Impacts of climate change on Brazilian agriculture: an analysis of irrigation as an adaptation strategy

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Abstract
This paper aims to analyze the effects of climate change on Brazilian agriculture considering irrigation adoption as an adaptation strategy. Investigation on how climatic variability influences irrigation adoption was performed as well as whether this adaptation measure actually reduces producers' vulnerability to climate change. We used matching methods to analyze the choice of irrigation in the first stage and the land values for two types of farmer (irrigators or dryland) in the second stage. Temperature and precipitation projections for the 2010-2099 time period were used, considering different climate scenarios, according the 4th Assessment Report of IPCC (2007). Simulation results showed that irrigation can be a very effective tool to counteract the harmful effects of climate change. Land values for irrigated production are less vulnerable than those of rainfed production. Farmers' income tends to grow on lands where irrigation techniques are practiced, while on those where agricultural production is exclusively rainfed, losses can sum to approximately 14% in relation to current period. These conclusions confirm the need to invest in adaptation strategies in order to make Brazil ready to cope with the adverse effects of global climate change.

1. Introduction

Climate change will potentially transform the physical and human geography of the planet, but this process is still characterized by considerable uncertainty. Changes in temperature levels and rainfall variability depend on the operation of climate for the world as a whole; however, their impacts are very distinct regionally and among economic sectors (Stern, 2008). The agricultural sector, by direct dependence on temperature and rainfall, is one of the most vulnerable to climate change (Deschênes and Greenstone, 2007; Fisher et al, 2009).

Although there is no consensus on the exact impact of climate change on agriculture, it is usually accepted that developing countries, such as Brazil and other nations of Latin America and the Caribbean, will be more negatively affected. The explanation for this is their location, predominantly at low latitudes; in these areas, temperatures are already too hot, sometimes above optimum levels for agriculture. In low latitudes, the rural poor tend to live in the hotter and drier regions of each country. Warming is likely to damage these regions more severely than the more temperate zones of each country. Moreover, according to Cline (2007) and Stern (2007), as the sector accounts for a significant portion of the income in developing nations, a certain percentage reduction in agricultural potential would lead to higher losses than in developed economies.

According to Seo and Mendelsohn (2008b), in order to adequately quantify the impacts of climate change on agriculture, one must take into account adaptation strategies. The analysis cannot

simply estimate how a particular culture will be affected, but should recognize that producers will change their production decisions to maximize profit according to each climate scenario. Studies which assume that producers will continue performing the same activities without changing their production techniques certainly overestimate losses.

Planning for climate adaptation necessarily requires comparison of decision options, taking into account the possibilities and limitations of each technique as well as the uncertainties associated with climate change (Pidgeon and Fischhoff, 2011). According to Magrin et al. (2007) and Seo (2011), irrigation is a major adaptation measure by farmers in Latin America and elsewhere in response to climate change. Irrigation increases crop productivity and allows control of water stress on agricultural production.

Irrigation could be a powerful adaptive strategy in Brazil due to availability of water and suitable soils. The country withholds about 12% of fresh water reserves of the planet. Furthermore, it has approximately 30 million hectares of soil suitable for sustainable development[1] of irrigated agriculture (only 4.4 millions are currently being cultivated with irrigation systems and techniques). We must also consider that although there are estimates of reduction of surface water in Brazil due to climate change, the amount of groundwater of the main watersheds tends to increase or at least be the same (Margulis and Dubeux, 2010), without compromising the possibility of adopting this adaptive strategy.

In this context, this paper aims at carrying out an analysis of climate change effects on Brazilian agriculture considering irrigation adoption as an adaptation strategy. The objective is to investigate how climate variability influences irrigation and if this adaptation method will, in fact, reduce farms' vulnerability to climate alterations and, in affirmative case, how much is the loss for rainfed producers.

In Brazil, most investments in irrigation projects are performed by the private sector. The government develops an important role in this process, by providing loans and funding to farmers. However, public projects, whose infrastructure is established and operated directly by the public sector, represent only 4% to 6% of the irrigated area and are geographically concentrated in the Northeast part of Brazil. Therefore, in this study irrigation is characterized as an adaptive measure of producers and not deliberately promoted by the government.

The main studies that analyzed climate change impacts on Brazilian agriculture (Siqueira et al, 1994; Sanghi et al, 1997; Nobre et al, 2005; Ávila et al, 2006; Embrapa, 2008) are unanimous in

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[1] The term "sustainable" indicates that the estimate has taken into consideration the existence of suitable soils, the availability of water resources without risk of conflicts with other water utilization priorities and the compliance with environmental legislation and the Forest Code.

stating that climate change will cause a negative impact for the country. There is also agreement that the various regions will be affected differently, which is directly related to the substantial variation in climatic conditions throughout the national territory. However, with the exception of the analysis of change in land use of Evenson and Alves (1998), none of the several studies considered adaptation, which may overestimate the impacts. Therefore, in explicitly including irrigation as an adaptive strategy we can acquire a better understanding of impacts on the domestic agricultural sector and thus contribute more effectively to future public policies aimed at creating strategies to combat the effects of global warming on agriculture.

The paper proceeds as follows. The next section describes the methodological framework. In the third section, a detailed description of the data sources and variables is provided. In the ensuing sections, empirical results are presented, followed by simulation results of future climate change scenarios. A summary, conclusions and policy discussions are provided at the final section.

2. Methodological Framework

It was tested, in this study, the hypothesis that the irrigation practice, as an adaptive measure, tends to mitigate the negative effects of global climate change on Brazilian agricultural sector. However, the key problem with this hypothesis is that not all agricultural areas have the same likelihood to adopt irrigation techniques.

In fact, this decision is taken in a process of maximizing benefits that ensures that only optimal choices are observed, regardless of which option was selected. So the choice is an optimization action, influenced by the environment in which the producer is situated (his personal features, economic conditions etc.). Irrigation adoption is voluntary and may be based on individual self-selection. So, we have a classic nonrandom treatment assignment. In this context, the traditional regression analysis may not capture the true effects of irrigation on the agricultural profits. We may overcome this problem with matching methods, using a class of estimators called propensity score-matching estimators (PSM). This methodology was first suggested by Rosenbaum and Rubin (1983). In this paper, we follow the standard matching procedure described in Heckman and Robb (1986), Heckman et al. (1997), Heckman et al. (1998) and Bento et al. (2007).

Following Bento et al. (2007), let Y_1 be the potential outcome in the "treated" state, which is the land value[2] of the county that adopted irrigation and Y_0 the potential outcome that would have happened in these counties had they not adopted irrigation. We call these potential outcomes

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[2] The farmer profitability was represented by land values because, according to Mendelsohn et al. (1994), land values are simply the present value of profits (or net revenues).

because we observe only one of (Y_0, Y_1) for each county. Let $D=1$ indicate a county that has irrigated areas and $D=0$ indicate a county that did not. Finally, let X be a vector of observed covariates affecting both the irrigation adoption and outcomes. These covariates, such as soil, climatic characteristics and socioeconomic features of the counties, will be presented in great detail in the next section.

The effect of irrigation on farm profitability, measured by land values, is the parameter of interest. It is calculated by the mean effect of being in a county that has irrigated areas versus an observationally equivalent county, as measured by X, that it is not under irrigation techniques. Formally, the parameter of interest is:

$$\Delta TT = E\left(Y_1 - Y_0 \mid D=1\right) \tag{1}$$

where ΔTT denotes the average treatment effect on the treated observations.

According to Bento et al. (2007), the matching method consists of finding a "proxy" for Y_0, since we do not observe Y_0 for this treated observation (i.e., $D=1$). This "proxy" is called counterfactual outcome, e. g., the one which would have resulted in case the individual farmer did not irrigate. The propensity score estimators will be define an estimator for $E\left(Y_0 \mid D=1\right)$ using an appropriate subset of the $D=0$ data. Matching estimators pair each treated observation with one or more observationally similar nontreated observations, using the conditioning variables, *X*, to identify the similarity. This methodology is justified if it can be argued that conditional on these *X*'s, outcomes are independent of the selection process. Rosenbaum and Rubin (1983) showed that this independence condition holds conditional on the propensity score $P(X)$ as well, which leads to the propensity score matching method.

The estimation of the model consists of three steps. In the first one we estimate a probit model of irrigation adoption. The estimated coefficients were used to predict the irrigation probability for each observation, e. g., the propensity score. In the second, the data were divided into the treatment group (the counties that were in fact under irrigation techniques) and the control group (the counties that were not under irrigation but had similar characteristics to the areas that are under irrigation), using the propensity scores. In the last step, we estimate a counterfactual for each treated observation $\left(Y_1 \mid D=1, P[X]\right)$ based on $\left(Y_0 \mid D=0, P[X]\right)$ using the kernel matching. The average effect of treatment on the treated (the conditional mean difference), e.g., what impact irrigation has on farmers who actually irrigated is:

$$\Delta TT = \left\{ Y_1 - Y_0 \,\middle|\, D = 1 \right\}$$
$$= E\left[E\left\{ Y_1 - Y_0 \,\middle|\, D = 1, P[X] \right\} \right] \qquad (2)$$
$$= E\left[E\left\{ Y_1 \,\middle|\, D = 1, P[X] \right\} - E\left\{ Y_0 \,\middle|\, D = 0, P[X] \right\} \,\middle|\, D = 1 \right]$$

As the main objective of this research was to analyze the effects of climate change on agriculture on a medium and long-term, simulations were performed. In these simulations, projections of temperature and rainfall were used for three time periods: 2010-2039, 2040-2069 and 2070-2099. We considered two climate scenarios, A1B and A2, according to the Intergovernmental Panel on Climate Change (IPCC, 2007).

3. Data

In order to compose the *X* vector, three categories of variables were used: socioeconomic, agronomic and climatic (Table 1). The unit of observation was the *Minimum Comparable Area* (MCA), which refers to the aggregated area of the smallest number of counties needed to ensure the comparisons of a same geographical area from different time periods. Since MCAs represent county-level observations, in order to simplify the exposition we will refer to them as "counties"[3].

Socioeconomic variables (features related to education, age, income, access to water resources etc.) and those related to land use (irrigated and rainfed) were obtained from the 2006 Agricultural Census, published by Instituto Brasileiro de Geografia e Estatística (IBGE). The agronomic features used refer to soil types, altitude, and erosion potential, provided by IPEADATA. These variables were created by overlaying geo-referenced county boundaries over geo-referenced land-attribute data.

Information about observed temperature and precipitation were extracted from CL 2.0 10' dataset, produced by the Climate Research Unit − CRU/University of East Anglia. The observed climate variables are temperature (°C) and precipitation (mm/month) for the 1961-1990 period. Monthly values were averaged to create two seasonal means: December through February (summer) and June through August (winter). This seasonal specification decreases the information loss associated with the conventional use of one month from each season and, at the same time, maintaining a measure of the trends in intra-annual variation. In order to construct the variables, all climate data was converted into arcGIS shapefiles using their XY coordinates, joined these grid-

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[3] The use of farmer-level data for each variable would be ideal. However, Instituto Brasileiro de Geografia e Estatística only provide this data without identifying geographic coordinates (latitude and longitude) to preserve the privacy of farmers who answered to Agricultural Census' questionnaires. Therefore, it is not possible to assign values of climate variables to each producer. To overcome this difficulty, we used MCA.

points with the MCA boundaries layer, and the average temperature and precipitation were calculated for each MCA. Unlike analysis already done for Brazil, which included only the first moments of temperature and precipitation distributions, in this study climate variability was considered by including the second moments of these distributions.

Table 1 Variables description

Variables	Description
Climatic variables	
Summer temperature	Summer average temperature (°C).
Summer precipitation	Summer total precipitation (mm).
Winter temperature	Winter average temperature (°C).
Winter precipitation	Winter total precipitation (mm).
Temperature variability	Second moment of temperature distribution.
Precipitation variability	Second moment of precipitation distribution.
Agronomic variables	
Water resources	Number of agricultural establishments with water resources.
High agricultural potential	Proportion of land area in the county with high soil quality.
Low agricultural potential	Proportion of land area in the county with low soil quality.
Erosion potential	Proportion of land area in the county with high erosion potential.
Socioeconomic variables	
Land owner	Number of farms in which the farmer is the land owner.
Internet access	Number of farms with access to the Internet.
Farm's income	Value of income earned by the farms (1,000 R$).
Age of head	Number of farms runned by someone whose age group is 25 to 45 years old.
Education of head	Number of farms which is managed by someone graduated in a university.
Without technical guidance	Number of farms that had not received any technical guidance.
Land value	Counties land value (1,000 R$).

It is important to highlight that the option of considering only summer and winter temperature and rainfall, instead of the four seasons, was based on studies by Seo and Mendelsohn (2008a) and Seo (2010, 2011). According to the authors, such specification is more appropriate to studies regarding South America, since this region does not present four well defined seasons, such as in the USA[4].

For the projected climate values, average data generated by ten GCMs were used[5]. The emission scenarios, A1B and A2, are based on the 4th Assessment Report of IPCC (2007). For each model, climate data for four timeslices were provided: 1961-1990, 2010-2039, 2040-2069 and

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[4] However, several specifications, including also other seasons, were tested. The estimated models, with variables regarding summer, autumn, winter, and spring, generally present few statistically significant coefficients, confirming their low adequacy to the Brazilian case

[5] The models used were: CNRM_cm3, CSIRO_MK3.0, GFDL CM2.1, GISS ER, IPSL_CM4, MIROC3.2_medres, MPI ECHAM5, MRI CGCM2.3.2, UKMO_HADCM3 and UKMO_HadGEM1.

2070-2099. Timeslices were used rather than single year projections in order to avoid the possibility of selecting an outlier projection-year. Timeslices provide a better measure of the overall trend, which is the purpose of this study. Data on projected climate change was provided by the Centro de Previsão de Tempo e Estudos Climáticos/Instituto Nacional de Pesquisas Espaciais – CPTEC/INPE.

Finally, the dependent variable of the Treatment Effect Model is land value. This variable, provided by the IBGE 2006 Agricultural Censuses, is measured in terms of monetary units (1.000 R$). Land values represent farmers' best estimations of the value of their land without any improvements, such as buildings.

4. Results and Discussion

We start by examining descriptive statistics of the variables presented by the two types of agricultural production shown in Table 2. Mean temperature did not show significant differences. Difference between rainfed and irrigated production can be observed mainly in precipitation variables. Irrigated production was exposed to a lower volume of rainfall; this difference was more significant during winter. Therefore, when precipitation is abundant, farmers tend to practice rainfed agriculture, but as the conditions becomes drier, there is a gradual change to irrigated systems. Similar results are found by Seo (2011), who examined irrigation in Latin America. It is also important to emphasize that irrigators and dryland farmers were exposed to high precipitation variability and low temperature variation.

Differences can be seen in agronomic and socioeconomic variables as well. Dryland producers had less access to water and were located in counties with low soil quality. The average of farms that did not get technical guidance was lowest among irrigators; these ones also had greater access to Internet and higher education. In general, it is expected that producers with these characteristics have good knowledge about irrigation technology and therefore are more likely to adopt the technique.

Finally, land value of irrigators was higher than dryland farmers. This is the first evidence that use of irrigation techniques, to reduce the risk associated with climate variability, generates higher income to the farmer, becoming an effective adaptation strategy.

Table 2 Descriptive statistics on agricultural production in Brazil.

Variables	Irrigators		Rainfed	
	Mean	Std	Mean	Std
Summer temperature	24.43	1.97	24.67	2.01
Summer precipitation	168.86	74.10	171.46	74.64
Winter temperature	20.02	3.65	20.63	4.31
Winter precipitation	52.67	51.31	59.46	52.15
Temperature variability	3.74	2.71	3.75	3.28
Precipitation variability	5,437.18	3,398.00	5,529.35	4,137.05
Water resources	969.14	2,478.62	958.06	1,949.93
High agricultural potential	0.11	0.27	0.09	0.24
Low agricultural potential	0.56	0.43	0.57	0.41
Erosion potential	0.43	0.36	0.38	0.35
Land owner	1,160.67	2,475.59	1,189.63	2,078.59
Internet access	25.64	66.02	12.2	21.90
Farm's income	41,641.30	134,372.00	20,597.36	38,461.33
Age of head	527.93	1,195.65	585.52	1,119.25
Education of head	47.69	83.35	29.10	43.68
Without technical guidance	42,999.50	219,918.60	71,510.35	254.928,80
Land value	161,793.50	217,654.60	135,048.00	245,810.90
Number of counties	3,123		808	

Note: Land values are represented in R$ 1,000.

Following the proposed methodology, the first part of the analysis consisted of estimating a probit model in order to obtain the propensity score (Table 3). The dependent variable took the value 1 if there was irrigated area in a given county and 0, otherwise. Three thirds of the counties had irrigation and the rest was rainfed. The included explanatory variables were those described in Table 1. The model was highly significant according to the Likelihood Ratio statistic. The parameters are mostly significant at 5% level and all climate coefficients are statistically different from zero.

Table 3 Probit estimatives

Variables	Estimatives	P-Value[HC]
Summer temperature	-0.973374	0.076
Summer temperature squared	0.019682	0.059
Summer precipitation	-0.003958	0.000
Winter temperature	0.496995	0.034
Winter temperature squared	-0.014755	0.001
Winter precipitation	-0.003417	0.000
Temperature variability	-0.104093	0.025
Precipitation Variability	0.000053	0.000
Water resouses	0.000146	0.059
High agricultural potential	0.232210	0.035
Low agricultural potential	-0.008683	0.908
Erosion potential	0.262831	0.001
Land owner	-0.000079	0.192
Internet access	0.007533	0.000
Farm's income	0.000004	0.000
Age of head	0.000217	0.060
Education of head	0.004495	0.002
Without technical guidance	-0.000002	0.000
Intercept	9.333422	0.051

Notes: The Likelihood Ratio statistic for the model is 292.46 with P-value < 0.0000; P-Value[HC] denotes heteroscedasticity consistent P values.

The estimated probit model indicates that the agronomic, socioeconomic, and climate conditions influence the use of irrigation in Brazil. Access to water resources and the availability of land in good conditions for agricultural practice (in terms of soil quality and erosion potential) are important. The farmer decision is also conditioned by his technical expertise and management capacity, which involves understanding the potential and limitations of the technique, and its operation and functioning. Good conditions of income are very important, since the installation of an irrigation system involves high costs. The expectation concerning the fact that irrigation is influenced by climate variations and, thus, can effectively be modeled as an adaptive strategy was confirmed.

After propensity score estimation it was possible to evaluate the performance of irrigated and rainfed production in the present and future climate change scenarios proposed by IPCC (2007). This analysis was performed by calculating the average effect of treatment on the treated (ΔTT), for which the variable of interest was land value. Possible benefits of irrigation as adaptive measure were evaluated as well as losses related to the decision of not irrigating. Table 4 contains mean estimates of land value for each period of time and climate scenario.

Following Mendelsohn et al. (1994) and Seo (2011), simulations were performed changing the climatic conditions and keeping socioeconomics and agronomic conditions unchanged. According to Seo (2011), it should be noted that many things other than climate will change in the future, i.e. such technological factors, economic development, agricultural policy, international trade regimes etc. However, Seo (2011) explains that the aim of this kind of simulation is to separate the effects of climate from other changes in economic conditions.

Table 4 Impacts of climate scenarios on conditional land value (irrigated and rainfed production)

Variable	Irrigated prodution	Rainfed production	ΔTT	P-Value
Land value (current period)	153,504.54	158,493.00	-4,988.46	0.0060
A1B Scenario				
Land value (2010-2039)	159,334.30	148,091.54	11,242.76	0.0040
Land value (2040-2069)	161,410.56	142,387.28	19,023.28	0.0030
Land value (2070-2099)	161,283.88	136,521.30	24,762.58	0.0050
A2 Scenario				
Land value (2010-2039)	160,050.10	147,919.81	12,130.29	0.0070
Land value (2040-2069)	161,514.27	136,725.95	24,788.32	0.0060
Land value (2070-2099)	161,289.03	135,740.94	25,548.09	0.0090

Notes: Land values are represented in R$ 1,000; ΔTT was estimated with kernel matching; P-values based on the standard error calculated by bootstrap.

Results on Table 4 show that, in future simulations, returns associated to the irrigated production is always higher than the rainfed production. The p-value indicates that the differences between the two classes of producers are statistically significant at less than 1%. In the counties where agriculture is practiced using irrigation techniques, the average value of land tends to increase (although there is little reduction in the period 2070-2099 compared to 2040-2069). In the counties where agricultural production is exclusively rainfed, reduction in the average value of land is significant. Losses can range from R$ 11.2 million (scenario A1B) in the short term to 25.5 million (scenario A2) in the long term, while estimates of rising temperatures become higher. Results are roughly similar for both scenarios.

Therefore, irrigation is efficient as an adaptation measure. As discussed by Schlenker et al. (2005), the benefits and costs (including expenses related to the implementation of irrigation system) are capitalized in future land values. Thus, it can be stated that under climate change scenarios, the profits achieved with irrigation adoption outweigh its costs. This result is consistent with those presented by Margulis and Dubeux (2010). According to these authors, in Brazil the relationship between the cost of installing an irrigation system and the benefit (measured by the

losses avoided), appears to be advantageous, ranging from 2% in 2020 to 19% in 2070 for corn production, and 11% to 41% for rice production.

Observing the two scenarios under study, it was possible to create ranges for the expected gains and losses. When using supplementary irrigation there is an expectation of earnings growth that may vary from 3.8% to 4.2% in 2020, from 5.1% to 5.2% in 2050, and from 5% to 5.1% in 2080. For non-irrigated agriculture, expected losses range from 6.6% to 6.7% in 2020, from 10.2% to 13.7% in 2050, and from 13.9% to 14.4% in 2080. Considering the current average land value in Brazil (irrigated production and rainfed summed) the estimated losses in scenario A2 can reach approximately R$ 10.3 million in 2020, R$ 21.2 million in 2050, and R$ 22.8 million in 2080.

The results of this study agree with those of Seo (2011) concerning the direction of effects. In that study, adaptation schemes using irrigation in South America were analyzed. According to the author, land values will decrease 17.2% for rainfed farmers, and increase about 17% for producers who use private irrigation projects, considering the PCM model (Parallel Climate Model). It is believed that the more modest gains and losses estimated in this study are due to different conditions of the structure of Brazilian agricultural production. Compared to other countries under study by Seo (2011), Brazil has the most diverse and modern agriculture, and, therefore, is more able to take adaptive actions. Moreover, results of this study were also conditioned by the climate scenarios considered, since in both of them it is predicted higher increases in rainfall than in the temperature. Mendelsohn and Seo (2007) and Seo and Mendelsohn (2008a), studying South American producers, demonstrated that both irrigators and non-irrigators are positively impacted by increases in rainfall.

It is possible to state that producers who can irrigate will be less exposed to the adverse effects of changes in climate. Moreover, land values of irrigated areas tend to be more stable than rainfed areas. From these observations and analysis of studies about the impact of climate change on developing countries (Mendelsohn and Seo, 2007; Kurukulasuriya and Mendelsohn, 2007; Seo and Mendelsohn, 2008a; Seo, 2011), it was found that irrigation can be a very effective tool to counteract the harmful effects of climate change. Rents for irrigated production are less vulnerable than those of rainfed production.

Some studies for Brazil, which also based their estimates on data of land value, showed results ranging from minor losses, e.g. 2.2% or 3.7% (Sanghi et al, 1997), to losses of 47% to 80% (Ávila et al, 2006). The results of this research, however, indicate a less pessimistic portrayal about the effects of climate change in Brazilian agriculture, as it assumes that producers will not continue doing the same activities, without changing their production techniques. This confirms the need to include adaptation measures in the estimation of impacts, allowing a more complete assessment of

what will really happen. Ignoring adaptation can make the estimation of impacts over-estimate the damage, sometimes dramatically.

6. Conclusions

The main objective of this paper was to analyze the effects of global climate change on agriculture in Brazil. But, unlike other studies performed for Brazil, it was considered that producers will try to adapt to climate change. Irrigation was considered as an adaptive strategy, since the country presents favorable conditions for sustainable development of this activity.

Results confirmed prior expectation that irrigation is influenced by climate variations and, thus, should be modeled as an adaptive measure. Given current conditions, irrigation has been adopted more as a response to reduced rainfall occurrences than to temperature variations. In a general sense, the analysis of factors associated with its adoption in Brazil showed that to be an irrigator, the farmer must have enough income to afford the costs of investment, technical knowledge (which involves understanding the potential and limitations of the technique, and its operation and functioning) and administrative capacity. Besides this, his/her farm must have good water availability as well as good soil conditions.

It is possible to conclude that irrigators' land values tends to be more stable, demonstrating the effectiveness of irrigation as an adaptive measure. Given the predictions of climate change, irrigation has the potential to contribute to improve agricultural performance of the country, making producers less vulnerable to the climate. It is confirmed, thus, the need to include adaptation measures in the estimation, providing a good assessment of what really happens. Ignoring the adjustment makes the estimation of impacts overestimates damages, sometimes in a dramatic way.

In a general sense, results of this study suggest that the impacts of climate change on agriculture in Brazil will not be so pessimistic. At the same time, they reinforce the need for public policies that seek strategies to combat the effects of global warming in the sector. Moreover, given the evidence of irrigation importance as an adaptive measure, the creation of specific credit policies to the implementation of this practice should be encouraged, especially for less capitalized producers. It would be a way to avoid the increase of regional inequalities in the country.

It is important to highlight that, to make the potential benefits of irrigation more effective, in terms of avoided loss of profit, it will be necessary to make this practice more environmentally sustainable. One must invest in technologies that ensure the proper management of irrigation, avoiding the waste of water and other problems caused by improper use of the technique. In this process, it is essential to inform producers so the selection of irrigation methods could be guided by the characteristics of production and location where it will be developed.

It is necessary to point out some limitations of this study. First, it was not possible to include the future water availability in the model. The amount of water available for the diverse consumptive uses will probably change, which has implications for irrigation. Moreover, this study does not capture the full range of adjustments that can be performed; in particular, when assuming fixed portions of land, it was not possible to analyze how the pattern of land use for (non) agricultural purposes will change. Due to the fact that it is a partial equilibrium study, it does not study the implications of these results in terms of the effects on other sectors of the economy. It is suggested that future studies take into account these issues.

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