CLIMATE FORECASTING AND EMERGENCY POLICIES EVIDENCE OF OPPORTUNITIES FROM CEARÁ, BRAZIL

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ABSTRACT

We take small steps towards the approximation between economic analysis and the science of climate forecasting in the formulation of policies to alleviate the impact of climatic shocks. We do so by estimating the relationship between climate variables and corn production in Ceará, an important State in the Brazilian semi-arid. Using parametric and non-parametric regression models, we first estimate the relationship between contemporaneous sea surface temperatures (SSTs) for the Pacific and Atlantic oceans and the local rainfed corn market. Next, we investigate the forecasting potential of future corn production conditional on information on current SSTs. We find strong evidence that climate determinants are important in determining current and future corn production, a key indicator of the climatic stress to which a large number of small farmers are subject in the Brazilian semi-arid. Additionally, corn production in the region is negatively correlated with federal government transfers meant to mitigate the impact of local droughts. These resources have been subject to lethargic bureaucracies, corruption and economic inefficiencies in general. The observation and forecasting of corn production can be invaluable in the design of more efficient, expeditious and transparent policies to mitigate the effects of droughts in the region. (JEL codes: I38, O13, Q11)
Keywords: *climate forecasting, emergency policies, rainfed agriculture, semi-arid*

RESUMO

Este artigo dá passos iniciais na direção da aproximação entre análise econômica e a ciência da previsão do clima no que diz respeito à formulação de políticas públicas para aliviar o impacto de choques climáticos. Para este fim, estimamos a relação entre variávies climáticas e a produção de milho no Ceará, um Estado importante do semi-árido brasileiro. Fazendo uso de regressões paramétricas e não paramétricas, primeiramente estimamos a relação contemporânea entre temperaturas da superfície do mar (TSMs) para os oceanos Pacífico e Atlântico e o mercado do milho local. Em seguida, investigamos o potencial de previsibilidade da produção do milho condicionada à informações presentes das TSMs. Os resultados sugerem forte evidência de que determinantes do clima têm importante papel na determinação da produção contemporânea e futura do milho, um indicador expressivo do estresse climático a que um grande número de pequenos agricultores estão sujeitos no semi-árido brasileiro. Adicionalmente, a produção de milho na região é negativamente correlacionada com tranferências de recursos da União dedicadas à redução do impacto das secas. Estes recursos têm sido sujeitos à morosidade da burocracia para liberação de fundos assistenciais, corrupção e ineficiências econômicas em geral. A observação e previsão da cultura do milho pode ser de grande valor na confecção de políticas públicas para o combate aos efeitos da seca que sejam mais efficientes, ágeis e transparentes. (Classificação JEL: I38, O13, Q11)
Palavras-chave: *previsão do clima, políticas emergenciais, agricultura não irrigada, semi-árido*

Área 5 da ANPEC: Economia Regional e Economia Agrícola

1. INTRODUCTION

The scientific progress on the understanding of global climate phenomena of the 1980s enabled scientists to start exploring the potential to forecast seasonal climate variability in several regions of the world. Climate forecasts differ from weather forecasts in that weather forecasts are limited to one to two weeks, whether climate forecasts focus on the prediction of the density function of future climate conditions, three to six months ahead. The very nature of climate forecasting suggests its potential benefits for decision makers, whose decisions map into outcomes that are conditional on future climate. The prospect that climate forecasts can be a valuable piece of information to society spawned the recent creation of a number of national and international institutions dedicated to linking climate science to socially relevant applications (Mjelde et al., 1998), and the interest of local meteorological offices in disseminating climate information to end users. Reports of efforts in closing the gap between scientific climate knowledge and applications already exist, but progress seems to be slow, with the existing experiences showing limited success and some instances of clear failure.[1]

But how important are climate oscillations to the economy in general? Some scholars argue that the importance of climate goes far beyond agricultural markets, with significant implications to the world and national economies, especially for those countries in the developing world. For example, Brunner (2002) establishes a significant connection between climate variability and world primary commodity prices (except for oil), world consumer price inflation and world economic activity. Datt and Hoogeveen (2003) estimate that the impact of the Asian financial crisis of the late 1990s on the Philippine economy was dwarfed by the impact of the 1997/98 El Niño with respect to the incidence, depth and severity of poverty in the country as well as the increase of national income inequality. In the field of economic development, Gallup and Sachs (2000) suggest that climate forces are a key variable in explaining the development gap in the tropics.

If climate forecasts are indeed valuable, as some studies suggest, it is natural to expect that the social sciences should play a fundamental role in building a bridge between the scientific knowledge on climate variability and social applications. However, progress in that direction has been modest and the contribution of economics has been disappointingly coy. We make an important distinction between the explosive number of studies on the economics of long term climate change, and the small literature on the economics of seasonal to interannual climate variability. Ironically, the profession pays a great deal of attention to the economic outcomes of uncertain future climate change and associated policies, but there is only a small literature on the economic consequences of observed climate variability and associated policies.

Perhaps because of the undeniable role that institutions play in shaping economic activity and the false and obsolete premise that the physical world exercises a deterministic control over economic development, economic studies of the importance of existing climatic conditions are scarce. Existing contributions on the economics of climate variability can be divided into two broad groups. The first group focuses on the

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[1] See for example Mjelde et al. (1998), Podbury et al. (1998), Lemos et al. (2002) and Orlove and Tosteson (1999).

impact of climate on the economy, whereas the second specializes to the theory and estimation of the economic value of climate forecasts. [2] These studies, however, provide little guidance to policy makers in different parts of the globe on how to use climate forecasts in the design of policies to mitigate the negative impacts of climate variability.

In this paper, we take small steps towards the approximation between economic analysis and the science of climate variability. More specifically we investigate the foundations for the use of climate forecasts in the formulation of policies to alleviate the impact of climatic shocks. Despite our focus on public policies, the rationale of our analysis is applicable to any decision making processes that involve attention to future climate realizations.[3]

To pursue our goal, we estimate the effect of climate determinants on future rainfed corn production in a region of the Brazilian semi-arid. We implement our analysis in two steps. First, we estimate the relationship between current climate forces and the rainfed corn market. This step identifies with those studies that investigate the connection between climate and the economy and is relevant in establishing the validity of our analysis. Next, we investigate the forecasting potential of future economic outcomes conditional on information on current climate determinants. By doing so, we hope to provide subsidies to the design and implementation of more efficient, transparent and expeditious public policies to combat the effects of catastrophic climatic events.

This paper is organized in four sections besides the introduction. Section 2 briefly describes the Brazilian semi-arid and the connection between global climate forces and local impacts. Section 3 presents a preliminary graphical analysis of the data, whereas Section 4 contains the results of a simple econometric model for the link between local climate and its economic impacts. Section 5 concludes.

2. THE BRAZILIAN SEMI-ARID

The Brazilian semi-arid is located mainly in the Northeast and a small portion of the Southeast regions of the country. It extends for over 900 thousand Km^2, with a population of 19 million inhabitants, representing 11.4% of the Brazilian total population (Brazilian Institute of Geography and Statistics, IBGE, 200 Census). This part of the country is subject to recurrent droughts and has challenged the ability of the local and national governments in the design of effective and efficient policies to mitigate the effects of local climatic shocks. Since the "very strong" El Niño (Quinn, 1992, p. 122) of 1877-1879, when over 150,000 people died[4], the national government has sought actions and policies to prevent and mitigate the effects of droughts in the region, including the recent creation of a limited drought insurance plan for small rainfed farmers by the federal government (PRONAF, 2003).

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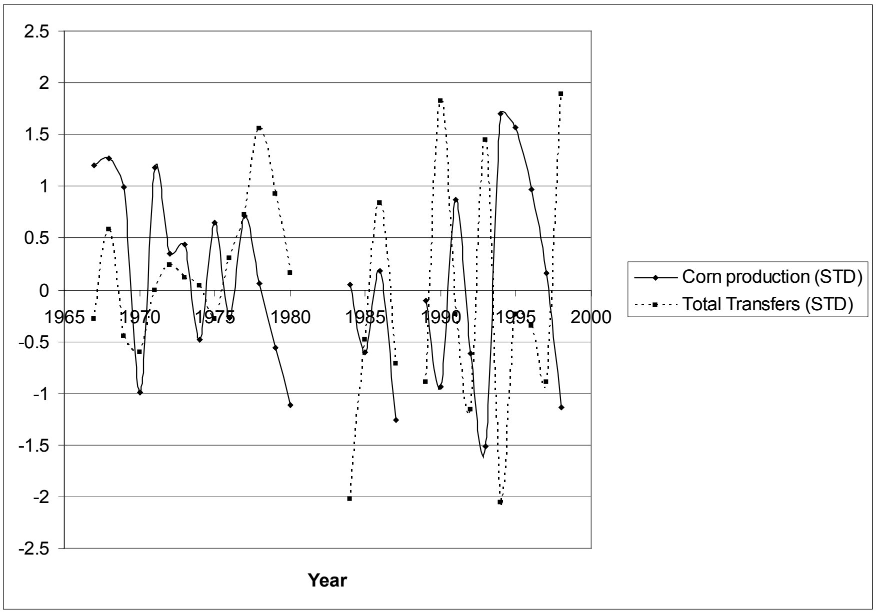
[2] Recent examples of studies linking climate and the economy are Brunt (2004), Datt and Hoogeveen (2003), Brunner (2002), and Gallup and Sachs (2000). For studies on the theory and estimation of the value of climate forecasts, see for example, Summer et al. (1998), Costello et al. (1998), and Adams et al. (1995).

[3] An alternative mechanism with hedging potential against the risk of climatic shocks is the market for catastrophe bonds – see for example, Miranda and Vedenov (2001), Mahul (2001) and Chichilnisky and Heal (1998). However, catastrophe bonds aren't widely used, especially in developing countries, where the population tends to be more vulnerable to natural disasters.

[4] Estimates of the number of deaths resulting from the 1877-1879 drought range from 150,000 to the often publicized number of 500.000 (Carvalho, 1988).

Most policies to combat the socio-economic consequences of droughts in the Brazilian semi-arid have been funded by transfers from the federal government to affected states and municipalities (Magalhães, 1991). These transfers, however, have been subject to inefficiencies stemming from the lethargy of the bureaucracy of several layers of government, the lack of planning of expenditures common to situations of crises, and corruption. The assumption underlying this study is that the understanding of the connection between climate and its impacts, and the forecasting potential of these impacts conditional on current climate information, can aid policy makers in the design of more efficient, expeditious and transparent drought-related policies.



Source: Planning Secretariat, Ceará (SEPLAN/CE)

Figure 1: Corn Production and Total Transfers (standardized and detrended values)

We pursue our goals by specializing to rainfed corn production in the State of Ceará. This choice is not accidental. Around 95% of the State territory (146,817 Km^2) is classified as semi-arid, and although agriculture responded to only 5.58% of the State GDP in 2000, it employed 40% of its labor force, mostly small rainfed farmers highly vulnerable to climatic shocks (World Bank, 2000). Among the crops that rainfed farmers produce, corn is likely to be the most important to their consumption and income.[5] Furthermore, rainfed corn production serves as a barometer for the economic impact of droughts in the region as well as for public spending on the alleviation of such impact. Figure 1 shows total transfers from the federal government to the State of Ceará and local corn production[6]. Federal government transfers have been negatively correlated with corn production in the State. This correlation pattern is weaker for the years following the two

[5] Personal communication with local experts.

[6] Total transfers do not discriminate the portion of federal resources that are actually devoted to drought relief but we are constrained to using the aggregate indicator due to limited data availability. Thus, in Figure 2, we implicitly assume that total and drought-related transfers are positively related.

oil crises that tightened the federal government budget (early 1970s and early 1980s) as well as during the crisis of the 1980s generated by the payment of the services of the Brazilian foreign debt. Subsequently, during the last 10 years of the sample, the correlation between corn production and Federal government transfers was -0.7.

To investigate the link between climate and corn production in Ceará, we turn to perhaps the most important driving force of local climate, namely the sea surface temperatures (SSTs) of specific regions of the tropical Pacific and Atlantic oceans (Moura and Sukla, 1981 and Hastenrath, 1984). As SSTs in the central and eastern portions of the tropical Pacific Ocean increase above their climatologic averages, this region of the globe experiences low atmospheric pressure and increased rainfall. These changes tend to be associated with increased atmospheric pressure and decreased rainfall in the Brazilian Northeast (Ropelewski and Halpert, 1987 and 1989). This is the so-called El Niño effect, whereas the opposite phenomenon, with typically symmetrical consequences for the Brazilian Northeast, is known as the La Niña effect[7].

Another determinant of local climate is the position of the Inter Tropical Convergence Zone (ITCZ) – an east to west wind current around the globe that is associated with low pressure and rainfall. The precise position of the ITCZ is strongly influenced by the difference between average southern and northern Atlantic Ocean SSTs, a gradient termed in the scientific literature as the "Atlantic Dipole". In general, a strong Atlantic Dipole – defined here as average southern Atlantic SSTs minus average northern Atlantic SSTs – causes the ITCZ to migrate south and towards the Brazilian Northeast (Moura and Shukla, 1981). Thus, the Atlantic Ocean can either reinforce or compensate for the influence of the Pacific Ocean over the climate of the Brazilian semi-arid.

We proceed with the investigation of the statistical relationship between rainfall, relevant SSTs and the corn market in Ceará. The following section is dedicated to a preliminary graphical analysis of the phenomena to be investigated.

3. PRELIMINARY GRAPHICAL ANALYSIS

In this section we present a preliminary discussion of the relationship between precipitation, production, and price of rainfed corn in Ceará, followed by the relationship between SSTs, production and prices for this crop. The findings from this section contribute to the econometric analysis in Section 4. Prices and quantities of corn are aggregated at the State level including output from humid regions. However, most of the production of corn takes place in the semi-arid. A similar problem happens with respect to precipitation data for the State. These are disaggregated by geographic regions, which do not necessarily coincide with the regions where only rainfed corn is produced. To tackle this problem, we use indices of precipitation for the *Sertão Central* geographic region, a semi-arid part of the State where rainfed agriculture prevails. Figure 2 shows the relationship between production and prices of corn and precipitation in *Sertão Central*. The lines in the graphs correspond to the estimated smoothing spline functional relationships between the variables of interest.

[7] In general, the SST oscillations in the tropical Pacific Ocean is known as the El Niño Southern Oscillation or ENSO.

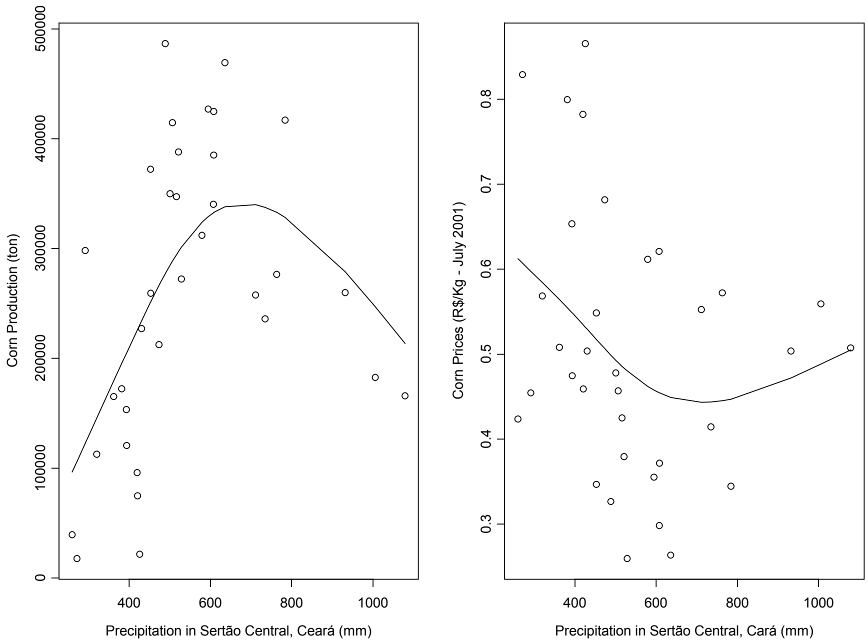


Figure 2: Precipitation, Quantities and Prices of Corn in Ceará (1964-1997)

The estimated functional forms suggest that as precipitation increases, the quantity produced of corn increases, reaches a peak and eventually starts to decrease. The left portion of the production graph characterizes crop losses during dryer years, whereas the right portion indicates crop losses due to excessive rains causing siltation, excessive soil humidity and floods. The graph for precipitation and prices indicates the opposite relationship. In an open economy where local prices fully responded to external forces in a larger market, prices would be uncorrelated with local climate[8]. However, the graphs for prices suggest otherwise, i.e. crop losses due to climate variations imply higher prices, whereas abundant crops as a response to ideal levels of rainfall are associated with relatively lower prices.

The graphs in Figure 2 added to the fact that local corn production is carried out by small price taking farmers contribute to the argument that a competitive partial equilibrium model has some explanatory power over the determination of prices and quantities of corn in the State. Casual observation of Figure 2, however, suggests that the relationship between climate and quantities produced is stronger than the relationship between climate and prices. This statement is corroborated by a more detailed econometric analysis. One likely explanation for weaker correlations between prices and local climate is that, although local climate does play a role in determining locally observed prices, large external markets may also influence these prices to some extent. Alternatively, the elasticities of supply and demand for corn can explain the pattern in

[8] This would not be the case if the local climate were correlated with the climate of other producing regions of the country and the world, which doesn't seem to be the case.

Figure 2. However, the detailed investigation of this phenomenon is beyond the scope of this paper. Our main interest is the fact that the data suggest endogeneity in the formation of equilibrium prices and quantity in the State, which justifies the simultaneous equation model from Section 4.

The objective of this study is to establish the link between rainfed agricultural markets and climate and explore the forecast potential for quantities and prices of rainfed corn based on climate predictors. One of the major forces affecting climate in Ceará are the Pacific and Atlantic Oceans SSTs. Therefore, it is interesting to explore the statistical relationships between seasonal averages of SSTs and the quantities and prices of the selected crop. First, we look at the simple correlations between average SSTs for the rainy season in the State (February through May[9]) and quantities and prices of corn, followed by simple correlations between lagged SSTs (average from October through December of the preceding year) and quantities and prices of corn. The reason for this approach is that we want to investigate the potential to forecast rainfed agriculture in Ceará given information on SSTs. Next, we plot quantities and prices of corn against selected average SSTs for February through May in order to explore likely functional forms involving climate and rainfed agriculture and lay the ground for later econometric analysis.

When calculating the correlations between SSTs and rainfed agriculture indicators, we expect the tropical Pacific Ocean SSTs to be negatively correlated with production and positively correlated with prices (El Niño effect); the North Atlantic SSTs are expected to be negatively correlated with production and positively correlated with prices, whereas the opposite is expected with respect to the South Atlantic SSTs (Atlantic Dipole effect). We plot graphs with the correlation patterns for both concurrent and lagged SSTs.

3.1 Trends in the Local Corn Market

Before proceeding, however, we need to remove the effect of a myriad of forces that affect prices and quantities, so that we can isolate the effect of climate on these variables. These forces include institutional and technological changes and trends that predominate in different periods of our data sample. For example, *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), a Brazilian public research agency devoted to agriculture, developed new hybrid corn types in 1987 that improved the productivity of that crop in the country (Pray, 2001). That same year, the government of Ceará introduced a seed distribution plan ("*Hora de Plantar*") that makes use of climate and soil information to decide on the timing of distribution of hybrid corn seeds to small rainfed farmers (Santana et al., 1999). These measures have progressively improved the efficiency as well as the productivity of corn producers in Brazil and Ceará. Other institutions also affect the prevailing quantities and prices of corn in the state and the country. For example, barriers to the importation of transgenic corn in Brazil affect internal corn prices. The international market for corn also influences prevailing prices. For example, King (2001) reviews the major worldwide institutional trends that affected the international corn market in the past several decades: the Asian financial crises of the

[9] Rainfall in the period between June and December is negligible, causing rainfed agriculture to concentrate in the first semester of the calendar year.

late 1990s depressed the global demand for corn; U.S., Chinese, and Argentine policies significantly affected the corn market since the 1970s; and differentiated treatment of the international commercialization of corn and soybeans (a substitute for corn) during the GATT and WTO negotiations have affected those markets in different time periods.

The national, state, and international institutional and technological trends that prevailed in the period covered in out data set (1952 through 2000) are potentially non linear, and the data generating process is likely to be non-stationary in general. To tackle the problem of removing local trends and focusing on the effect of climate we resort to non-parametric supersmoothing regression. This method has the property of automatically choosing the optimal span of the data in the neighborhood of the predictor variable at each data point. That is, for each data point (x, y) the technique breaks the set of predictor values (x) into possibly overlapping intervals and derives a curve that best describes the local relationship between x and y and is smooth over the entire domain. The optimal span selection is done through local cross-validation. This property of a local regression model is convenient in that it allows for the interplay of different forces influencing the variable of interest at different time periods. This way, problems of changing trends with possibly different error distributions at different periods as described for the case of corn can be accounted for (Friedman, 1984).

After removing the local trends in our data set, we calculate the residuals from the non-parametric local regression of quantity and price on time and compare them to climate variables. As the plots of the autocorrelation functions in Figure 3 show, these residuals do not indicate a significant pattern of autocorrelation, a feature that simplifies our subsequent econometric analysis.

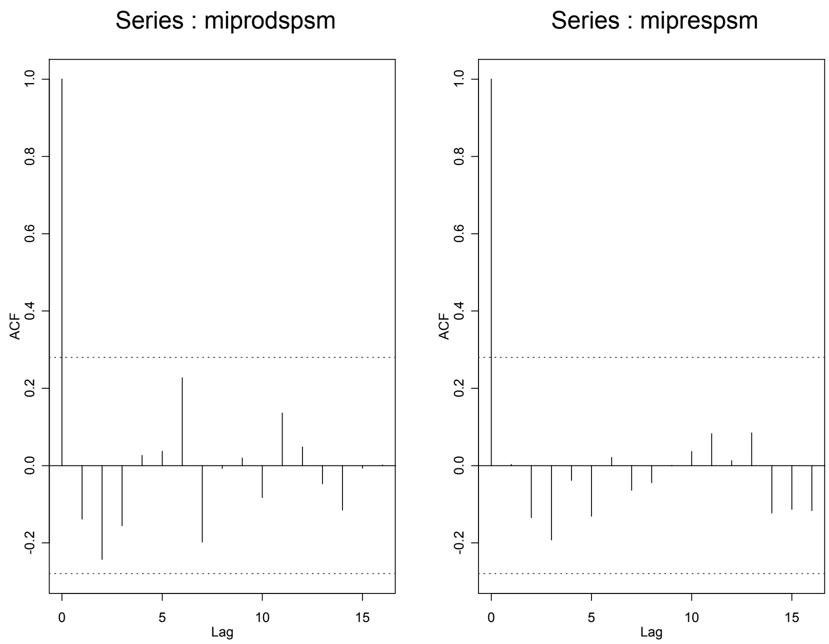


Figure 3: Autocorrelation functions for the supersmooth residuals for corn and bean production and prices.

3.2 Climate Determinants and the Ceará Corn Market

We can now proceed with the investigation of the correlation patterns between the de-trended variables of interest and SSTs. Figure 4 shows the linear correlation[10][11] between the Pacific and Atlantic Oceans SST anomalies (standardized difference between observations and climatologic averages – SSTA) during the rainy season in Ceará and state corn production. If we concentrate on the inter-tropical band of the oceans, we notice the expected correlation patterns. On one hand, the warming up of the tropical Pacific SSTs contributes to reduced rainfall and crop losses in Ceará (El Niño effect). On the other hand, warming up of the South Atlantic SSTs tends to promote the opposite effect, whereas colder than average SSTs in the North Atlantic can reinforce the El Niño effect originated in the tropical Pacific. More precisely, the correlation pattern in the Atlantic suggests the role of the Atlantic Dipole in determining local precipitation and corn production.

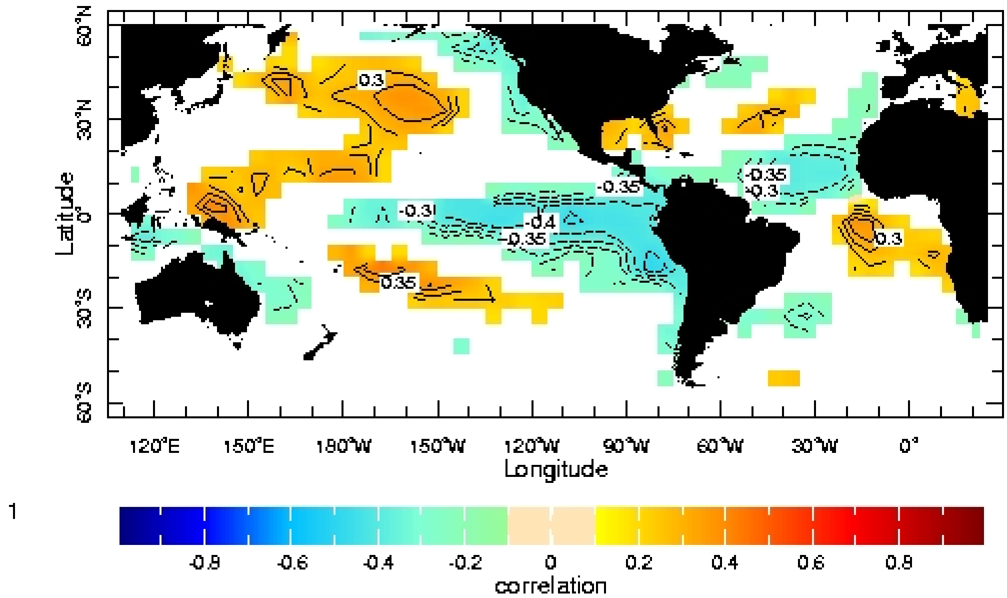


Figure 4: Linear correlation between corn production and SSTAs averaged over the Feb—May period.

[10] Critical values for statistical significance of the correlations plotted in Figures 4 through 7 at the 1%, 2.5%, 5% and 10% significance levels are 0.375, 0.307, 0.252 and 0.193 respectively, with 47 degrees of freedom. Correlations below the 10% significance level are "masked out" and appear as white areas in the oceans.

[11] Rank correlation graphs have the same pattern and similar magnitudes when compared to the liner correlation graphs. This fact suggests that extreme values are not spuriously influencing the results, as well as the absence of strong non-linearities in the relationship between quantity and price of corn with SSTs.

Figure 5 shows the correlations between SSTAs and corn prices. The observed pattern is opposed to that of Figure 4, as a competitive partial equilibrium model would predict. We can also notice that the climatic signal is weaker for prices than for quantities of corn produced in the State. Nevertheless, several regions of both oceans have correlation coefficients that are significant at the 2.5%, 5% and 10% significance levels, and a few have correlation coefficients that are significant at the 1% level. As we mentioned before, the weaker relationship between climate and prices is likely due to some influence of corn markets in other regions in determining local prices.

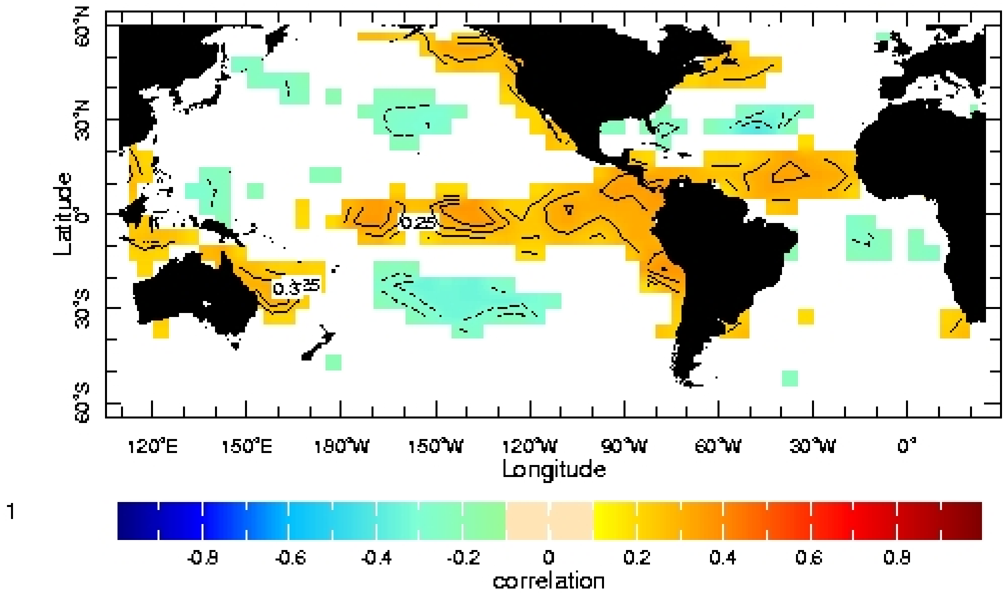


Figure 5: Linear correlation between corn prices and SSTAs averaged over the Feb—May period.

Figures 4 and 5 help us to establish the link between SSTs during the rainy season and the market for corn in Ceará. Next, we investigate whether the climate signal can be observed before the rainy season. This is relevant as we pursue crop forecasts based on lagged climate signals. The scientific understanding of climate patterns and their determinants has developed substantially in recent years and one of the main variables that contain signals of future climate is SSTs, especially in the Pacific Ocean. Along these lines, Figures 6 and 7 show the linear correlation between average SSTAs for October through December[12] with the quantities and prices of corn during the following year. Forecasting the effect of a drought in the beginning of the calendar year, several months before crop harvesting and commercialization[13], can contribute to the preparation

[12] The use of average values for the last trimester of the year instead of the most recent information (December only) avoids random oscillations of the SSTs which do not significantly affect future climate.

[13] According to the Planning Secretariat of Ceará about 80% of the State corn is harvested and commercialized in July and August.

of drought contingency plans and the improvement in the efficiency of drought relief expenditures.

Figures 6 and 7 show the El Niño effect in the correlations between lagged SSTAs and quantities produced and prices of corn. As we could expect, the correlation pattern for the tropical Pacific lagged SSTAs with production and prices is not as strong as in the case of concurrent SSTAs. Nevertheless, the sign of the correlations is as expected based on the global physics involving SSTs and precipitation in the Brazilian Northeast. This is the case because the configuration of the Pacific Ocean SSTs takes place relatively slowly, already indicating by the end of the calendar year the predominant pattern for the first semester of the following year. This is due to the peculiar characteristics of the Pacific Ocean Basin, which is deeper and much larger than that of the Atlantic Ocean. The configuration of the Atlantic Ocean SSTs for the rainy season becomes clear only later on, during the first semester of the calendar year. Hence, the correlations between the Atlantic lagged SSTAs and quantities produced and prices shown in Figures 6 and 7 differ more markedly from those in Figures 4 and 5.

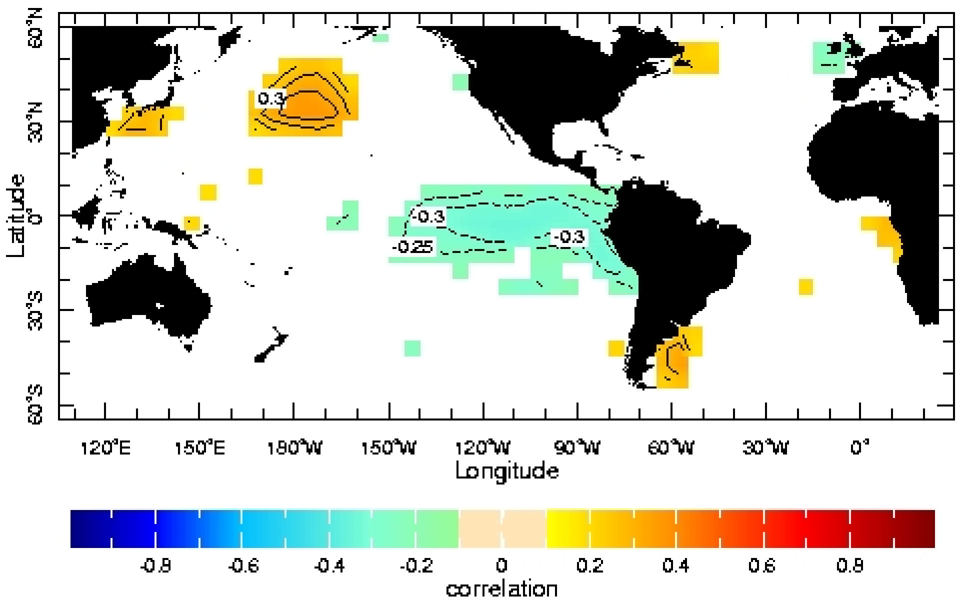


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Figure 6: Linear correlation between corn production and SSTAs averaged over the Oct—Dec period for the year prior to the crop.

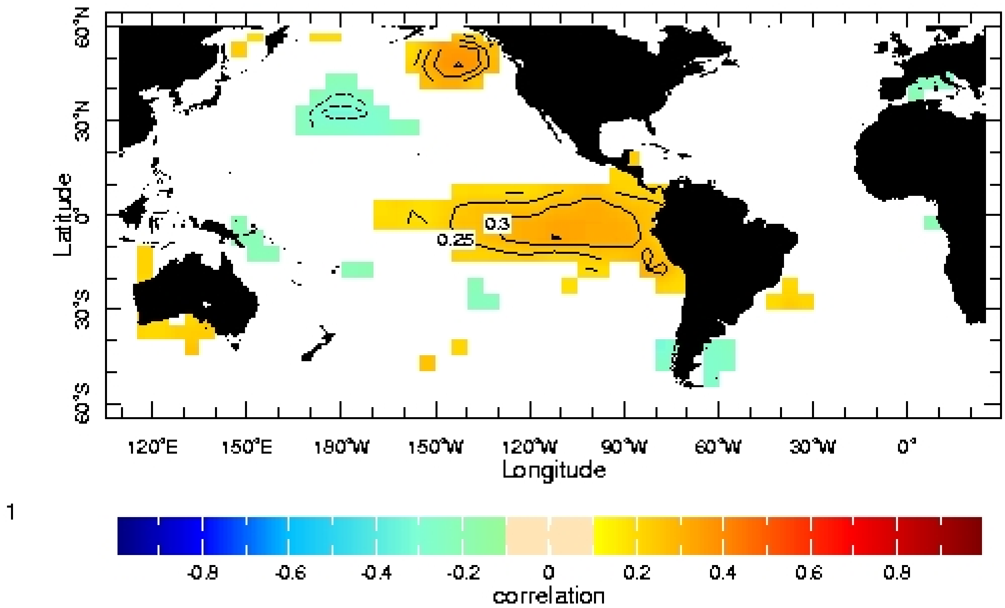

Figure 7: Linear correlation between corn prices and SSTAs averaged over the Oct—Dec period for the year prior to the crop.

Finally, Figure 8 tries to capture the likely functional forms describing the relationships between SST anomalies, quantities produced and prices through non-parametric smoothing spline regressions. In constructing these figures, we start with the existing climate literature and select the SSTs from specific regions of the tropical Pacific and Atlantic Oceans. SST anomalies from the Nino 3 region of the tropical Pacific capture the El Niño effect, and the Atlantic Dipole, defined as the anomalies of the South Atlantic SSTAs minus the North Atlantic SSTAs, characterize the effect of the Atlantic Ocean during the rainy season in Ceará[14]. The tropical Pacific Ocean seems to have a negative impact on the production of corn. This general pattern holds true even if we eliminate the large SST outliers from the sample. On the other hand, the Atlantic Dipole seems to influence quantities and prices in a non-monotonic fashion. There is a range of the Atlantic Dipole SST anomalies that seems to contribute to the highest levels of production and lowest levels of prices for corn. Departures from this range in either direction contribute to crop losses and relative price increases.

[14] For example, Souza-Filho and Lall (2002) use these predictors in their statistical forecast of reservoir streamflow in Ceará.

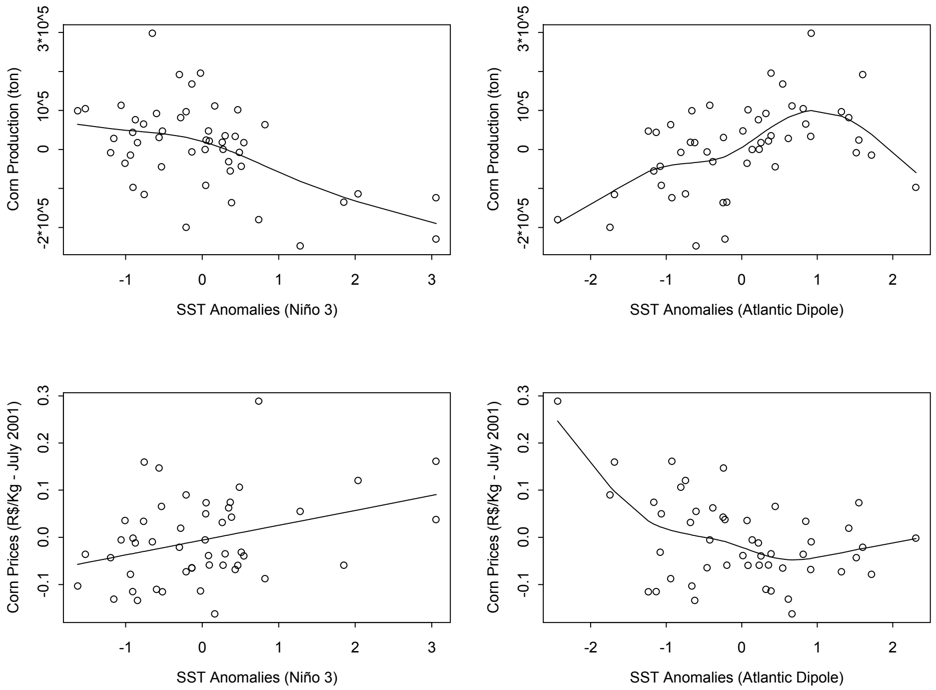

Figure 8: Non-parametric estimation of the relationship between corn production and prices in Ceará and Niño 3 and Atlantic Dipole SST anomalies.

Figure 8 suggests an interesting interpretation of the effect of the oceans on rainfed agriculture in Ceará. Crop losses and price increases due to excessive rains are most likely the result of large positive Atlantic Dipole anomalies. Ropelewski and Halpert (1987 and 1989) show that colder than average SSTs in the tropical Pacific Ocean (La Niña) tend to result in increased precipitation over much of the Brazilian Northeast, but our results suggest that, holding everything else constant, this effect doesn't seem to be strong enough to cause crop losses in Ceará.

The preceding results help us to establish benchmark relationships for our analysis. In particular, the preceding graphs implicitly assume single-variable single-equation models for the relationships of interest. In the next section, we relax this assumption and estimate such relationships using a simultaneous equation model to better quantify and forecast the effect of the Oceans on the corn market in Ceará.

4. RESULTS

In this section we estimate the impact of climatic forces on current and future equilibrium outcomes in the corn market. Our objective is not to design policies to mitigate the effect of droughts in the Brazilian semi-arid, but rather to gather climatic information to be used in the design and implementation of such policies. Thus, we estimate a simple reduced form model of the simultaneous determination of corn prices and quantity as a function of climate determinants in Ceará. We use the de-trended data (residuals from the supersmoothing regression from section 3) on corn quantities and prices to estimate the following system of equations:

$$q = \pi_{10} + \pi_{11} Z + \pi_{12} X + \mu_1$$
$$p = \pi_{20} + \pi_{21} Z + \pi_{22} X + \mu_2$$

The variables q and p represent the equilibrium quantities and prices of corn, X and Z are the climatic and economic variables of the model, π_{ij} stand for the model coefficients, and μ_1 and μ_2 are the stochastic error terms. This model is estimated with a FGLS regression.

4.1. Data

The data for production of corn (*miprod*) refer to the annual production of corn in the State of Ceará, measured in tons and covering the period from 1952 to 2000. Corn prices (*mipre*) are given in R$ per Kg at the July 2001 price level, according to the price index IGP-DI from Fundação Getúlio Vargas. Data for SSTs (*fmamnn3, fmamdip, ondnn3l, onddpl, fmamst, ondsatll, fmamntl, ondnatll*) were calculated from the Extended Kaplan dataset for sea surface temperature anomalies for selected areas of the Pacific and Atlantic Oceans. Finally, data for consumers' income were not directly available. Since most of corn production is consumed in the rural areas, we used total revenues with traditional agricultural outputs with 0 to 5-year lags (*incb* through *incb5*) as proxies for our income variable. The source of the data for production and prices used was the Anuário Estatístico do Brasil, from Instituto Brasileiro de Geografia e Estatística (IBGE), and data manipulated by Fundação de Pesquisa e Informação do Ceará (IPLANCE).

4.2. Climate, Production and Price of Corn

Several econometric models were estimated to assess the impact of climate on equilibrium quantities and prices of corn in Ceará. They involve the data for key regions of the Pacific Ocean (Nino 1, Nino 2, Nino 3, Nino 3.4 and Nino 4) and the Atlantic Ocean (South Atlantic, North Atlantic and Atlantic Dipole), income, prices and quantities of corn. The model presented below was selected based on the statistical significance of the estimated individual coefficients and the selected set of variables (χ^2 statistic), as well as the portion of the variance of price and quantity explained by the exogenous variables (R^2). The model results presented below uses the sum of the output value for corn, beans, cassava and cattle with a three-year lag (*incb3*) as our proxy for income. Other proxies were tested, but were dominated by *incb3* in terms of statistical significance of their coefficients. The effect of the Pacific Ocean is captured by the SST anomalies for the Nino 3 region[15] averaged for the February through May period (*fmamnn3*), whereas the Atlantic Ocean is captured by Atlantic Dipole (*fmamdip*) defined as South Atlantic SST anomalies minus North Atlantic SST anomalies averaged for the same period. Other

[15] Other regions of the Pacific were tested, but produced inferior results.

formulations focusing on the individual contributions of the North and South Atlantic SSTAs were tested, but were outperformed by the inclusion of the gradient between these two variables, namely the Atlantic Dipole. Among the various formulations estimated here, the best results were obtained with a quadratic relationship involving the Atlantic Dipole (*dipfmam2*). The results appear in Table 1.

Table 1: Simultaneous Equation Model Estimates for Concurrent SSTs and Income.

Varible	Coefficient
miprod	
incb3	0.0026374 (0.0204686)
fmamnn3	-51057.29 * (12600.17)
fmamdip	36436.35 * (12203.06)
fmamdip2	-27397.43 * (9056.111)
constant	29724.11 (28092.24)
R^2	0.46
χ^2	42.55 *
mipre	
incb3	-2.18e-08 (1.77e-08)
fmamnn3	0.0311514 * (0.0109123)
fmamdip	-0.0278697 * (0.0105684)
fmamdip2	0.0307785 * (0.007843)
Constant	-0.0091729 (0.0243292)
R^2	0.40
χ^2	33.59 *

* Statistically significant at the 1% significance level.
Standard deviations in parenthesis.

The estimated coefficients of all explanatory climate variables are statistically significant at the 1% significance level, and have the expected signs. The estimated coefficients of our income proxy are not statistically significant in either equation. The set of variables used in the regression accounts for 46% of the variance of production and 40% of the variance of prices of corn. The estimated χ^2 statistic allows us to reject the hypothesis that the coefficients of the selected set of explanatory variables are all equal to zero.

In general the estimation of our simple model lends strong support to a sizable link between global climate forces -- represented by the Pacific and Atlantic Oceans

SSTs – and the local market for rainfed corn. More specifically, our model estimates a linear relationship between the tropical Pacific SSTs and corn production and prices in Ceará[16]. Everything else constant, a one standard deviation (approximately 0.6^0 C) increase in the average sea surface temperature of the Nino 3 region over the rainy season contributes to a decrease of about 51,000 tons of corn in the State. This corresponds to crop losses of around 20% of the historical average production in our sample. The same increase in Nino 3 SSTs causes a R$ 0.03 increase in prices (at the price level of July of 2001) – a 6% increase with respect to the historical average.[17] On the other hand, the effect of the Atlantic Dipole is ambiguous, contributing to the variation of prices and quantities of corn in a quadratic form. For an important range of the Atlantic Dipole SSTs, increases in SSTs contribute to increased production and lower prices. However, a strong Atlantic Dipole favorable to precipitation in Ceará tends to cause crop losses and higher prices in the State. This result is consistent with the smoothing spline curves estimated in Section 3.

In summary, our results suggest that we can make inferences on the variation of the mean quantities and prices of corn conditional on the observation of the Pacific and Atlantic Ocean SSTs. More precisely, we took initial steps to establish the quantitative connection between climate determinants and the rainfed corn market in Ceará. This was the first step of our analysis.

Once we estimated the sign and magnitude of the effect of the SSTs on production and prices of corn, the next question we pose is whether we can predict future variations in the price and quantities of corn conditional on currently observed SSTs. Given the relationship between rainfed corn production and government expenditures on drought relief, such a forecast could contribute to more efficient and expeditious public policies to minimize the effect of droughts in Ceará. We turn to this question next.

4.3 Forecasting Market Prices and Quantities of Corn

We study the future performance of the market for corn in Ceará by investigating the forecast potential of quantities and prices based on Pacific and Atlantic Ocean SSTs averaged over the October—December trimester of the calendar year prior to the crop season. As suggested by Figures 6 and 7, the signal from the Pacific Ocean seems to be more evident than that of the regions of the Atlantic Ocean typically used in the literature.

Several models for forecasting the impact of climate on agriculture were explored. We adopt a procedure similar to that from Section 4.2, except that lagged SSTs were used. As we should expect from the comparison of Figures 4 and 5 with Figures 6 and 7, the results for the forecast model were not as significant as those with concurrent SSTs.

For purposes of comparison, Table 2 shows the estimation results of a model directly comparable to that of Section 4.2. The signs of the estimated coefficients for SSTs are consistent with those of the analogous coefficients from Table 1. This provides indication that the climate signature on the local corn market can be observed several months before the harvest and commercialization of the grain. More specifically, the contribution of the Niño 3 SSTs to future price and quantity movements seems to be pretty clear already at the end of the calendar year. The quadratic term of the Atlantic

[16] Other polynomial functions were tested for Niño 3, but did not produce statistically significant results.
[17] The average sea surface temperature for the Niño 3 region is 27^0 C during in the Feb—May period.

Dipole, on the other hand, is statistically significant at the 3% level when explaining production, but not prices.

Table 2: Simultaneous Equation Model Estimates for Lagged SSTs and Income.

Variable	Coefficient
miprod	
incb3	-0.0116855 (0.0250024)
ondnn3l	-52046.22 * (14637.87)
onddl	12296.82 (14486.78)
onddl2	-29298 ** (12960.66)
constant	49249.78 (37055.16)
R^2	0.24
χ^2	15.58 *
mipre	
incb3	-1.24e-08 (2.20e-08)
ondnn3l	0.0342135 * (0.0128635)
onddl	-0.0083521 (0.0127307)
onddl2	0.0088742 (0.0113896)
constant	0.0007265 (0.0325633)
R^2	0.13
χ^2	7.59

* Statistically significant at the 1% significance level.
** Statistically Significant at the 3% significance level.
Standard deviations in parenthesis.

Whereas the results for prediction of the corn market conditional on climate information are obviously not as strong as the results on the linkages between contemporaneous climate and market performance, they still endorse the inclusion of climate information in the policy maker's toolbox. In the case of Ceará, our analysis suggests that statistically significant information on the performance of rainfed agriculture is already present in the end of the calendar year, five months prior to the harvesting and commercialization of our indicator crop.

More than understanding the behavior of future prices of corn, we are concerned with the quantities produced. This is because a large portion of total production is dedicated to subsistence consumption, which makes production data a good indicator of the economic stress that small farmers are subject to in dryer years. Thus, the results in Table 2 lend support to the hypothesis that observation of the behavior of the oceans signalizes future effects of droughts in the region. Although the forecasting results are obviously not as strong as those from contemporaneous climate (Table 1), the impacts of the Pacific Ocean SSTs and the Atlantic Dipole are surprisingly clear several months before the harvesting and commercialization of corn in Ceará. For example, a one standard deviation (approximately 1^0 C) increase in the average SSTs for the Niño 3 region during the Oct—Dec period[18] causes an expected crop loss of 52,000 tons in the following year (compared to 85,000 tons for each additional 1^0 C of SSTs during the rainy season).

As the local governments search for more efficient policies and actions to mitigate the effects of droughts in the Brazilian Northeast, comparison of the coefficients from Tables 1 and 2 lends support to the inclusion of climate variables in the policy makers' toolbox. We hope that these results contribute the strengthening of the bridge between economic analysis, climate prediction and the design of public policies meant to alleviate the impact of climatic shocks.

5. CONCLUDING REMARKS

In this paper, we take small steps towards the approximation between economic analysis and the science of climate forecasting in the formulation of policies to alleviate the impact of climatic shocks. We do so by estimating the relationship between climate variables and corn production in Ceará, an important State in the Brazilian semi-arid. We first estimate the relationship between contemporaneous sea surface temperatures for the Pacific and Atlantic oceans and the local rainfed corn market. Next, we investigate the forecasting potential of future corn production conditional on information on current sea surface temperatures. We find strong evidence that climate determinants are important in determining current and future corn production.

The importance of the Pacific Ocean miles away from the Brazilian semi-arid is remarkable. A 1^0 C increase in the sea surface temperatures of the tropical Pacific during the rainy season in Ceará causes an expected loss of 34% in the local corn production. The same increase six months prior to the harvesting and commercialization of corn in the State causes an expected loss of 20% of that crop. Since rainfed corn is a key indicator of the climatic stress to which that a large number of small farmers are subject in the Brazilian semi-arid, observation and forecasting of this crop can be of great value in the design of more efficient, expeditious and transparent policies to mitigate the effect of droughts in the region.

The applicability of our analysis goes beyond the Brazilian semi-arid, droughts and agricultural production. A large body of the earth sciences literature is dedicated to the understanding and predictability of climatic variability around the globe.[19] The impact of climate variability can come in several forms, including, in the case of ENSO, droughts in southeastern Africa, Australia and Southeast Asia, increased temperatures in

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[18] Average SSTs during the last trimester of the year is 25^0 C.

[19] See for example Ropelewski and Halpert (1987, 1989) for an early mapping of the impact of ENSO on precipitation and temperature in several regions of the globe.

India, Northeast and Northwest North America, and typhoons in Southeast Asia among others. These may result in thin insurance markets in the presence of correlated risks for large areas, increased energy consumption, large expenditures on the mitigation of catastrophic climatic events, and pressures on national and world prices and economic activity. To the extent that these impacts can be forecasted, defensive actions can be better planned and implemented.

Although we base our analysis on the (rather simple) statistical treatment of climatic and economic data, our results also encourage the exploration of other ways of forecasting climatic shocks and their economic impacts. The development of physical climate forecasting models may add to the spatially finer understanding of economic responses to climate variability, and further specify the basic physical forces affecting economic outcomes.

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