

Assessing the Impact of Climate Change on the Brazilian Agricultural Sector

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Resumo

Este artigo apresenta simulações espaciais dos efeitos de longo prazo das mudanças climáticas globais sobre a lucratividade e o preço da terra na agricultura brasileira. Para tanto, especifica e simula dois modelos econométricos alternativos, o modelo de efeitos fixos proposto por Deschênes e Greenstone (2007) e o modelo hedônico proposto por Mendelsohn et al (1994), cujos parâmetros são estimados com base em um painel de dados municipais incluindo, além das variáveis dos Censos Agropecuários no período 1970-1995, variáveis geográficas diversas, destacando-se as observações e projeções em nível municipal da temperatura e precipitação. Os resultados das simulações sugerem que os efeitos de longo prazo das mudanças climáticas globais na agricultura brasileira serão radicalmente diferente nas diversas regiões, sendo particularmente severos nas regiões Norte e Centro-Oeste do país.

Palavras-chave: mudanças climáticas, agricultura brasileira.

Abstract

This paper aims at estimating the effects of climate change on the Brazilian agriculture both in terms of agricultural profitability and land values. To accomplish this task, we estimate two econometric models: the fixed-effects model proposed by Deschênes and Greenstone (2007) and the hedonic model proposed by Mendelsohn et al. (1994). Both models are estimated for a panel of municipalities covering the period 1970-1995. Simulation results suggest that the overall impact of climate change will be quite modest for the Brazilian agriculture in the medium term, but these impacts are considerably more severe in the long term. Simulations also suggest that the consequences of climate change will vary across the Brazilian regions. The North and the Center West regions may be significantly harmed by climate change.

Keywords: climate change, Brazilian agriculture.

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1. Introduction

There is a growing consensus that the rising concentration of greenhouse gases in the atmosphere will lead to higher temperatures and increased precipitation over the next century. The changes in climate are predicted to have a significant impact on economic activity.

One of the most significant ways that global climate change is predicted to affect economic activity is through its effects in agriculture, since temperature and precipitation are direct inputs to agricultural production. In northern latitudes and some dry areas for which rain is predicted to increase with climate change, agriculture may well get a boost from longer growing seasons and greater water supply. On the other hand, in areas where the temperatures are already near the upper bound of most plants' tolerance, warming may make farming unprofitable.

The prospects are particularly critical in tropical countries, like Brazil. Indeed, Brazilian agricultural and forestry sectors are particularly vulnerable to global warming since considerable production is currently undertaken under high-temperature conditions. Among the several consequences, falling farming incomes may have an expressive negative impact on economic development, may increase poverty and reduce the ability of households to invest in a better future. In such a context, evaluating the economic impacts of climate change on agricultural activities is of fundamental importance in order to support formulation of policy measures regarding risk mitigation and adaptation strategies.

This paper aims at estimating the effects of climate change on the Brazilian agriculture both in terms of agricultural profitability and land values. To accomplish this task, we estimate two econometric models: the fixed-effects model proposed by Deschênes and Greenstone (2007) and the hedonic model proposed by Mendelsohn et al. (1994). Both models are estimated for a panel of Brazilian municipalities covering the period 1970-1995. The estimated coefficients are then used to simulate the effects on agricultural profitability and land value of projected changes in precipitation and temperature. Simulations of spatially differentiated climate scenarios are based upon four General Circulation Models (GCMs).

The remainder of this paper is organized as follows. In Section 2, we review the empirical literature on the economic impacts of climate change on agricultural activities. Section 3 presents methodology and data. Section 4 reports the simulation results for agricultural profitability and land values of GCM-projected changes in precipitation and temperature, predicted for the 2050s and the 2080s under the IPCC A2 and B2 scenarios. Finally, Section 5 concludes.

2. Literature Review

There is a vast economic literature on the impacts of climate change on agriculture. The pioneering studies adopted the so-called “production function approach” (Decker et al. (1986), Adams (1989), among others). This approach, also called “agronomic model”, takes an underlying production function and varies the relevant environmental input variables to estimate the impact of these inputs on production. Due to its experimental design, the production function approach provides estimates of the effect of weather on yields of specific crops that are purged of bias due to determinants of agricultural output that are beyond farmers’ control. Its disadvantage is that these estimates do not account for the full range of compensatory responses to changes in weather made by profit-maximizing farmers. For example, in response to changes in climate, farmers may alter their use of fertilizers or change their mix of crops. Since farmers’ adaptations are completely constrained in the production function approach, it is likely to produce estimates of climate change that are biased downward.

By using economic county-level data on land values, Mendelsohn et al. (1994) develop a hedonic model that in principle corrects for the bias in the production function approach. Instead of looking at the yields of specific crops, they examine how climate in different places affects the value of farmland. The clear advantage of the hedonic approach is that if land markets are operating properly, prices will reflect the present discounted value of land rents into the infinite future. The hedonic approach accounts both for the direct impacts of climate on yields of different crops as well as the indirect substitution of different activities. Several applications of the hedonic approach to US agriculture have found mixed evidence on the sign and magnitude of the impacts of climate change on agricultural land. (Mendelsohn, Nordhaus and Shaw (1999), Schelenker, Hanemann and Fischer (2005,2006)).

The hedonic approach has been recently criticized by Deschênes and Greenstone (2007). The authors observe that the validity of the method rests on the consistent estimation of the effect of climate on land values. However, it has been recognized that unmeasured characteristics are important determinants of output and land values in agricultural settings. Consequently, the hedonic approach may confound climate with other factors, and the sign and magnitude of the resulting omitted variable bias is unknown.

Deschênes and Greenstone (2007) propose a fixed-effects model that exploit the presumably year-to-year variation in temperature and precipitation to estimate the impacts of climate change on agricultural profits and yields. More specifically, the authors use a county-level panel data to estimate the effect of weather on US agricultural profits, conditional on county and state by year fixed effects. The weather parameters are identified from the county-specific deviations in weather about the county averages after adjustment for shocks common to all counties in a state. This variation is presumed to be orthogonal to unobserved determinants of agricultural profits, so it offers a possible solution to the omitted variable bias problems that appear to plague the hedonic approach. Using long-run climate change predictions from the Hadley 2 Model, their preferred estimates indicate that climate change will lead to a 4.0 percent increase in annual

agricultural sector profits. They also find the hedonic approach to be unreliable because it produces estimates that are extremely sensitive to seemingly minor choices about control variables, sample and weighting.

Regarding the Brazilian case, Sanghi et al. (1997) evaluate the effects of climate on Brazilian agricultural profitability using the hedonic method. They estimate the impacts of a 2.5°C temperature increase and a 7% increase in precipitation, and they find that the net impact of climate change on land value is negative, between -2.16% and -7.40% of mean land values.

Sanghi et al. (1997) results are more moderate than the results of the Siqueira et al. (1994) study, even considering that the temperature change under consideration is more conservative. However, their state-level analysis confirms the Siqueira et al. (1994) results that the Center-West states are the most negatively affected. This land is primarily the hot, semi-arid, and most recently developed *cerrado*. The cooler Southern states benefit mildly from warming. Results from different agricultural census years are not substantially different, however both the sign and the magnitude of the climate variables change considerably across census years.

Evenson and Alves (1998) extend the Sanghi et al. (1997) exercise to include the effects of climate change on land use, and the mitigating effects of technology on the relationship between climate change and agricultural productivity. They model land value as well as the profit-maximizing share of farmland in different land uses (perennials, annuals, natural pasture, planted pasture, natural forest, and planted forest) as a function of climate, technology, and control variables. They jointly estimate the six land share functions and the land value function. Results show that a combined increase of 1°C and 3% rainfall will lead to a 1.84% reduction in natural forest and an increase of 2.76% in natural pasture. Their analysis suggests that increased investments in research and development would partially mitigate the loss of natural forest due to climate change. This same mild climate change is predicted to reduce land values by 1.23% in Brazil as a whole. As in Sanghi et al. (1997), the North and Northeast and part of the Center-West face the most severe negative impacts. Many municípios in the Center-East, South, and Coastal regions benefit from climate change.

Generally speaking, the empirical evidence indicates that the net impact of climate change on Brazilian agriculture is negative, although there are varying regional consequences. However, these studies present some important limitations. First, the simulations regarding climate change are based on scenarios of uniform increase in temperature and precipitation. No published studies have used geographically differentiated climate projections. Second, these studies are based on climate data which is not as precise as the more recent ones. Our observed climate measures are both more accurate than in past research, resulting from sophisticated interpolation and re-analysis by meteorological experts, and more precise, being distributed in 10 minute grids. Finally, to our knowledge, there has been any application of the fixed-effects model to the Brazilian case. There exists, therefore, the potential for new research to substantially refine results.

3. Econometric model and data

*The Ricardian approach*¹

The Ricardian approach estimates the importance of climate and other variables on farmland values. The model assumes that profit-maximizing farmers at particular sites take environmental variables like climate as given and adjust their inputs and outputs accordingly. It is also assumed that the economy has completely adapted to the given climate, so that land prices have attained the long-run equilibrium that is associated with each municipality's climate.

Equation (1) provides a standard econometric formulation of the Ricardian model:

$$y_{it} = X_{it}'\beta + \sum_j \theta_j f_j(\bar{W}_{ji}) + \varepsilon_{it} \quad (1)$$

where y_{it} is the value of agricultural land per hectare in municipality i in year t . X_{it} is a vector of observable determinants of farmland values, some of which are time-varying. The last term in equation (1) is the stochastic error term.

Vector \bar{W}_{ji} represents a series of (long run) climate variables (indexed by j) for municipality i . Our climate variables are restricted to temperature (°C) and precipitation (mm/month). In our applications, the monthly values were averaged to create four seasonal means: December through February, March through May, June through August, and September through November. While maintaining a measure of the trends in intra-annual variation, this seasonal specification decreases the information loss associated with the conventional use of one month from each of the four seasons. The appropriate functional form for each of the climate variables is unknown, but we follow the convention in the literature and model the climatic variables with linear and quadratic terms.

The coefficient vector θ measures the “true” effect of climate on farmland values. Once these coefficients are estimated, they are used to simulate the impact of projected climate values according to two scenarios of greenhouse gases concentrations: the A2 (high emissions) and B2 (low emissions) scenarios defined by the Intergovernmental Panel on Climate Change (IPCC). Since we use a quadratic model for the climate variables, each municipality's predicted impact is calculated as the discrete difference in agricultural land values at the municipality's predicted temperature and precipitation after climate change and its current observed climate.

¹ The description of the Ricardian and fixed-effects approaches closely follows Dêschenes and Greenstone (2007).

Consistent estimation of the vector θ , and consequently of the effect of climate change, requires the orthogonality condition $E[f_j(\bar{W}_{ji})\varepsilon_{it} | X_{it}] = 0$ for each climate variable j . This assumption will be invalid if there are unmeasured permanent α_i and/or transitory u_{it} factors that covary with the climate variables. As observed by Dêschenes and Greenstone (2007), unmeasured characteristics are important determinants of land values in agricultural settings. So, the hedonic approach may confound climate with other factors, and the sign and magnitude of the resulting omitted variable bias is unknown.

The Fixed-Effects Model

The fixed-effects model proposed by Dêschenes and Greenstone (2007) tries to circumvent the misspecification issues associated to the hedonic approach. The model exploits the presumably year-to-year variation in temperature and precipitation to estimate whether agricultural profits are higher or lower in years that are warmer and wetter. The econometric specification is given by

$$y_{it} = \alpha_i + \gamma_t + X_{it}'\beta + \sum_j \theta_j f_j(W_{ji}) + u_{it} \quad (2)$$

Equation (2) includes a full set of municipal fixed effects α_i . The appeal of including the municipal fixed effects is that they absorb all unobserved municipal-specific time invariant determinants of the dependent variable. The equation also includes year indicators γ_t that control for annual differences in the dependent variable that are common across municipalities. The year dummies are supposed to incorporate time-varying determinants to agricultural profitability such as technology improvements.

The dependent variable in equation (2) is agricultural profits. This is because land values capitalize long-run characteristics of sites and, conditional on municipality fixed effects, annual realizations of weather should not affect land values. It should also be remarked that, since our model include municipal fixed effects, we cannot use \bar{W}_{ji} since there is no temporal variation in our long-run climate variables. Consequently, the long run climate variables \bar{W}_{ji} are replaced by the annual realizations W_{ji} .

The validity of any estimate of the impact of climate change based on equation (2) rests crucially on the assumption that its estimation will produce unbiased estimates of the θ vector. This requires the orthogonality condition $E[f_j(W_{ji})u_{it} | X_{it}, \alpha_i, \gamma_t] = 0$ to hold. By conditioning on the municipality and year fixed effects, the θ s are identified from municipal-specific deviations in weather about the municipal averages after controlling for shocks common to all counties in a state. So, in order to guarantee to orthogonality condition, all the climate variables W in the fixed-effects model are introduced as deviations about their municipal averages. Since this variation is presumed to be orthogonal to unobserved determinants of agricultural profits, it provides a potential solution to the omitted variables bias problems that appear to plague the estimation of equation (1).

As in the Ricardian analysis, once the coefficients in θ are estimated, they are used to simulate the impact of projected climate values according to A2 and B2 scenarios for greenhouse gases concentrations, as defined by the IPCC.

Data

Our dataset is based on the 1970, 1975, 1980, 1985, and 1995/96 Agricultural Censuses, produced by the Instituto Brasileiro de Geografia e Estatística (IBGE). The unit of observation is the *minimum comparable area* (MCA), which is the smallest unit of analysis at the municipal-level that accommodates the changing municipal boundaries over the panel period. For each year we have information on 3,202 MCAs but, due to missing and/or inconsistent data, we end up with 3,124 observations by year. Since MCAs represent municipal-level observations, in order to simplify the exposition we will refer to them as ‘municipalities’.

By using the Agricultural Censuses information, we constructed the dependent variables of our two econometric models: agricultural profitability (for the fixed-effects model) and land values (for the Ricardian model). Both variables are measured in terms of monetary units by hectare (R\$/ha). Agricultural profitability is computed as the difference between total revenues and expenditures, divided by the total area of the agricultural establishments. The land prices represent farmers’ best estimations of the value of their land without any improvements, such as buildings. Since land prices were not available in the 1995/96 Census, our hedonic model is estimated for the 1970-1985 period.

Our database also contains information on land quality and erosion potential for each municipality. Such agronomic variables are key determinants of land’s productivity in agriculture. These variables were created by overlaying geo-referenced municipal boundaries over geo-referenced land-attribute data. It should be remarked that these variables are essentially unchanged across years. Given their time-invariant pattern, both variables cannot be explicitly included in the fixed-effects model. However, we believe that the municipal fixed effects may capture the effects of these agronomic features.

The observed climate variables were extracted from CRU CL 2.0 10' dataset, produced by the Climate Research Unit at the University of East Anglia (<http://www.cru.uea.ac.uk>).² Our observed climate variables are temperature (°C) and precipitation (mm/month) for the period 1961-1990. The monthly values were averaged to create four seasonal means: December through February (DJF), March through May (MAM), June through August (JJA), and September through November (SON). While maintaining a measure of the trends in intra-annual variation, this seasonal specification decreases the information loss associated with the conventional use of one month from each of the four seasons. To construct the variables, we converted all climate data into arcGIS shapefiles using their XY coordinates, joined these grid-points with the MCA boundaries layer, and calculated the average temperature and precipitation for each MCA.

² For an analysis of the treatment and interpolation methods adopted by the Climate Research Center in the construction of the Brazilian climate dataset, see Anderson and Reis (2007).

In the case of small municipalities, inside of which there are no grid points, we used the value of the closest point to the municipal boundary.

For the projected climate values, we used data generated by four GCMs.³ The models used were *HadCM3* from England, *CSIRO* from Australia, *CCCma* from Canada, and *CCSR/NIES* from Japan. Each model predicts daily temperature and precipitation given parameter specifications as described by the IPCC A2 (high emissions) and B2 (low emissions) scenarios of greenhouse gas concentrations. The emission scenarios are based on the Third IPCC Assessment Report⁴. For each model, we received climate data for four timeslices: 1961-1990, 2010-2039, 2040-2069, and 2070-2099. We chose to use timeslices rather than single year projections in order to avoid the possibility of selecting an outlier projection-year. The timeslices provide a better measure of the overall trend, which is what we are interested in. To produce the timeslices, the daily simulations were aggregated to month-level values by summing the mm of precipitation over each month and by averaging the daily temperatures across each month. The month-level values were then averaged across the 30 years within each period. Since we are interested in evaluating medium- and long-term effects of climate changes, we concentrate our analysis on the 2040-2069 and 2070-2099 timeslices.

4. Results

We begin by analyzing the results of the fixed-effects approach that relies on annual fluctuations in weather to estimate the impact of climate change on agricultural profits. Table 1 presents estimates of the impact of two climate change scenarios on agricultural profits. These results are derived from two econometric specifications of equation (2). The first one includes municipal fixed effects and year dummies. Municipal fixed-effects are supposed to absorb all unobserved municipal-specific time invariant determinants of the dependent variable. The year dummies are believed to incorporate time-varying determinants to agricultural profitability such as technology improvements that are common across municipalities. This specification is referred to as the pair of columns (1) in Table 1. The second specification, whose results are presented in the pair of columns (2), replace the year dummies by state by year fixed effects. The introduction of state by year fixed effects allow us to capture unobservable determinants to agricultural profits that are common for the municipalities within a certain state that could be changing over time.

The climate variables are temperature and precipitation. They are constructed as the difference between the annual weather realization and the average for the municipality during the period 1970-1995. Following the empirical literature, we include in the regression equation linear and quadratic terms of the climate variables. All regressions are weighted by the total municipal-level hectares of farmland.

The estimated regression coefficients are then used to simulate the effects on agricultural profitability. Simulations of spatially differentiated climate scenarios are based upon the

³ Data on projected climate change was provided by Wagner Soares, from CPTEC/INPE.

⁴ See IPCC (2001).

average of the four GCMs climate projections, defined according to the IPCC A2 and B2 scenarios for greenhouse gas concentrations. The climate change impacts are analyzed for the timeslices 2040-2069 and 2070-2099, which we call medium-term and long-term, respectively.

Due to the nonlinear modeling of the weather variables, each municipality's predicted impact is calculated as the discrete difference in per hectare profits at the municipality's predicted temperature and precipitation after climate change and its current climate. The resulting change in per hectare profits is multiplied by the number of hectares of farmland in the municipality, and then the national effect is obtained by summing across all municipalities in the sample.

We focus our analysis on the results of the pair of columns (2), since the state by year fixed dummy regression provided a better fit than the regression with year dummies. As showed in Table 1, the medium-term impact of climate change will be quite modest for the Brazilian agriculture at the national level: in the more pessimistic A2 scenario, our estimates indicate that climate change will lead to a reduction of 3.7% in annual agricultural profits. In the more optimistic B2 scenario, the reduction in agricultural profits will be less than 1%. The impacts are considerably more severe for the projected climate in 2070-2099: in the case of the A2 scenario, agricultural profits decrease by 26%, while the reduction associated to the B2 scenario reaches 9%. These simulations provide some evidence that the impact of climate change in the Brazilian agriculture will be quite mild in the medium term. However, the negative effects may be significant in the long run.

Table 1: Fixed-effects estimates of agricultural profit models at the national level for two global warming scenarios

	(1)		(2)	
	A2 scenario	B2 scenario	A2 scenario	B2 scenario
<i>Climate change effects</i>				
<i>medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	-0.04	0.18	-0.21	-0.05
Standard error	0.65	0.52	0.82	0.67
Relative profitability change	-0.6%	3.1%	-3.7%	-0.8%
<i>Climate change effects</i>				
<i>long term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	-1.17	-0.2	-1.49	-0.54
Standard error	1.38	0.85	1.67	1.06
Relative profitability change	-20.5%	-3.5%	-26.0%	-9.4%
Municipal fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	No
State-year fixed effects	No	No	Yes	Yes

Note: This Table reports predicted impacts of climate change on agricultural profits using the estimation results from the fitting of versions of equation (2) and two climate change scenarios. All regressions are weighted by total municipal-level hectares of farmland. Due to the nonlinear modeling of the weather variables, each municipality's predicted impact is calculated as the discrete difference in per hectare profits at the municipality's predicted temperature and precipitation after climate change and its current climate (i.e., the average over the 1961-1990 climate). In order to obtain the national impact, the resulting change in per hectare profits is multiplied by the number of hectares in a certain municipality and then summed across all municipalities. Relative profitability changes are computed with respect to the mean annual profits.

Table 2 explores the distributional consequences of climate change across the Brazilian regions. The North and the Center West regions may be significantly harmed by climate change. This is somewhat expected, since in both regions production is undertaken under high-temperature conditions. The losses in agricultural profits in the North region, which corresponds to the Amazonian forest area, is approximately 35% in the medium-term and 65% in the long term.⁵ In the Center-West region, currently one of the main axis of the agricultural production frontier expansion, the losses may reach approximately 25% in the medium term and 75% in the long term. On the other hand, the Southeast and South regions may benefit mildly from climate change. Similar results were found by Sanghi et al. (1997) and Siqueira et al. (1994).

⁵ It should be remarked that, given the small number of municipalities in the North region, the results concerning this area should be taken with some caution.

Table 2: Fixed-effects estimates of agricultural profit models at regional level for two global warming scenarios

	(1)		(2)	
	A2 scenario	B2 scenario	A2 scenario	B2 scenario
North Region				
<i>Climate change effects: medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ³ billion)	0.19	0.55	-1.84	-1.28
Standard error	1.42	1.1	1.76	1.37
Relative profitability change	5.2%	14.9%	-50.0%	-34.8%
<i>Climate change effects: long-term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ³ billion)	-1.18	0.32	-4.46	-2.42
Standard error	3.22	1.97	3.82	2.38
Relative profitability change	-32.1%	8.6%	-124.6%	-65.7%
Northeast Region				
<i>Climate change effects: medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ³ billion)	-1.59	-1	-2.02	-1.42
Standard error	1.51	1.22	1.83	1.49
Relative profitability change	-16.0%	-10.1%	-20.4%	-14.3%
<i>Climate change effects: long-term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ³ billion)	-4.78	-2.17	-5.14	-2.76
Standard error	3.39	2.09	4.03	2.5
Relative profitability change	-48.2%	-21.9%	-51.8%	-27.8%
Southeast Region				
<i>Climate change effects: medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	0.19	0.21	0.16	0.16
Standard error	0.13	0.11	0.17	0.14
Relative profitability change	10.1%	11.2%	8.5%	8.5%
<i>Climate change effects: long-term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	0.05	0.18	-0.01	0.12
Standard error	0.24	0.17	0.31	0.22
Relative profitability change	2.6%	9.6%	-0.5%	6.4%
South Region				
<i>Climate change effects: medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	0.16	0.09	0.26	0.18
Standard error	0.14	0.12	0.19	0.16
Relative profitability change	8.2%	4.6%	13.3%	9.2%
<i>Climate change effects: long-term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ⁴ billion)	0.13	0.11	0.34	0.25
Standard error	0.25	0.17	0.31	0.22
Relative profitability change	6.6%	5.6%	17.3%	12.8%
Center-West Region				
<i>Climate change effects: medium term (2040-2069)</i>				
Profitability variation (Cr\$ 10 ³ billion)	-2.4	-0.78	-2.44	-1.23
Standard error	2.19	1.68	2.62	2.08
Relative profitability change	-45.3%	-14.7%	-46.0%	-23.2%
<i>Climate change effects: long-term (2070-2099)</i>				
Profitability variation (Cr\$ 10 ³ billion)	-7.55	-3	-8.58	-3.88
Standard error	4.78	2.82	5.59	3.38
Relative profitability change	-142.4%	-56.6%	-161.8%	-73.2%
Municipal fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	No
State,year fixed effects	No	No	Yes	Yes

Note: This Table reports predicted impacts of climate change on agricultural profits using the estimation results from the fitting of versions of equation (2) and two climate change scenarios. All regressions are weighted by total municipal-level hectares of farmland. Due to the nonlinear modeling of the weather variables, each municipality's predicted impact is calculated as the discrete difference in per hectare profits at the municipality's predicted temperature and precipitation after climate change and its current climate (i.e., the average over the 1961-1990 climate). In order to obtain the regional impact, the resulting change in per hectare profits is multiplied by the number of hectares in a certain municipality and then summed across all municipalities pertaining to the region. Relative profitability changes are computed with respect to the mean annual profits.

The entries in Table 3 report the predicted changes in land values for the B2 scenario. These predicted changes are based on the estimated parameters from the fitting of the hedonic model (1). As mentioned, since land prices were not available in the 1995/96 Census, our hedonic model is estimated for the 1970-1985 period. The 20 different sets of estimates of the national impact on land values are the result of five different data samples, two specifications and two distinct timeslices. The data samples are denoted in the row headings. There is a separate sample for each Agricultural Census year and results for the pooling database. Specification (1) includes state dummies, while the regression equation (2) includes state dummies and agronomic characteristics as explanatory variables. It can be noted that results are quite similar for both specifications.

Analogously to the fixed-effects model, the predicted change in land values is calculated as the difference in predicted land values with the current climate and the climate predicted by the average of the GCMs under the B2 emissions scenario. We then sum each municipality's change in per hectare land values multiplied by the number of hectares devoted to agriculture in each municipality to calculate national effects.

Results for the pooled sample show that, regarding the projected climate for 2040-2069, land values may decrease approximately 21% in comparison to current land values. In the long term, land value losses rise up to approximately 42%. The negative impact is considerably higher than the one found for agricultural profitability. One possible explanation for this finding is that, since the estimation of the hedonic model is based on the 1970-1985 period, it fails to capture in an adequate way the technological progress experienced by Brazilian agriculture after 1985, in particular in the Center-West and North Regions. As a consequence, the model would tend to overestimate the effects of temperature and precipitation changes. On the other hand, since the fixed-price model can be estimated for the period 1970-1995, it takes into account more recent technological adaptations to climate factors. Indeed, most of the successful agricultural research in Brazil during this period was the creation of cultivars – soybean, cotton, corn, among other – adapted to the high temperatures and dry climate conditions of those regions.

It should also be noted that the estimated value can vary greatly depending on the sample. This result is somewhat unexpected, since there is no ex-ante reason to believe that the estimates of a particular year are more reliable than those from other years. Such lack of robustness provides some evidence on the existence of an omitted bias variable in the specification, as pointed out by Dêschenes and Geenstone (2007).

Table 3: Hedonic estimates of impact of B2 climate change scenario on agricultural land values 1970-1985

	Timeslice 2040-2069		Timeslice 2070-2099	
	(1)	(2)	(1)	(2)
Pooled 1970-1985				
Land value variation (Cr\$ 10 ⁴ billion)	-1.8	-1.87	-3.61	-3.75
Standard error	0.33	0.29	0.53	0.47
Relative land value change	-21.0%	-21.8%	-42.1%	-43.8%
Single year 1970				
Profitability variation (Cr\$ 10 ⁴ billion)	0.05	0.09	-0.13	-0.08
Standard error	0.14	0.12	0.22	0.19
Relative land value change	1.8%	3.2%	-4.7%	-2.9%
Single year 1975				
Land value variation (Cr\$ 10 ⁴ billion)	-2.11	-2.27	-3.34	-3.64
Standard error	0.44	0.4	0.7	0.64
Relative land value change	-27.4%	-29.5%	-43.4%	-47.3%
Single year 1980				
Land value variation (Cr\$ 10 ⁴ billion)	-0.78	-0.79	-2.52	-2.57
Standard error	0.64	0.52	1.04	0.83
Relative land value change	-8.8%	-8.9%	-28.7%	-29.2%
Single year 1985				
Land value variation (Cr\$ 10 ⁵ billion)	-0.43	-0.45	-0.83	-0.87
Standard error	0.09	0.07	0.15	0.12
Relative land value change	-28.5%	-29.8%	-54.9%	-57.6%
State dummies	Yes	Yes	Yes	Yes
Agronomic variables	No	Yes	No	Yes

Note: The 20 different sets of estimates of the national impact on land values are the result of five different data samples, two specifications and two distinct timeslices. There is a separate sample for each census years and for the pooled censuses. The specification details are noted in the row headings at the bottom of the table.

5. Conclusion

This paper aimed at estimating the effects of climate change on the Brazilian agriculture both in terms of agricultural profitability and land values. To accomplish this task, we estimate two econometric models: the fixed-effects model proposed by Deschênes and Greenstone (2007) and the hedonic model proposed by Mendelsohn et al. (1994). Both models are estimated for a panel of Brazilian municipalities covering the period 1970-1995. The estimated coefficients are then used to simulate the effects on agricultural profitability and land value of projected changes in precipitation and temperature, according to the A2 and B2 emission scenarios defined in the IPCC Third Assessment Report.

Our simulation results suggest that the overall impact of climate change will be quite modest for the Brazilian agriculture in the medium term: for the projected climate for the period 2040-2069, agricultural profit losses range between 0.8% and 3.7%. The impacts

are considerably more severe for the projected climate in 2070-2099, when estimated agricultural profit reductions may attain 26%. Such results suggest that, although the consequences of climate change may be mild in the medium-term, policymakers should be aware of the significant long term impacts. In this sense, the modest effects in the medium term may not be seen as an incentive for not taking any actions, but as an opportunity for the implementation of policy measures regarding mitigation and adaptation strategies.

Simulations also suggest that the consequences of climate change will vary across the Brazilian regions. The North and the Center West regions may be significantly harmed by climate change. This is somewhat expected, since in both regions production is undertaken under high-temperature conditions. On the other hand, the Southeast and South regions may benefit mildly from climate change.

Finally, the hedonic model estimates indicate significant climate change impacts on land values. However, estimated values vary greatly depending on the sample. Such lack of robustness provides some evidence on the existence of an omitted bias variable in the hedonic model specification, as pointed out by Dêschenes and Geenstone (2007).

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