The Effects of Climate Changes on Brazilian Agricultural Production – A MultisectorGrowth Model Analysis

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Abstract: This paper develops a multisector growth model to examine the potential effects of climate change and Brazilian agriculture. In keeping with the current literature, the model assumes climate (here temperature and rainfall) affects agricultural output via its impact on total factor productivity (TFP). We begin by estimating an aggregate agricultural technology for Brazil, with econometric results suggesting a strong relationship exists between rainfall, temperature and agricultural TFP. We then introduce the climate effects into a dynamic multisector growth model of Brazil. Model resultssuggest climate change could have a negative impact on agriculture, but benefit manufacturing, with long run agricultural output per unit of labor being less than half of agricultural output per worker in a no climate change world.

Key words: Climate Changes, agricultural growth, multisector growth model

JEL: O10, O11, Q1

1. Introduction

In 2007, the World Economic Forum (WEF) highlighted climate change as one of the main themes of the 21stcentury, and suggested it may have undesired effects on economic growth. Results from an International Panel on Climate Change (IPCC) study predicts increasing temperatures will lead to an increase in the number, and severity, of extreme climates events like tornadoesand heavy rainfall in some regions, and droughts in others (IPCC, 2007). The IPCC study also argued the climate changes would lead to increased levels of disease transmission, and lead to a decrease in agricultural output.

Lobell, Schelenker and Costa-Roberts (2011) findthat over the years 1980 - 2008, temperature trends were higher than one standard deviation of historic variability in most countries. Tol (2009) argueschanges in weather patterns can have deleterious effectson agriculture, with low-income countries being especially vulnerable to its effects. Deschênesand Greenstone (2007) consider the effects of changes in temperature and precipitation on agricultural land rents, and conclude that climate change could lead to a slight increase in U.S. corn and soybean profit, although Fisher et al. (2012) find higher potential impacts of climate changes on US agriculture.

This paper examines the potential effect of temperature and rainfall on Brazilian agricultural production (via its impact on total factor productivity) and the effect on the sector's growth trajectory with, and without climate effects. It proceeds by first estimating the relationship between temperature and rainfall (the climate variables), and then introduces the econometric results into a dynamic, multisector model of economic growth. The model is used to estimate the potential impact of climate changes on agricultural GDP growth, and the indirect impact of these effects on the rest of the Brazilian economy.

Understanding the potential impact of climate change on the Brazilian economy is also relevant, as the agribusiness sector corresponds to approximately 25% of total Brazilian

GDP[1], and constitutes about 25% of its exports. In this sense, the potential climate change in Brazil is relevant since the country is one the most important exporter of commodities, and the shocks on its agricultural production could affect some international markets like grains, meat and energy (biofuels).[2]

Another relevant question is whether the potential impact of climate change on Brazilian agriculture can dominate the high rates of technical change that has kept the sector competitive with manufacturing and services (Spolador and Roe, 2013).[3]Gasques et al. (2011) performed a growth accounting exercise on Brazilian agricultural production, with their results suggesting the growth in Brazilian agricultural production has been driven primarily by the growth in total factor productivity (TFP): a phenomenon particularly pronounced in the last decade (see table 1).

Table 1. Contributions to rates of growth of Brazilian agricultural GDP

Period	1975-2010	1991-2010	2001-2010	2006-2010
Labor	-0.24	-0.43	-0.50	-1.00
Land	0.01	-0.07	-0.29	-0.12
Capital	0.35	0.56	0.26	0.22
Inputs	0.12	0.05	-0.53	-0.89
TFP	3.62	4.60	5.31	4.75
Agricultural GDP Growth	3.74	4.65	4.75	3.81

Moraes (2010) implemented a computable general equilibrium model to simulate the impacts of climate change on Brazilian agricultural production for eight crops: beans, corn, soybeans, cotton, rice, sugar cane, cassava and coffee. Using scenarios provided by Brazilian Agricultural Research Corporation(Embrapa), and based on the Intergovernmental Panel on Climate Change (IPCC) projections, the results suggest climate change would lead to a small reduction in economic activity, increasing food prices and lead to a movement of workers in Northeast and Mid-West Brazil to other regions. As for individual crops, scenarios with small increases in temperature, the projections suggest a reduction of land use and production for all crops, except sugar cane.

Information published by the InstitutoNacional de Meteorologia (INMET)[4] show temperatures for all Brazilian regions[5] have been trending upward since 1975 (seetable 2). These observations are consistent with the scenarios implemented by Moares (2010), and suggest a potential negative impact on the long run growth of Brazilian agriculture.

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[1] Data from CEPEA (Center For Advanced Studies on Applied Economics): www.cepea.esalq.usp.br

[2] According to OECD-FAO by 2022, the world ethanol production should to increase by almost 70% compared to the average of 2010-12, and United States and Brazil are the most important players on the ethanol markets.(Source: OECD-FAO Agricultural Outlook 2013).

[3] The basic model used in this paper does not include the agriculture's relative price index as defined and used by Spolador and Roe (2013), p. 345.

[4] There is no information of temperature and precipitation for the state of Rondonia for all period in the INMET website and for some states in some years of 1980s.

[5] Brazil has 27 states divided in 5 regions.

On average, comparing temperatures in 1975 (first year with available data on the INMET website) with those in 2012, Brazil's temperaturesin the countryhas increased about 4.24% in the period.Appendix A provides a more complete temperature and precipitation series.

Table 2. Temperature average by region for selected years (^{o}C)

Region	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2012**
North	25.66	26.29	25.77	26.14	26.60	26.38	27.09	27.20	26.84
Northeast	25.07	25.13	24.98	26.52	25.56	25.48	26.11	26.33	26.10
Southeast	22.01	22.25	21.03	23.09	22.72	22.39	22.82	22.78	22.81
Midwest	22.78	23.04	23.40	22.98	23.59	23.18	23.66	23.65	23.64
South	18.13	19.62	18.31	18.22	18.82	18.00	18.87	18.45	19.07
Country Average*	**23.58**	**24.00**	**23.43**	**24.19**	**24.28**	**24.00**	**24.62**	**24.66**	**24.58**

Source: INMET(www.inmet.gov.br) and authors

* This average was calculated from the 27 Brazilian states average annual temperature.

Between 1975 and 2012, average Brazilian rainfall levels decreased, except for the Midwestern region. Table 3 shows the average country precipitation levels decreased 16.84% over the period.

Table 3. Precipitation average by region for selected years (mm)

Region	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2012**
North	180.32	135.83	202.85	188.73	175.87	195.62	183.04	171.65	177.67
Northeast	109.90	69.05	164.11	91.07	87.17	118.04	89.84	84.68	56.13
Southeast	110.45	90.54	74.07	93.90	110.24	126.44	123.61	105.63	99.06
Midwest	114.42	125.98	117.15	106.41	118.92	127.61	127.27	117.61	118.86
South	139.81	94.76	106.47	126.93	136.51	149.29	143.48	158.68	125.35
Country Average**	**130.38**	**99.49**	**146.00**	**123.45**	**121.77**	**142.31**	**128.49**	**121.58**	**108.42**

Source: INMET(www.inmet.gov.br) and authors

** This average was calculated from the 27 Brazilian states average annual precipitation.

Preliminary econometric results suggest both temperature and rainfall have statistically significant effects on Brazilian agricultural TFP, with an increase in temperature leading to a fall in agricultural productivity, while an increase in rainfall leads to an increase in agricultural productivity. We introduce the econometric results into a dynamic, structural, (multisector, general equilibrium) growth model implemented and implement two model scenarios. The first scenario is a no-climate-change model, while the second assumes climate change occurs – here with average temperatures increasing from 24.25 to 26.1 degrees centigrade over a one hundred year period and average rainfall falling from 133 to 106 millimeters[6] over the same period. Validation exercises show the model predicts, within sample, nicely, and tracks Brazilian manufacturing and service sectors especially well. Model projections suggest Brazilian climate change will have a negative impact on agriculture, but benefit manufacturing, with long run agricultural output per unit of labor being less than half of agricultural output per capita in a no climate change world.

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[6] The average temperature and precipitation in 2004 was 24.25^{o}C and 133.46 mm, respectively. As our dataset from GTAP refers to 2004, we chose that year averages as the starting points for the climate change simulation.

2. Relation to Literature

Stern (2008) observes climate changeis a global event that will have impacts on all countries, some impacts of which are long term, and could be irreversible.Tol (2009) summarizes results of some of the first studies of climate change effects on economic growth (e.g., Nordhaus, 1991, and Hohmeyerand Gaertner, 1992), and emphasizes that the economic studies on climate change establish some assumptions on *"future emissions, the extent and pattern of warming, and other possible aspects of climate change such as sea level rise and changes in rainfall and storminess"* (p. 30-31).

Dell et al. (2012) summarizes the economics literature on climate change, noting the analysis typically examines the relationship between climate and economic activity using two approaches. The first – emphasized in the growth and development literature – uses cross-section data to examine the relationship between temperature and aggregate economic variables. The most frequent criticism of this approach is that the correlation between temperature and economic variables could be spurious, and does not necessarily capture important national characteristics such as the quality of local institutions (Acemoglu and Robinson, 2012). A second approach utilizes output from integrated assessment models (IAM) to explain links between climate and a variety of indicators, e.g., agricultural productivity, health and crime. A major criticism of IAMs is they are difficult to validate.

Several studies have investigated the potential impact of climate change on agriculture. Deschênes and Greenstone (2007) provide evidence that weather conditions can change long run production costs and trigger changes in relative prices[7]. Weber and Hauer (2003) use cross-section data to examine the relationship between Canadian agricultural land rents, and temperature and rainfall. Their results suggest Canadian agriculture would benefit climate change. On the other hand, Mendelsohn and Dinar (2003) find that the value of irrigated cropland is not sensitive to rainfall and temperature increases.Following a different approach to those described by Dell et al. (2012), Kaminski, Kan and Fleischer (2013) specify and estimate a structural model of Israeli agricultural production. They use the model to understand how climate changes might affect Israeli agricultural land use, and to identify areas in which to focus research and development efforts to mitigate against the potential impact of climate change on Israeli agriculture.

Dell et al. (2012) is one of the few studies that panel data on temperature and aggregate economic activity to investigate the potential effects of temperature on economic growth, and on agricultural productivity (and other variables not directly related to economic indicators). The authors obtain two main results. First, they find high temperatures have a significant and negative effect on the economic growth of poor countries, but no discernible effect on the growthof rich countries. Second,they provide

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[7] Weber and Hauer (2003) highlighted the climate changes impacts on agricultural production could be positive for North America and, more specifically, for Canada, where agriculture is constrained by short growing seasons and where it could benefit by warmer temperatures.

results that support the notion that temperature affects economic activity byinfluencing the level of output directly – for example, through agricultural productivity – or influences the economic capacity for growth by affecting investments or institutions that positively influence productivity or growth.

Next section we present more carefully the methodology and the hypothesis used to construct the dynamic model.

3. Methodology

Dell et al. (2012) examined the link between temperature, rainfall and productivity, by regressing gross domestic product (GDP) on labor force, a measure of labor productivityand temperature. They also examined the impact of temperature, labor productivity and population growth on GDP growth. One of their results suggests temperature has a negative relationship with per capita income, and the poorer the country, the more pronounced the temperature effect. Their results also suggest the negative temperature effect extends to manufacturing as well as agriculture.

This paper introduces the results of an extended Dell et al. (2012) type of analysis into a structural dynamic general equilibrium growth model. Our research strategy is to:

1. Construct a panel of data (for 25 Brazilian states; Rondoniaand Tocantins were excluded because the available series are not complete) taken from the following sources:
   a. Historical weather (Temperature and Precipitation) from INMET (InstitutoNacional de Meteorologia) from 1975 to 2012
   b. GDP, labor force and planted area data from the Brazilian Agricultural Census
   c. Capital stock series developed by Bragagnolo, SpoladorandBarros (2010).

2. Use the temperature, precipitation, GDP, labor force and capital stock data to estimate the following Cobb-Douglas production technology

   $$Y_{it} = e^{\beta_0+\beta_1 TEMP_{it}+\beta_2 RAIN_{it}+\beta_3 t} K_{it}^{\alpha_1} L_{it}^{\alpha_1} Z_{it}^{\alpha_1} \qquad (1)$$

   Here the *it* subscript indexes state and time, $Y_{it}$is GDP, $K_{it}$is capital stock, L_{it} is labor force and $Z_{it}$is cultivated area. The climate variables are denoted $TEMP_{it}$ and $RAIN_{it}$ and represent temperature and rainfall respectively. The parameters to estimates are the factor elasticities α_1, α_2 and α_3, the technical change parameter β_3 and the climate parameters β_1 and β_2.

3. Use the temperature coefficient to adjust TFP in a Ramsey (endogenous savings) economic growth model having multiple sectors. The Ramsey model takes as its point of departure, the three sector, dynamic general equilibrium growth model detailed in Roe, Smith and Saraçoglu. (2010).

4. Evaluate the impacts of climate changes on Brazilian agricultural, manufacturing and service sector GDP, investment and factor income over time.

4. A multisector Ramsey model with climate

4.1 The economic environment

Brazil is modeled as a small, open, and perfectly competitive economy that produces three final goods indexed by$j \in J = \{a, m, s\}$, where *a,m* and *s* represents agriculture, manufacturing and services. At each time *t*, each final good-j is traded at price$p_j(t)$. Denote the time *t* production of the agricultural, manufacturing, and service good respectively by $Y_a(t), Y_m(t)$and$Y_s(t)$. In the discussion that follows, for most variables we suppress the time notation: e.g., we represent the time *t*level of agriculture by Y_a instead of $Y_a(t)$.

The service good is a pure consumption good that is non-traded. Agricultural output is also a consumption good, but is traded in domestic and international markets at given world prices. The manufacturing good is used either as a consumption good traded in domestic and international markets, or saved, and hence, augments the capital stock. Let Z denote the agricultural sector's land endowment, assumed to remain constant over time. Labor and capital, however, are mobile across all sectors.

At each instant in time, household income derives from: (i) providing labor services L in exchange for unit wage *w*(*t*), (ii) earning interest income at rate$r^k(t)$ on capital assets *K*(*t*), and (iii) receiving rent τ(t) per unit of land *Z*. A representative agent uses income to invest in capital and purchase final consumption goods$Q_j(t)$. Here, Q_j is the consumption of good-*j*. The initial capital stock, denoted K_o, is given, and the initial endowment of labor is denoted L_o. Being traded goods, the agricultural and manufacturing good prices, denoted p_a and p_m, are exogenous and constant over time. We set these prices equal to unity. The service good price, p_s, is traded only within the country, and hence it's price is endogenous: $p_s(t)$ is equal to unity in the initial period *t*=0, but evolves over time.

We assume labor force grows at rate *n*, and hence aggregate normalized labor supply is given by $L(t) = e^{nt}L_0$. In addition to labor force growth, the economy benefits from Hick's neutral, labor augmenting change: i.e., labor becomes more efficient over time. Here, the rate of growth in labor efficiency is represented by the positive scalar *x*.

In addition to the capital, labor and land employed in producing agriculture, its' production is also influenced by rainfall and temperature, denoted *RF(t)* and *TP(t)*, respectively. Neither of these variables are assumed to influence manufacturing or service sector output. Rainfall enters agricultural production as a primary factor endowment provided by nature, and as a variable that influences TFP. Temperature enters production only via TFP effects. These influences will be discussed in more detail shortly.

Production

Let $L_j(t)$ denote the time t level of labor used by sector-j. Likewise, let $K_j(t)$ denote the time t level of the capital stock employed in producing good-j. Firms in each sector employ a constant returns to scale technology. Agricultural production is governed by the aggregate technology:

$$Y_a = F^a(A(t)L_a, K_a, Z, RF{:}\, RF, TP)$$

while manufacturing and service sector production is governed by the aggregate technologies:

$$Y_m = F^m(A(t)L_m, K_m)$$

$$Y_s = F^s(A(t)L_s, K_s)$$

The functions *A(t)* and *B(t)* represent the exogenous level of growth in labor productivity and land productivity, respectively.

Households

Let $q_j(t)=Q_j(t)/L(t)$ and define the representative household's time t consumption vector per household member as:

$$q(t) \equiv (q_a, q_m, q_s)$$

The present value of intertemporal utility is a time-separable weighted sum of all future utility flows

$$U = \int_0^\infty u(q(t)e^{-\rho t}\, dt$$

Here $\rho>0$ is the discount rate of future consumption. We assume the felicity function $u(\cdot)$ is homothetic, continuous, increasing and strictly concave in each argument, and satisfies the standard Inada conditions.

Given prices

$$p(t) \equiv (p_a, p_m, p_s)$$

the minimum expenditure capable of yielding welfare level $\tilde{u}(t)$per household member is given by

$$\in (p, \tilde{u}) = \chi(p)\tilde{u} \equiv \min\{(p.q){:}\, \tilde{u} \leq u(q)\}$$

The properties of $\underline{u}(\cdot)$ imply that the expenditure function is increasing and concave in p, increasing in$\tilde{u}$, and satisfies *Shepard's lemma.*

The flow budget constraint expresses time t savings, denoted$\dot{K}(t)$, as the difference between income and expenditures. Let τ denote rent per effective unit of land. Income is derived from labor income, wL, returns to the capital asset,$r^k K$, and returns to land rent, *τBZ*. Then the representative household's flow budget constraint in per worker terms is expressed as:

$$\dot{k}(t) = w + (r^k - \delta - n)k + \tau\tilde{B}Z - \varepsilon$$

Where, $k(t) = K(t)/L$and $\tilde{B}(t)/L$. The representative household chooses the sequence of consumption bundles $\{q(t)\}_{t\in[0,\propto)}$to maximize intertemporal utility subject to the flow budget constraint.

The maximum utility obtained from the present value Hamiltonian yields the following Euler equation:

$$\frac{\dot{\varepsilon}}{\varepsilon} = r^k - \delta - \rho$$

Normalizing the initial stock of labor at $L=1$, the initial capital stock is given by:

$$k(0) = K_0$$

And the transversality condition satisfies:

$$\lim_{t\to\infty}[\lambda(t)k(t)] = 0$$

Here the costate variable $\lambda(t)$ is the present value shadow price of income. The Euler equation and the capital equation of motion, together with the initial condition and the transversality condition, characterize the representative household's optimization problem.

In the next section, the production side of the economy is normalized in terms of effective labor units, $A(t)L(t)$, where

$$A(t) = e^{xt}$$

and$x$ is the Harrod neutral rate of technical change. The budget constraint and the Euler equation are used to characterize equilibrium and to derive the model's differential equations. Hence, the budget constraint and the Euler equation need to be specified in units of effective labor. Specifying expenditure ε in per effective labor units, we have

$$\hat{\varepsilon} = \varepsilon e^{-xt}$$

so that

$$\frac{\dot{\hat{\varepsilon}}}{\varepsilon} = \frac{\varepsilon}{\varepsilon} - x$$

Thus the Euler equation becomes:

$$\frac{\dot{\hat{\varepsilon}}}{\varepsilon} = r^k - \delta - \rho - x$$

Similarly, normalizing the budget constraint by e^{-xt} yields

$$\dot{\hat{k}} = \hat{w} + (r^k - \delta - n - x)\hat{k} + \tau\hat{B}Z - \hat{\varepsilon}$$

where $\hat{w} = we^{-xt}$, $\hat{k} = ke^{-xt}$, $\hat{B}(t) = \tilde{B}(t)e^{-xt}$.

A competitive equilibrium with centrally planned allocations

We now examine characteristics of the economy's baseline equilibrium: the case where there is no climate change. The following indirect objective functions (sector value-added and cost functions) are each expressed in per labor-efficiency-unit (LEU) terms.

We begin with defining the cost functions corresponding to the manufacturing and service sectors. Define for each sector-j, the following variables in intensive form:$l_j = L_j/L$, $\hat{k}_j = K_j/AL_j$, $\hat{Z} = BZ/AL$. These variables will be used for the remainder of the discussion.

Given manufacturing and services sectors and the properties of the corresponding technologies $F^m(\cdot)$and$F^s(\cdot)$, the manufacturing and service sector unit cost function are defined as:

$$C^j(\hat{w}, r^k) = \min\{l_j\hat{w} + r^k : l \leq f^j(l_j, \hat{k}_j)\}, j = m, s$$

These unit cost functions are concave, linearly homogeneous in input prices, and satisfies Shepard's lemma.

Given the agricultural technology, the land rental function is given by

$$\prod^a = (p_a, \hat{w}, r^k, Z : RF, TP) \equiv \max\{l_a[p_a f^a(\hat{k}_a, Z : RF, TP) - \hat{w} - r^k\hat{k}_a]\}$$

where

$$f^a(\hat{k}_a, Z : RF, TP) = F^a(1, \hat{k}_a, Z : RF, TP)$$

Given the properties ofF^a, the rental function $\prod^a$is concave in$\hat{w}$, $r^k$and p_a, and satisfies Hotelling's Lemma. Furthermore, constant returns to scale in the inputs yields a total returns function that is separable in prices and endowments, i.e.,

$$\prod^a(p_a, \hat{w}, r^k, Z : RF, TP) = \pi^a(p_a, \hat{w}, r^k : RF, TP)Z$$

If land rental markets are complete, π is the rental rate per effective unit of land among all farmers.

Decentralized equilibrium

Definition

Given initial factor endowments

$$\{K(0), L(0), Z\}$$

projected rainfall and temperature trajectories $\{RF, TP\}_{t\in[0,\infty)}$, and the endogenous sequence of values {k,ε}_{t∈,∞)}, the five-tuple sequence of positive values:

$$\varrho = \{\widehat{w}, r^k, p_s, \hat{y}_m, \hat{y}_s\}_{t\in[0,\infty)}$$

must satisfy the following intra-temporal conditions at each *t*:

1.Zero profit in manufacturing and services

$$C^j(\widehat{w}, r^k) = p_j, j = m, s$$

2.Labor market clearing

$$-\frac{\partial\pi^a(p_a, \widehat{w}, r^k : RF, TP)Z}{\partial\widehat{w}} + \sum_{j=m,s}\frac{\partial C^j(\widehat{w}, r^k)\hat{y}_j}{\partial\widehat{w}} = 1$$

3.Capital market clearing

$$-\frac{\partial\pi^a(p_a, \widehat{w}, r^k : RF, TP)Z}{\partial\widehat{w}} + \sum_{j=m,s}\frac{\partial C^j(\widehat{w}, r^k)\hat{y}_j}{\partial\widehat{w}} = \hat{k}$$

and

4.The service good market clears

$$\frac{\partial\hat{\varepsilon}}{\partial p_s} = \hat{y}_s$$

If a solution to the system exists, it will be an five-tuple sequence of endogenous variables, with each variable being a function of the exogenous variables and the $\{p_a, p_m, Z\}$remaining endogenous variables$\{\hat{k}, \hat{\varepsilon}\}$. Hence, the solution can be identified with two equations of motion. The next subsections derive the steady-state solution and the equations of motion.

Characterization of equilibrium

The inter-temporal equilibrium consists the transitional path of two variables $\hat{k}$ and p_s and indirectly, expenditure $\hat{\varepsilon}$. For homothetic preferences, differentiate the expression $\tilde{\varepsilon}(p_s, \hat{k})$ and use the Euler´s condition to obtain:

$$\tilde{\varepsilon}(p_s, \hat{k})\cdot(\tilde{r}(p_s) - \delta - \rho - x) = \tilde{\varepsilon}_{ps}(p_s, \hat{k} : \mathrm{RF,TP})\dot{p}_s + \tilde{\varepsilon}_{\hat{k}}(p_s, \hat{k} : \mathrm{RF,TP})\dot{k} + \tilde{\varepsilon}_Z(p_s, \hat{k} : \mathrm{RF,TP})$$

Solving for $\dot{p}_s$:

$$\dot{p}_s = \frac{\left[\tilde{r}(p_s) - \delta - \rho - x\right] - \tilde{\varepsilon}_{\hat{k}}\left(p_s, \hat{k}\right) \cdot \tilde{K}\left(p_s, \hat{k}\right) - \tilde{\varepsilon}_Z\left(p_s, \hat{k} : \mathrm{RF}, \mathrm{TP}\right)}{\tilde{\varepsilon}_{ps}\left(p_s, \hat{k}\right)}$$

Using the relaxationmethodof Trimborn et al (2008),*Mathematica* software was used to solve equations system, to obtain the sequence $\left\{\hat{k}(t), \hat{\varepsilon}(t)\right\}_{t\in[0,\infty)}$.

4.2 The model data and parameter estimation

We fit the empirical model to year 2004 Brazilian data. The main data sources were the Global Trade and Analysis Project (GTAP) version 7.1, the World Bank's World Development Indicators (WDI),and the Institute for Applied Economic Research(IPEA). From the Brazilian growth accounting exercise, we estimate Solow´s residual from which we obtain the Harrod rate of factor productivity growth (x), and the rate of growth of the labor force n. Following Pinto (2011) the rate of time preference parameter ρ was set to 0.045, this and other parameters are described in table 4.

Table 4. Parameters and initial conditions

δ	ρ	θ	x	n	K(0) in 2004 US $ (millions)
0.04	0.045	1.00	0.0165	0.024	231.597

Source: Authors estimates and calculations using GTAP, WDI and IPEA.

Temperature and rainfall projections were introduced into the model for the years 2004 to 2124, and are based onregional projections for the lasthalf of the twenty-first century from Marengo et al. (2009). His projections predict a trend of increasing temperatures and lower precipitation levels for Brazil, although their models have a higher level of uncertainty related to precipitation.

For the initial period of our analysis, 2004, we use an annual average temperature equal to 24.25 ^{o}Cand rainfalllevel equal to 133.46 mm: valuescalculated from the INMET database. We assume temperature levels gradually increases from 24.25 ^{o}C in 2004 until it levels of at 26.8 ^{o}C in 2095 – remaining at that level until 2124. Rainfall begins at 133 mm and gradually falls until it levels off at 106.40 mm in 2084 – remaining at that level until 2124.

Figures 1 and 2 show the series for temperature and rainfall constructed to be added on the climate changes dynamic model.

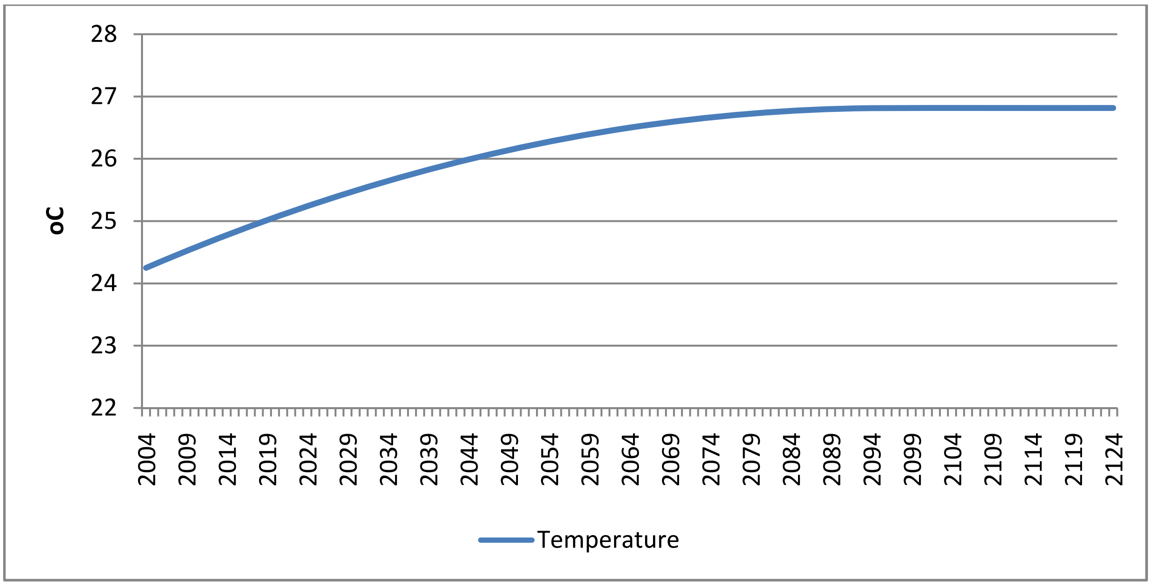

Figure 1. Temperature projected for the dynamic model (^{o}C) – 2004 to 2124
Source: The authors

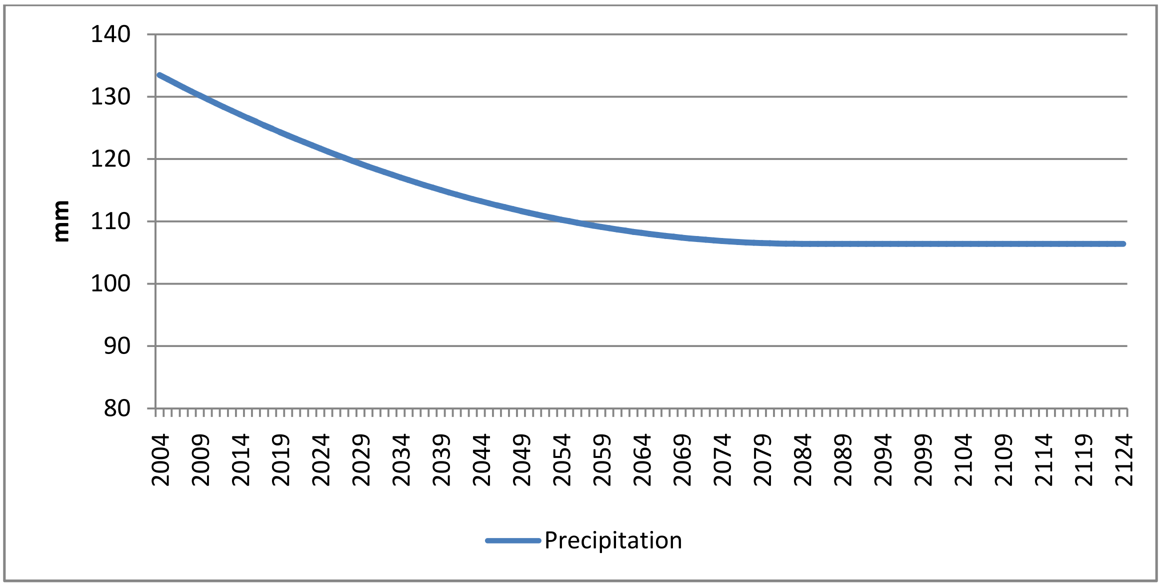

Figure 2. Precipitation series projected for the dynamic model (mm) – 2004 to 2124
Source: The authors

5. Results and Discussion

5.1 Econometric Results

To estimate Brazilian agricultural TFP, we used the GDP, labor force and capital stock levels available in the literature. The basic source of data in this paper is the Brazilian Rural Statistical Yearbook and the Brazilian Agricultural Census, of the following years: 1975, 1985, 1995 and 2006[8], and the Brazilian National Accounts both published

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[8] The last edition of the Brazilian Rural Statistical Yearbook published.

by published by the Brazilian Institute of Geographic and Statistics (IBGE – from its initials in Portuguese).

The variable for capital stock used in this paper is the same used by Bragagnolo, Spolador and Barros (2010). This capital stock seriesis based on the total number of capital owned by farmers (e.g., rural construction and buildings, equipment, machinery and land). Labor input is represented by the number of people employed in agriculture. Land quantities are given by the harvested area expressed in hectares.On the INMET website are available information about temperature and rainfall for states and cities; the information are not homogeneous for all states, and in this research we worked with the annual averages in each state.

Both capital stock and GDP were deflated by the IBGE implicit GDP deflator expressed in *Reais* (R$ - prices of 2004), and the data was organized as a panel to estimate the log linearized version of equation (1). Estimations were implemented using*Stata/SE® 11.2* and results were used to decompose the local (states) agricultural value added.

Following Greene (2003), we estimated the 25 state panel model with fixed and random effects. The results are in table 5.

Table 5.Agricultural Production Function Estimations

	Dependent variable: agricultural product		
	Pooled	Fixed effect	Random effect
Capital	0.5294^{***} (0.0457)	0.3896^{***} (0.0814)	0.4715^{***} (0.0526)
Labor	0.4641^{***} (0.0474)	0.1235 (0.2082)	0.4225^{***} (0.0608)
Land	-0.0182 (0.0558)	0.2345^{***} (0.0779)	0.0509 (0.0621)
Temperature	-0.0514^{***} (0.0147)	-0.0162 (0.0497)	-0.0497^{**} (0.0192)
Precipitation	0.00258^{***} (0.0074)	-0.0016 (0.0009)	0.0011 (0.0008)
Time	0.0119^{***} (0.0041)	0.0074^{**} (0.0033)	0.0112^{***} (0.0030)
Constant	-23.246^{***} (6.4414)	-11.2185 (7.2222)	-21.146^{**} (6.0061)
Sigma_u		0.44556	0.14857
Sigma_e		0.33027	0.33027
Rho		0.64539	0.16829
R^2	0.93	0.89	0.89
Number of Obs.	175	175	175

Source: Model results

* Statistically significant at the 10% level of significance.

** Statistically significant at the 5% level of significance.

*** Statistically significant at the 1% level of significance.

The random-effects estimates yielded statistically significant coefficients for the capital, labor and temperature coefficients. Having a negative, significant temperature coefficient is consistent with other results in the economic literature (but not adjusted for increasing rainfall). For some crops and regions, the rainfall effects could be reduced thorough the irrigation system.

In the economic growth simulations we introduced into the dynamic growth model, both the temperature and precipitation coefficients estimated in the random-effects model. To calibrate the initial values for both series in 2004 (the same year of our GTAP database), we used the national average level for both variables based on the INMET information. The dynamic model results are in the section 5.2.

5.2 Evaluating model performance

Figures 3 to 6 show the comparison between each sectoral GDP forecast by the basic model and the alternative model which includes the climate change effects on the agricultural production function.

As contrasted with the results for the U.S., by Deschenes and Greenstone, 2007, our results predict climate change will lead to a decrease in agricultural output growth over time (in section 5.4 we detail the impacts on the agricultural output growth). This result is consistent with results of Deschênes and Greenstone (2007), and Dell et al. (2012):increasing temperatures have a negative effect on agricultural yields, while precipitation has a positive effect, with the temperature effect dominating precipitation effect.

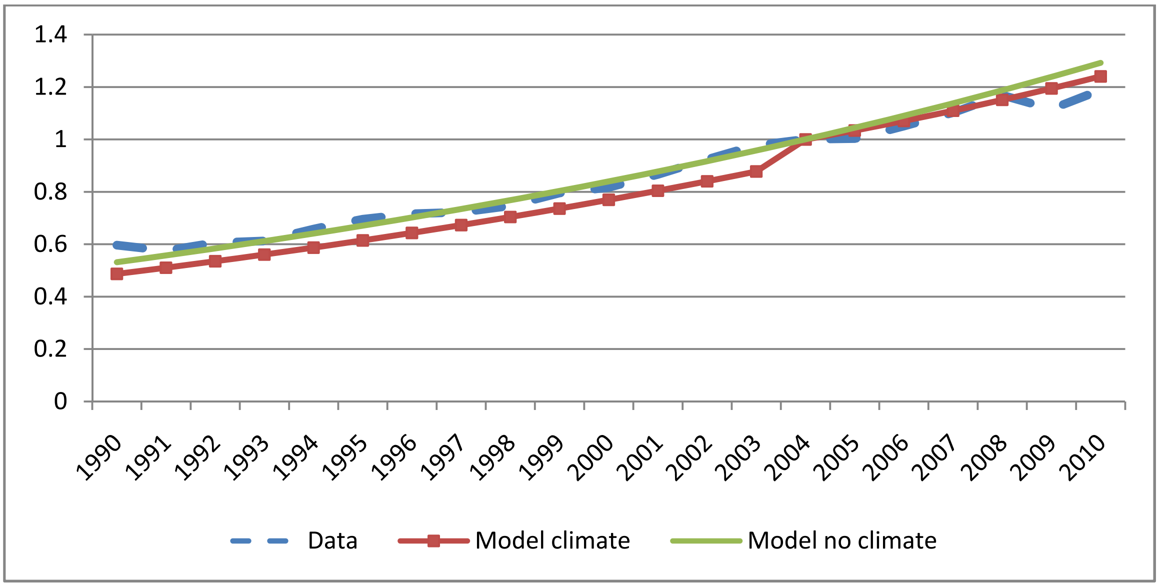

Figure 3. Model validation of agricultural GDP with and without climate change
Source: Model results

The decreased productivity of Brazilian agriculture associated with climate change was advantageous to industry, as the decreased productivity allowed manufacturing to better compete for resources in the climate change scenario.

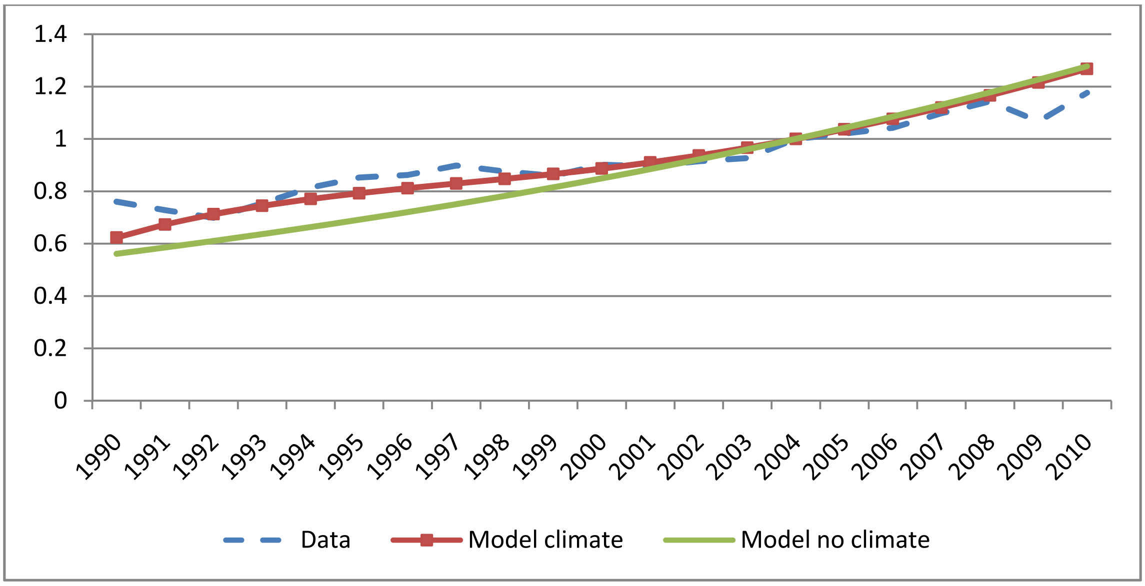

Figure 4.Model validation of industry GDP with and without climate change
Source: Model results

Finally, climate change has very little impact on service sector output. This result is consistent with the existing literature on the impact of climate change on the service sector.

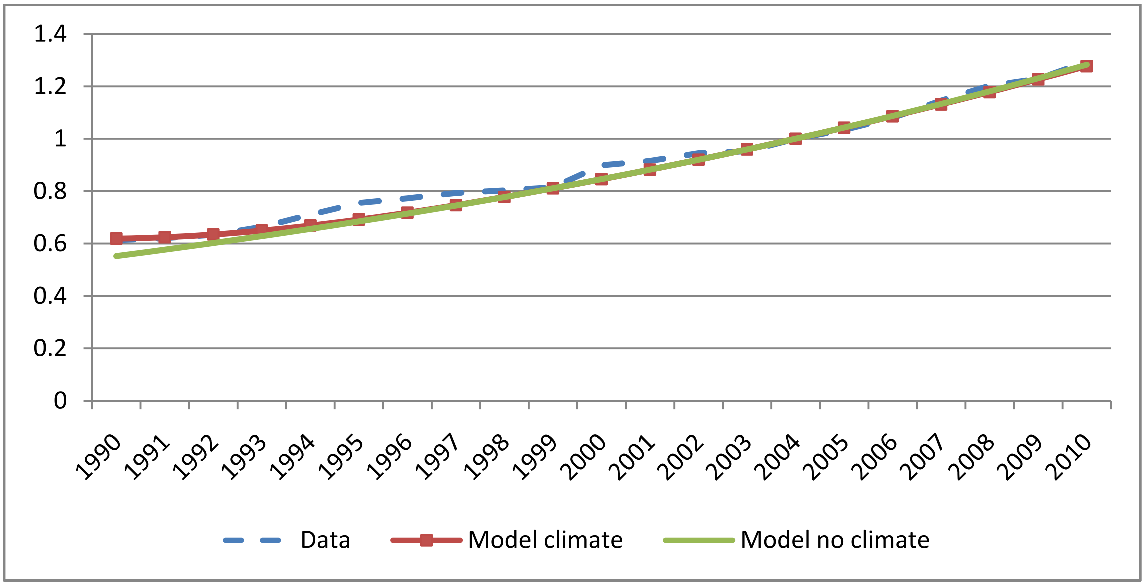

Figure 5.Model validation of service sector GDP with and without climate
Source: Model results

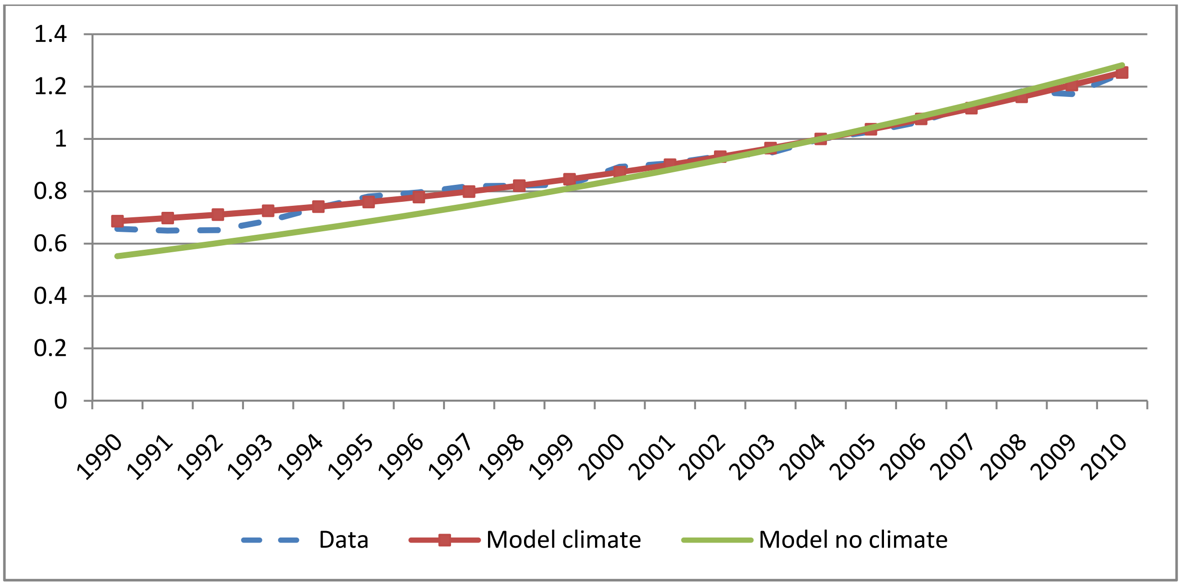

Figure 6. Model validation of total GDP with and without climate
Source: Model results

5.3 The Dynamic Model Results

Two dynamic models were estimated for the period 2004-2104: the first model does not have any climate shock. The model's accuracy is documented in Appendix B, table B-1, with the results suggesting the basic model does a reasonable job replicating Brazilian aggregate and sectoraleconomic growth. Table 7 shows the model predictsthat between 2004 and 2034, GDP per worker would grow from about 1.54% per annum, a positive growth rate but unlike many of the emerging Asian economies, and insufficient to double GDP per worker over the period.

As a major agricultural exporter, without any structural change and with the maintenance of the economic policy (high real interest rates and the exchange rate anchor), the international commodities market will be important to agricultural growth and, hence, to Brazilian economic growth.

Table 7. Factor income and expenditure per worker (US$ 2004)

Year	GDP	Capital	Wage	Capital rent	Land rental income	Expenditure
2004	6005.206	26970.21	3277.973	2677.192	50.04056	3951.933
2009	6421.275	28403.65	3525.203	2850.052	46.02003	4364.02
2014	6920.877	30407.08	3812.386	3065.263	43.22831	4743.383
2019	7483.802	32768.53	4131.736	3310.948	41.11862	5125.245
2024	8105.325	35423.6	4482.005	3583.831	39.48854	5525.98

2029	8786.068	38356.72	4864.195	3883.63	38.24344	5955.036
2034	9528.955	41571.95	5280.281	4211.343	37.33102	6418.912

Source: Model results

The second model has the same parameters and basic structure of the first model, but introduces the climate variables temperature and rainfall into agriculture's production function. This model was calibrated for climate changes using the parameters estimated in section 5.1.

5.4 Longer term forecasts and contrasts

The impact of climate change on agricultural growth is much more pronounced whew viewed from the perspective of sectoral output. Table 8 presents the projected differences between the sectoral outputs under climate change and no climate changes over the period 2005-2014. At the aggregate level, the difference in GDP levels is relatively small, and the same trend is observed for the service sector, despite the positive effect (2.53%) of a potential climate change on the first ten years.

Table 8.Percent differencesin aggregate and sector output – climate vs no-climate

	Industry	Agriculture	Service	Total GDP
2005-2014	-0.65	-9.43	3.58	1.35
2015-2024	2.08	-32.32	2.53	-0.37
2025-2034	5.61	-46.92	1.58	-1.06
2035-2044	8.55	-56.87	0.85	-1.40
2045-2054	10.80	-63.83	0.31	-1.59
2055-2064	12.46	-68.74	-0.08	-1.71
2065-2074	13.65	-72.16	-0.35	-1.78
2075-2084	14.45	-74.47	-0.53	-1.83
2085-2094	14.93	-75.89	-0.64	-1.86
2095-2104	15.13	-76.55	-0.69	-1.88

Source: Model results

The highest climate change impact projected is over the agricultural output. Within four decades (2044), projections suggest the sector output could be 56.87% (in 2034) smaller than it might have been without any negative climate change effect. In terms of policy implications, the estimated scenario indicates Brazil should invest in policies directed to develop new technologies to compensate and/or mitigate the negative climate impact, like new seeds generations resistant to higher temperatures and new soil use techniques. To compensate the rainfall decreasing, investments on irrigation is an alternative to compensate the lower precipitation.

By 2034, Brazilian industry in the presence of climate change was about 5.61% higher than that in the no-climate-change scenario. Results in Dell et al. (2012), however, suggest climate change will have a negative impact on manufacturing output in developing countries. At this point it is difficult to tell why our results differ from Dell et al (2012). One possible explanation for the different results is the approach followed here uses a structural model that captures the evolution of factor prices and capital deepening over time, and more accurately reflects the changing conditions under which the agricultural and manufacturing sectors compete for resources over time. Another explanation is we only impose climate effects on agriculture and not on manufacturing.

Conclusion

This paper developed and implemented a relatively new research methodology for studying some of the fundamental economic forces influencing the growth of Brazilian agriculture, how climate change might influence those forces, and understanding the sector linkages with the rest of the Brazilian economy.

The international economic literature presents two basic results: (i) poor and middle income countries are more affected by climate change than developed countries, and (ii) the agricultural sector realizes the brunt of the negative impact of climate change – mostly via decreased output due to increasing temperatures. These two results offer avenues within which climate change could constrain Brazilian long run economic growth.

The results of this study predict increasing temperatureswill have a negative (and dominant) effect on Brazilian agricultural TFP – a result consistent with other results in the economics literature. On average, over the period 2004-2044, climate change leads to about 58% less production when compared to a no-climate change world, while industry GDP in the presence of climate change is about 8% higher than GDP forecasted without climate change. Our results also suggest climate change will have a negligible effect on service sector GDP.

Much effort has been devoted to evaluating the potential impacts of climate change on economic growth and performance, and, in developing policies to reduce or mitigate its effects on economic performance. Stern (2008) mentioned that "*the discussion of that global framework will move forward strongly over the next few years. It is vital that economics and economists be more strongly involved, particularly if the criteria of efficiency and equity are to play their proper role*" (p. 33).

Almost certainly, climate change will have differential impacts on different regions of Brazil: exactly (or approximately) what those different impacts will be was beyond the scope of this paper. This study generated a modeling and analytical framework that can serve as a point of departure for more extensive climate studies in developing countries.

Hence, the dynamic model discussed in this paperis an ideal *starting point* for new and different simulations for different climate scenarios and effects in agricultural subsectors, considering the most important crops, like soybean, sugar cane, coffee, corn etc. Therefore, by including other agricultural subsectors, the dynamic model could generate relevant information for specific policies proposed to militate against, or compensate, the subsectors more sensitive to changes in temperature and rainfall.Another line of inquiry would be predicting the potential effect of economic policies designed to counteract the economic impact of climate change (e.g., investing in agricultural research and development).

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Appendix A – Econometric Results

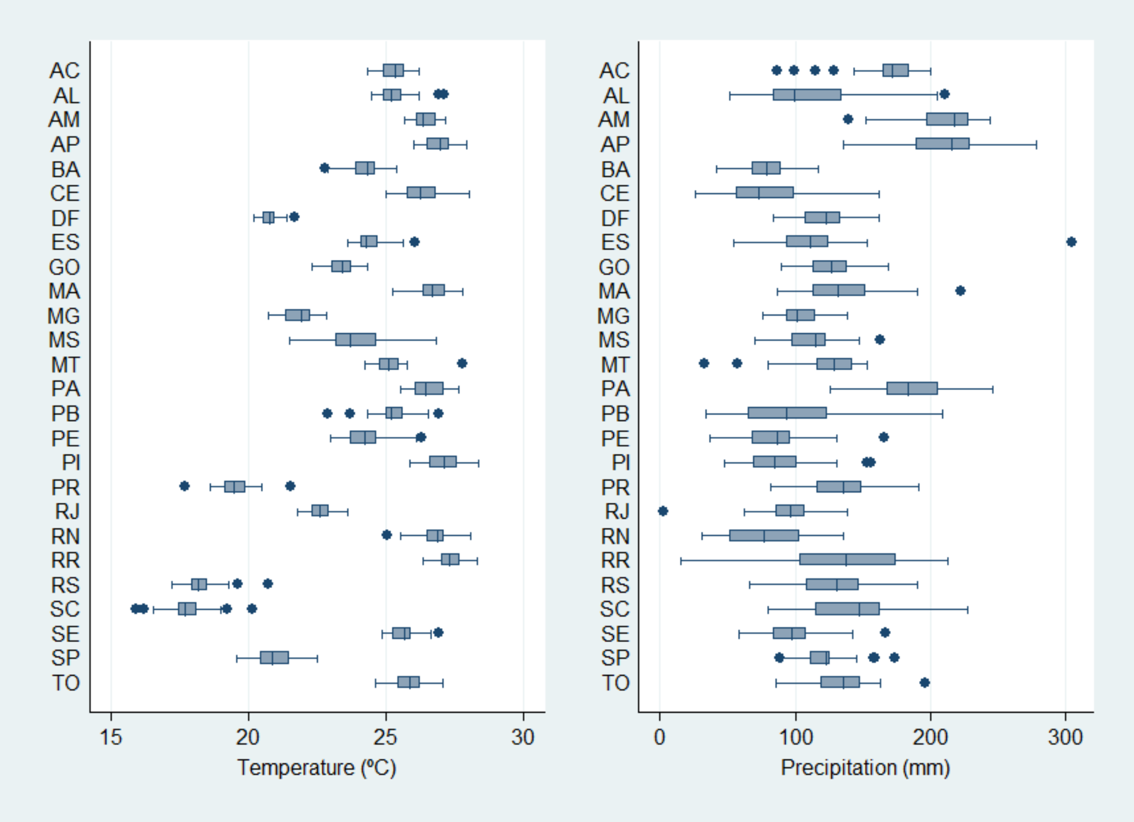

Figure A-1. Temperature and precipitation distributions at Brazilian states level – 1970 to 2012

Source: InstitutoNacional de Metereologia – INMET (www.inmet.gov.br), and authors

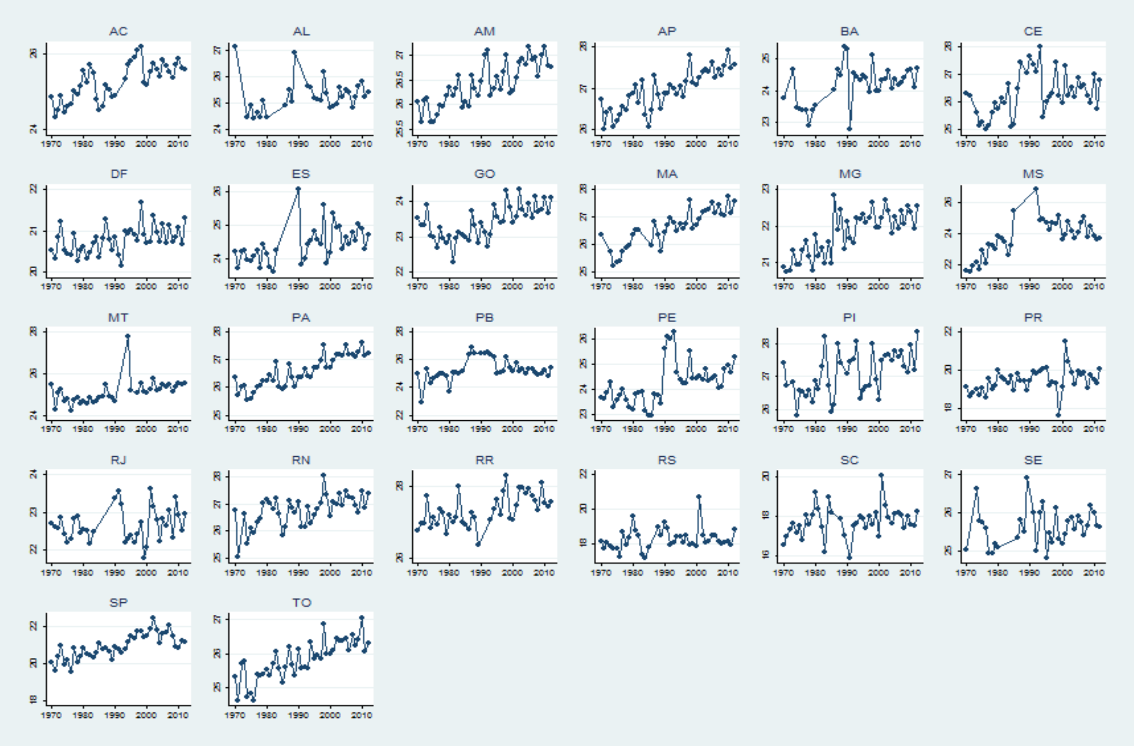

Figure A-2.State Annual Average Temperature 1970-2012
Source:InstitutoNacional de Metereologia – INMET (www.inmet.gov.br), and authors

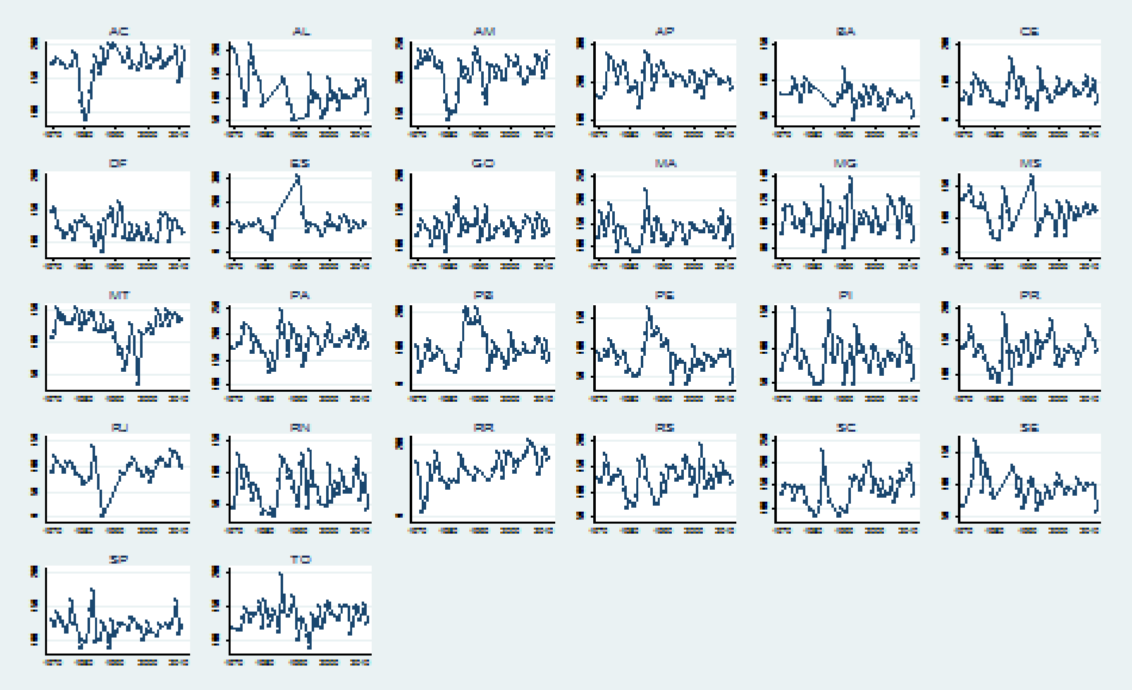

Figure A-3.State Annual Average Precipitation 1970-2012
Source: InstitutoNacional de Metereologia – INMET (www.inmet.gov.br), and authors

Appendix B – Model’s forecast accuracy, 1990-2010

Table below presents the values for the model’s forecast accuracy. The correlation coefficient is just a linear measure between the real and the forecast. Following the procedure proposed by Lin (1989), the concordance correlation measure is bounded between zero and unity, and accounts for discrepancies between the means of two series. The mean absolute error is relatively low for the economy, and to the agriculture and manufacturing sector, and higher for the service sector. Theis’s U statistic is unbounded from above with smaller values indicating a closer fit to the data. This measure tends to present the predicted values for service to be higher than for other sectors.

Table B-1.Measures of the basicmodel’s forecast accuracy, 1990-2010

	Economy GDP	Agriculture GDP	Manufacturing GDP	Service GDP
Correlation Coefficient	0.994659	0.992260	0.967682	0.996588
Concordance Correlation	0.919414	0.933443	0.796803	0.938844

Coefficient				
Theil's U Statistic	0.049617	0.047677	0.096736	0.035647
Mean Absolute Error (%)	2.7664	-1.806215	3.1650689	2.8124797

Source: Model results