption), a reduction in tax revenue²¹, and a decrease in the country's competitiveness in international markets as verified by the worsening of the international balance of trade (stronger decline of exports).

**Table 1. Macroeconomic Impacts of Climate Anomalies
(in percentage change)**

Variables	%
Real GDP	-0.163
Real household consumption	-0.163
Real investment	-
Real government consumption - Regional	-
Real government consumption - Federal	-
International export volume	-0.819
International import volume	-0.481
GDP deflator	0.705
Consumer price index	0.800
Investment price index	0.341
Government price index - Regional	0.683
Government price index - Federal	0.676
International export price index	0.412
International import price index	-
Employment	-0.403

From a spatial perspective, Figure 4 presents the impact of climate anomalies on the GRP of Brazilian states. 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 where more severe droughts occurred in 2005.

Such effects are determined by both the direct impacts of climate anomalies on the agriculture sector and the indirect and induced impacts on other sectors, since agricultural goods are not only

²¹ Our assumption regarding adjustment in the real government expenditure considers constant real expenditures adjusted by budget deficits/surpluses for both regional and federal governments.

used as intermediate inputs to other sectors, but also as 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 because of a reduction in real income caused by the general increase in prices led by the increase in the prices of agricultural products. Such an effect on prices also hampers Brazilian competitiveness in foreign markets.

Figure 4. Impacts on GRP

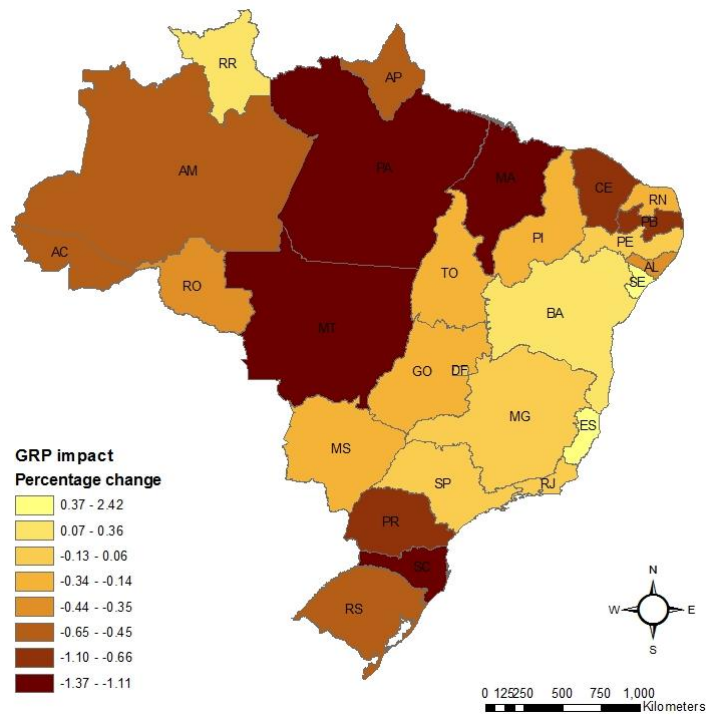
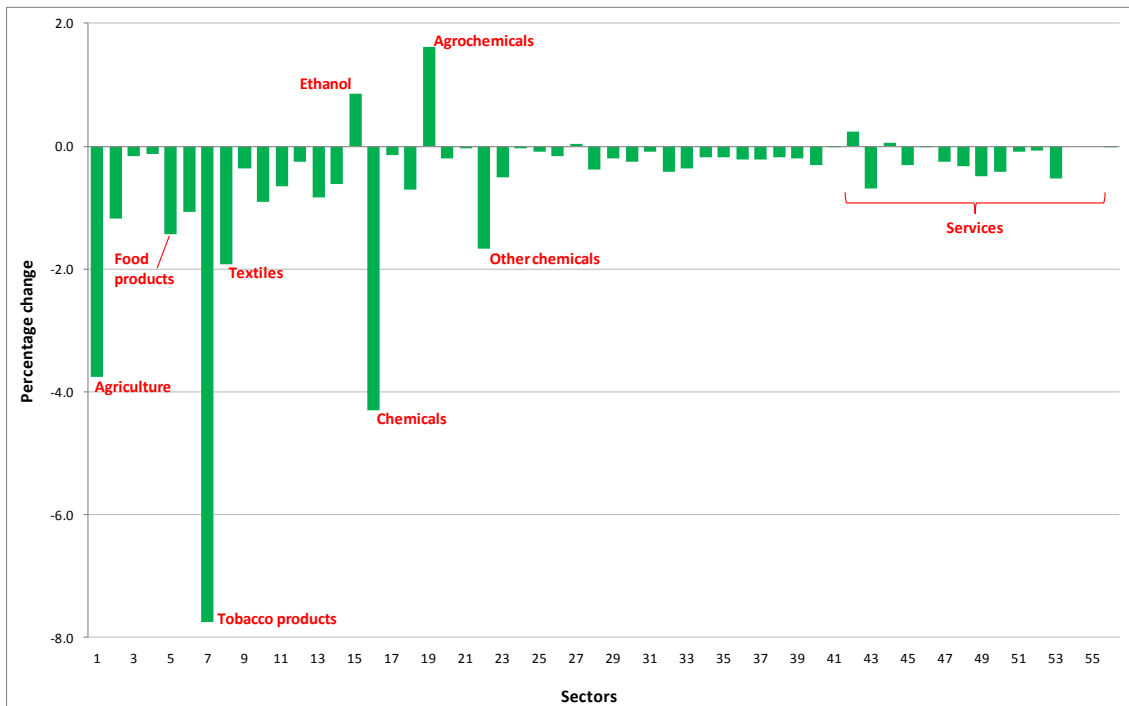


Figure 5. Impacts on Sectoral Value Added



A thorough analysis of the structure of the economy is needed to better understand the short-run regional results of the model (Haddad et al., 2009). A close inspection of the benchmark database, conducted not only on the relationships in the interregional input–output database, but also on the other relevant structural parameters of the model, is necessary. As shown in Haddad et al. (2002), structural coefficients are derived from the SAM lead short-run results in less flexible environments (closures). As one precludes factor mobility to a great extent, understanding of disaggregated results might be achieved through econometric regressions on key structural coefficients.

How important is the existing economic structure in explaining the short-run spatial results associated with climate anomalies in Brazil? Do backward and forward linkages matter? To answer these questions, following Dixon et al. (1982, 2007), we regress the model results (regional activity level) against selected structural coefficients of the model and the size of the shock (direct effects). The OLS regressions are shown in Tables 2, and they aim only at revealing the influence of the benchmark structure on the short-run results.

According to the results for the regional activity level, the selected structural indicators explain 82 percent of the variation across states in the CGE model results. Explanations for specific regional results should consider structural and parametric aspects of the database. Regions that present higher decreases in their output tend to face stronger initial impacts owing to inadequate climate

conditions; they also tend to have an overall higher share of agribusiness in their sectoral structure, thereby, suffering from the effects in the production value chain. In addition, regions that face stronger negative effects tend to concentrate their sales to foreign consumers. Finally, a higher labor share in the regional value added seems to benefit economic performance in the short-run as employment adjustment turns out to be more flexible. Thus, 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 agriculture and agribusiness activities and their backward and forward linkages into the integrated interregional economic system.

Table 2. Structural Analysis of Short-run Activity Level Results

Dependent Variable: ACT_SR

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-2.27925	0.68300	-3.33712	0.00300
AGR_SH	-0.94169	0.47047	-2.00160	0.05780
LSH	4.24702	1.31617	3.22680	0.00390
SHOCK	-0.02354	0.01081	-2.17696	0.04050
SHOCK*SAL4	-0.15878	0.05860	-2.70955	0.01280
R-squared	0.81668			

ACT_SR = percentage change in regional activity level; AGR_SH = share of agribusiness in regional productive structure; LSH = share of labor payments in regional value added; SHOCK = initial productivity change in the agriculture sector; SHOCK*SAL4 = interaction between initial productivity change in the agriculture sector and export share in total sales.

The evaluation of the importance of these structural characteristics for propagating 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.

Table 3 shows these economic costs calculated in terms of monetary changes in the sectoral production, in BRL 2011 values, and the total impact-damage ratio that 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 that are 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 owing to more favorable climate conditions toward the agricultural 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 that 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.

These results show 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 understanding of the systemic impact of climate anomalies, thereby, contributing to formulate public policies that are more consistent in order to mitigate the potential impact of extreme climate events. Moreover, our results suggest that intersectoral and interregional linkages as well as price effects are important channels for spreading the economic effects of climate changes on the entire country.

Table 3. Total Costs of Climate Anomalies (BRL millions 2011)

	<i>Direct damage</i>	<i>Total impact</i>	<i>Total impact-damage ratio</i>
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

References

Azzoni, C. R. (2001) Book Review: Regional Inequality and Structural Changes – Lessons from the Brazilian Experience. *Papers in Regional Science*, v. 83, n. 2.

Boyd, R. and Ibararán, M. E. (2008). Extreme Climate Events and Adaptation: An Exploratory Analysis of Drought in Mexico. *Environment and Development Economics*, v. 14, n.3.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W-T, Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C. G., Räisänen, J., Rinke, A., Sarr, A. and Whetton P. 2007. Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K B, Tignor M and Miller H L (eds)]. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

Dêschenes, O. and Greenstone, M. (2007). The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather. *American Economic Review*, v. 97, n. 1.

Ding, Y., Hayes, M. J. and Widhalm, M. (2010). Measuring Economic Impacts of Drought: a Review and Discussion. *Papers in Natural Resources*, Paper 196, <http://digitalcommons.unl.edu/>.

Dixon, P. B., Parmenter, B. R., Sutton, J. Vincent, D. P. (1982) *ORANI: A Multisectoral Model of the Australian Economy*. Amsterdam: North-Holland.

Dixon P. B., Rimmer M. T. and Tsigas M. (2007). Regionalizing Results from a Detailed CGE Model: Macro, Industry and State Effects in the US of Removing Major Tariffs and Quotas. *Papers in Regional Science*, v. 86.

Evenson, R. E. and Alves, D. C. (1998). Technology, Climate Change, Productivity and Land Use in Brazilian Agriculture. *Planejamento e Políticas Públicas*, v. 18.

Furtuoso, M. C. O. and Guilhoto, J. J. M. (2003). Estimativa e Mensuração do Produto Interno Bruto do Agronegócio da Economia Brasileira, 1994 a 2000. *Revista de Economia e Sociologia Rural*, Brasília, v. 41, n. 4, p. 803-827.

Gurgel, A. C., Reilly, J. M. and Paltsev, S. (2007). Potential Land Use Implications of a Global Biofuels Industry. *Journal of Agricultural & Food Industrial Organization*, v. 5.

Haddad, E. A. (1999) *Regional Inequality and Structural Changes: Lessons from the Brazilian Experience*. Aldershot: Ashgate.

Haddad, E. A., Bonet, J., Hewings, G. J. D., Perobelli, F.S. (2009). Spatial Aspects of Trade Liberalization in Colombia: A General Equilibrium Approach. *Papers in Regional Science*, v. 88.

Haddad, E. A., Hewings, G. J. D. and Peter, M. (2002). Input-Output Systems in Regional and Interregional CGE Modeling. In: G. J. D. Hewings, M. Sonis and D. Boyce. (Eds.). *Trade, Networks and Hierarchies*, Berlin: Springer-Verlag.

Haddad, E. A. and Hewings, G. J. D. (2005) Market Imperfections in a Spatial Economy: Some Experimental Results. *The Quarterly Review of Economics and Finance*, v. 45, p. 476-496.

Harrison, W. J. and Pearson, K. R. (1996). Computing Solutions for Large General Equilibrium Models Using GEMPACK. *Computational Economics*, v. 9, p. 83-127.

Horridge, M., Madden, J. and Wittwer, G. (2005). The Impact of the 2002-2003 Drought in Australia. *Journal of Policy Modeling*, v. 27.

Huffman, W. and Evenson, R. E. (1989). Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other Policies. *American Journal of Agricultural Economics*, 71(3), p. 761-773.

- Hewings, G. J. D. (1999). Economic Forecasting for Business Strategic Decision-Making in Minas Gerais. Unpublished Technical Note, Belo Horizonte: AERI.
- Jehle, G. A. and Reny, P. J. (2000). *Advanced Microeconomic Theory*. Addison Wesley, 2nd Edition.
- Joyce, R. J., Janowiak, J. E., Arkin, P. A. and Xie, P. (2004) CMORPH: A Method that Produces Global Precipitation Estimates from Passive Microwave and Infrared Data at High Spatial and Temporal Resolution. *J. Hydromet*, 5, 487-503.
- Lau, L. J. (1978). Application of Profit Functions. In: M.Fuss and D. Mcfadden (eds.). *Production Economics: Dual Application to Theory and Applications*, North Holland, Amsterdam.
- Magalhaes, A. R. (1996). Adapting to Climatic Variations in Developing Regions: A Planning Framework. In: J. B. Smith, N. Bhatti, G. V. Menzhulin, R. Benioff, M. Campos, B. Jallow, F. Rijsberman, M. I. Budyko and R. K. Dixon (Eds.), *Adapting to Climate Change: An International Perspective*, Springer, pp. 44-54.
- Marengo, J., Jones, R., Alves, L. M. and Valverde, M. C. (2009). Future Change of Temperature and Precipitation Extremes in South America as Derived from the PRECIS Regional Climate Modeling System. *International Journal of Climatology*, v. 29, n. 15.
- Mas-Colell, A., Whinston, M. and Green, J. (2006) *Microeconomic Theory*, Oxford: Oxford University Press.
- Matthews, R. B., Gilbert, N. G., Roach, A., Polhill, J. G. And Gotts, N. M. (2007). Agent-based Land-use Models : A Review of Applications. *Landscape Ecology*, v. 22, n. 10.
- Mendelsohn, R. W., Nordhaus, W. and Shaw, D. (1994). The Impact of Global Warming on Agriculture: a Ricardian Analysis. *American Economic Review*, v. 84, n. 4.
- Mendelsohn, R. W., Nordhaus, W. and Shaw, D. (1994). The Impact of Climate Variation on US Agriculture. In: R. Mendelsohn and J. E. Neumann (Eds.), *The Impact of Climate Change on the United States Economy*, Cambridge: Cambridge University Press.
- Moore, M. R. and Negri, D. H. (1992). A Multicorp Production Model of Irrigated Agriculture Applied to Water Allocation Policy of the Bureau of Reclamation. *Journal of Agricultural and Resource Economics*, v. 17, n. 1.
- Palatnik, R. R. and Roson, R. (2012) Climate Change and Agriculture in Computable General Equilibrium Models: Alternative Modeling Strategies and Data Needs. *Climatic Change*, 112 (3-4). pp. 1085-1100.
- Polenske, K. R. (2002). Book Review: Regional Inequality and Structural Changes – Lessons from the Brazilian Experience *Journal of Regional Science*, v. 42, n. 2.
- Ronnenberger, K., Berrittella, M., Bosello, F. and Tol, R. S. (2009). KLUM@GTAP: Introducing Biophysical Aspects of Land-use Decisions into a Computable General Equilibrium Model a Coupling Experiment. *Environmental Modeling and Assessment*, v. 14, n. 2.
- Sands, R. D. and Edmonds J. A. (2005). Climate Change Impacts for the Conterminous USA: An Integrated Assessment – Part 7 – Economic Analysis of Field Crops and Land Use with Climate Change. *Climate Change*, v. 69.

Sena, J. A., De Deus, L. A. B., Freitas, M. A. V. and Costa, L. (2012). Extreme Events of Droughts and Floods in Amazonia: 2005 and 2009. *Water Resources Management*.

Siriwardana, M. (2001) Book Review: Regional Inequality and Structural Changes – Lessons from the Brazilian Experience. *Economic Systems Research*, v. 13, n.1, 2001.

Appendix A. Profit Function Approach

In order to measure the short- and long-terms impacts of climate change on agricultural production, an econometric model was specified and estimated in accordance with the microeconomics production theory. By specifying a profit function, it was possible to obtain the optimal input-output allocation for each type of crop or farm product.

Based on the partial equilibrium approach postulated by microeconomic theory, 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, $p = (p_1, \dots, p_m)'$, each producer faces a vector of h exogenous climate variables, $z = (z_1, \dots, z_h)'$, which affects the production and the farmers' profits. Other variables, such as soil type; farmer's schooling (Huffman and Evenson, 1989)²³ and other r fixed factors, represented by $X = (X_1, \dots, X_r)'$, also significantly affect the production decision (q).

The farmer's optimization problem can be described as follow:

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

The first-order condition is:

$$\frac{\partial \Pi_i}{\partial q_i} = 0, \quad i = 1, \dots, m \quad (\text{A.2})$$

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.

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

²³ 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.

The chosen functional form for estimating the supply 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.

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

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 municipality²⁴. 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.

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 β_s are the vectors of parameters to be estimated.

Table A.1 summarizes the results of the supply equations estimated for the permanent and temporary crops. These 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.

²⁴ 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.

Table A.1. Production model for the permanent and temporary crops

Variables	(1) Permanent Crops Model	(2) Temporary Crops Model
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.