CLIMATE CHANGE IMPACTS ON LATIN AMERICAN FARMLAND VALUES: THE ROLE OF FARM TYPE[1]

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Abstract: This paper examines climate change impacts on South American agriculture using a set of Ricardian regressions estimated across different samples of farms in South America. Regressions are run for the whole sample and for subsamples of crop-only, mixed, and livestock-only farms. The results indicate that climate sensitivity varies a great deal across each type of farm. The analysis also reveals that the impacts will vary substantially across South America. The hot and wet Amazon and Equatorial regions are likely to lose the most from warming scenarios whereas the more temperate high elevation and southern regions of South America will likely gain.

Keywords: Climate change, agriculture, South America

1. Introduction

Economists have spent almost two decades quantifying the impacts of climate change on agriculture (Adams et al. 1990, Rosenzweig and Parry 1994, Mendelsohn et al. 1994, Reilly et al. 1996, Seo et al. 2005, Schlenker et al. 2005, Kurukulasuriya et al. 2006, Deschenes and Greenstone 2007, Seo and Mendelsohn 2008). Studies of the US have predicted a wide range of impacts from climate change. For example, mathematical programming analysis (Adams et al. 1990), two Ricardian studies (Mendelsohn et al. 1994; Mendelsohn and Dinar 2003) and a fixed effects time series (Deschenes and Greenstone 2007) analysis all suggest only a mild impact. In contrast, agronomic studies (such as Rosenzweig and

Parry 1994) and a subsequent Ricardian study (Schlenker et al. 2005) show large impacts on US agriculture. One explanation for this range of results is that the agronomic and farm specific analyses fail to capture important adaptations that cause them to overestimate damages. Another explanation is that different types of farms may have different climate sensitivities (Schenkler et al. 2005). The climate response function of rainfed farms may be quite different from the response function of irrigated farms. It is also true that livestock is an important component of agriculture. Livestock accounts for a sizeable fraction of agriculture in every country and it is an important tool for adapting to dry conditions.

This paper carefully examines the role of farm type in explaining climate impacts. We examine the role that climate plays in South America farms paying close attention to differences across farm types. We test whether crop only, livestock only, and mixed (livestock and crop) farms have similar climate sensitivities. We also test the importance of allowing farmers to endogenously choose these farm types versus assuming the farm types are exogenous. Ricardian models are used to measure climate sensitivity. The theoretical foundation of the Ricardian method is briefly reviewed in the next section. Section 3 describes the data used for the analysis. A sample of 2300 farms from 7 South American countries is at the core of the data set.

Section 4 examines a series of different Ricardian regressions. In each case, land value is regressed on climate, soils, and other control variables. In the first model, we examine all farms and look at the climate sensitivity across every farm. The remaining analyses compare the results from looking at the whole sample versus looking at subsamples of different farm types. The analysis of the whole sample implicitly takes into account the endogenous choices of each farmer whether to raise crops, livestock, or both. The model endogenously captures adaptation as each farmer adjusts his farm type to fit the local situation. The Ricardian models of the subsamples, in contrast, assume that the farm type is exogenous. Comparing the results of the subsamples to the regression of the whole sample reveals the importance of endogenous switching across farm

types. We also compare the climate sensitivity of the different farm types to test whether they are the same.

Using the empirical results from the Ricardian regressions, we then explore the impacts from two climate models for 2100. We compare the impacts predicted for each sample for each climate scenario. We then map the changes across South America to reveal how these impacts are distributed across the landscape. One of the important results of the paper is that the impacts of climate change will not be the same across South America. The paper concludes with a discussion of the results.

2. Theoretical Foundation

We assume that each farmer maximizes income subject to the exogenous conditions of their farm. Specifically, the farmer chooses the crop or livestock or some mix of them and inputs for each unit of land that maximizes net revenue:

$$Max\pi_i = \sum_{j \in J} P_{ij} R_{ij}(X_{ii} \mid C_i, W_i, S_i) - \sum_{j \in J} P_{ij} X_{ii}) \tag{1}$$

where π_i is the net revenue of farm i, P_{ij} is a vector of input and output prices R_{ij} is the production function for each crop or livestock j, X_{ij} is a vector of endogenous input choices such as seeds, fertilizer, irrigation, pesticides, hired labor, and capital, C_i is a vector of climate variables, W_i is a vector of economic control variables, and S_i is a vector of soil characteristics. Note that J denotes a choice set of outputs which includes any combination of crops and livestock.

Differentiating (1) with respect to each input identifies the set of inputs that maximize net revenue. The resulting locus of net revenues for each set of exogenous variables is the Ricardian function. It describes how net revenue will change as exogenous variables change:

$$\pi^* = \pi(C, W, S \mid P_v) \tag{2}$$

Assuming perfect competition for land, the land value will be equal to the present value of the net revenue of each farm:

$$V_{land} = \int_0^\infty \pi_t^* \cdot e^{-rt} \, dt \qquad (3)$$

where r is the market interest rate.

The literature concerning the climate sensitivity of individual crops and livestock suggest a concave relationship between yield and temperature (see Reilly et al. 1996). One would consequently expect a concave relationship between annual temperature and net revenue as well. With crop livestock switching, farmers can make their choice set less concave by moving to more advantageous crops as climate changes (Mendelsohn, Nordhaus, and Shaw 1994). It follows that the more limited the set of choices available to a farmer, the more concave the climate response function. Of course, the concavity of the response function can be quite different depending on the set of choices that a farmer is restricted to. Restricting a farmer to rainfed crops versus irrigated crops may be quite different. This paper tests the climate sensitivity of farming under different restrictions. By comparing farms that can adapt at will with farms that are assumed to grow only rainfed crops or only livestock, one can test whether these restrictions increase climate sensitivity. One can also measure which restrictions lead to different outcomes as each component of agriculture may have very different climate sensitivities.

We estimate Equation 3 using seasonal climate variables along with other control variables. Because the response is nonlinear, a quadratic functional form is used. The model is then,

$$V_i = a + b_1 T + b_2 T^2 + b_3 P + b_4 P^2 + mG + \varepsilon_i \qquad (4)$$

where the dependent variable is land value per hectare of land, T and P represent a vector of seasonal temperature and precipitation variables,

G represents a vector of relevant control variables, ε is an error term, and the other parameters are coefficients. In this analysis, we rely on winter and summer seasonal temperature and precipitation variables.

We examine six models. We estimate the full adaptation case using the entire data set. This model allows farmers to endogenously adjust farm type as conditions change. We estimate the limited adaptation options by restricting the data set in the Ricardian regression. The subsequent three models hold a farmer to a particular farm type: livestock-only farms, crop-only farms, and mixed farms.

The impacts of climate change are measured by the difference in land value before and after climate change. The change in land value, ΔV, resulting from a climate change from C_0 to C_1 can be measured as follows:

$$\Delta V_{land} = V_{land}(C_1) - V_{land}(C_0) \tag{5}$$

We calculate Equation 5 for the full adaptation model and the five limited adaptation models. We expect that the full model will result in smaller climate change damages than the damages from the three limited models because farmers have more options to cope with changes in the full model.

The analysis assumes that prices remain unchanged (Cline 1996). Although changes in local supply might be dramatic, prices of food crops tend to be determined by global markets. With the expansion of crop production in some parts of the world and the contraction in others, the changes in the price of crops from global warming is expected to be small (IPCC 2007b). The analysis also does not take into account transition costs (Kelly et al. 2005). The analysis is a comparative static analysis. It is intended to capture the long run equilibrium impacts not the dynamic year to year path of climate change damages. The analysis also does not take into account carbon fertilization from the higher CO_2 concentrations and so overestimates damages.

3. Data on South American Agriculture

Our empirical analysis relies on an economic survey undertaken by country teams from seven countries in South America (Mendelsohn et al. 2007b). The seven countries include: Argentine, Uruguay, Chile, and Brazil from the Southern Cone region, and Venezuela, Ecuador, and Colombia from the Andean region. The countries were selected to represent the diversity of climate zones in South America. Districts were selected to capture a wide range of climates within each country. However, climates that could not support any agriculture were not surveyed. In each country, 15-30 districts were selected and 20-30 households were randomly chosen in each district. Cluster sampling in the districts was done to control the cost of the survey. The surveys asked questions about farming activities, both crop production and livestock production, land value and income during the growing period from July 2003 to June 2004.

Climate data come from two sources: observations of temperature come from U.S. Defense Department satellites (Basist *et al*., 1998) and observations of rainfall come from the World Meteorological Organization (WMO, 1989). In earlier comparisons across Brazil, it was found that the temperature measures from the satellite were superior to the interpolated weather station measures (Mendelsohn *et al*., 2007a). Most rural areas do not have a weather station nearby and so require interpolation. The satellites make direct observations over the entire land area using microwave imagers. These measures are very effective at capturing temperature but cannot directly capture precipitation.

Soil data were obtained from the Food and Agriculture Organization digital soil map of the world CD ROM (FAO, 2003). The data was extrapolated to the district level using a Geographical Information System. The data set reports 26 major soil groups, soil texture, and land slope at the district level.

We summarize the data with descriptive statistics of several important variables by farm types. Out of 2300 observations, about 76% of the

farms are rainfed farms and 24% are irrigated. The whole sample can
also be divided into crop-only farms (32%), livestock-only farms (13%),
and mixed farms (56%). The land value of crop-only farms is 2700
USD per ha, mixed farms is 1500 USD per ha, livestock-only farms is
1200 USD per ha, rainfed farms is 1600 USD per ha, and irrigated farms
are 6000 USD per ha. Rainfed farms (17 ᵃ%C) and mixed farms are
located in hotter places while crop-only farms (15.7 ᵃ%C) and livestock-
only farms are located in relatively more temperate places. Where there
is a high level of natural rainfall, farmers tend to choose rainfed farms
and mixed farms but where it is drier, farmers tend to choose livestock-
only farms.

4. Empirical Analysis

We begin our analysis by estimating Equation 4 on the whole sample, the
full adaptation model. Table 2 shows a regression of farmland values on
climate and other control variables. Having electricity or being in flat
terrain increases the value of land while clay soils decrease the value.
The value of farmland is higher with Luvisol and Verisol soils but lower
with Cambisol soils. Most of the climate variables are significant.

In Table 3, we calculate the marginal impact of climate. The results
reveal that warmer temperatures are harmful. Any warming would reduce
land values immediately. The results also reveal that an increase in
precipitation would also be harmful. This result is somewhat due to the
heavy rains that fall in this region. An increase in seasonal precipitation
during the monsoons is more harmful than an increase in beneficial rains
during the dry seasons.

The second analysis, shown in Table 4, is conducted on three subsamples
of farms: crop-only, mixed, and livestock-only farms. Climate variables
are mostly significant except for the livestock-only farms. The climate
coefficients of each farm type are different. Both temperature and
precipitation climate coefficients vary a great deal across farm types.

Having electricity benefits all farm types. Clay soils harm all farm types. When the terrain is flat, it is more suited to crop-only or mixed farms than livestock-only farms. Cambisol and Verisol soils reduce the value of crop-only farms.

Table 5 compares the marginal climate impacts and elasticities for each of the regressions in Table 4. Mixed farms are slightly more temperature sensitive than crop-only farms. However, livestock-only farms are far more sensitive than either of the crop farms. This is consistent with the observation that the livestock only farms are largely in the southern temperate region of South America. However, both crop-only and mixed farms are more sensitive to rainfall whereas the livestock only farms have almost no sensitivity to rainfall. Surprisingly, higher rainfall in South America leads to lower land value. This is because a great deal of the rainfall comes during a single monsoon season where rainfall exceeds what is needed in that season. Comparing the full sample with the partial sample results reveals that the temperature sensitivity of the full sample is on average lower than with the subsamples. This supports our general hypothesis that allowing the farm types to be chosen endogenously increases adaptation options and lowers climate sensitivity.

5. Forecasting Climate Impacts

We now use the estimated models from the previous section to forecast the impact of climate change on South American agriculture. We assume all other factors remain constant so that this is not a forecast of how farming will actually change. The forecast does not include likely changes of technology, capital investments, infrastructure, and population. The analysis is merely trying to explain what role climate change may play. We are especially interested in comparing what the different Ricardian models across farm types imply.

We rely on two climate models to provide forecasts of future climate change for each country in South America: the Canadian Climate Center

model (CCC) (Boer *et al.* 2000), and the Parallel Climate Model (PCM) (Washington *et al.*, 2000). Table 6 summarizes the average climate scenarios of each model in 2100 for South America. The PCM scenario is relatively mild and wet whereas the CCC scenario is relatively hot and dry. The two forecasts reflect the range of outcomes judged likely by the Intergovernmental Panel on Climate Change (IPCC 2007a). Note that the country level changes differ slightly from the continental average.

For each climate scenario, we add the climate model's predicted change to the baseline temperature in each district. We then multiply the climate model's predicted percentage increase in precipitation to the baseline precipitation in each district. This gives us a new climate for every district in South America. We then compute the land value per hectare of the current climate and each new climate using the parameter estimates in the previous section. Subtracting the future land value estimate from current land values yields a change in land value per hectare in each location.

In Table 7, we compare the predicted economic impacts from the regression across the whole sample model with the predicted impacts from the regressions across the three different farm types. With the PCM scenario, crop-only farms are predicted to lose 23% of their income, mixed farms lose 13% of their income, and livestock-only farms increase their incomes by 38%. Assuming that the fraction of each farm type remains constant, the average change is equal to -12%. In comparison, the prediction with the entire sample is that incomes would increase by 8%. Allowing farmers to switch across farm types makes a large difference in the PCM scenario.

With the CCC scenario, the losses are much larger. Crop-only farms are predicted to lose 43% of their income, mixed farms lose 41% of their income, and livestock-only farms lose over 100% of their incomes. Assuming that farm types remain constant, the expected value of these losses is -53%. In comparison, the predicted loss using the whole sample is -54%. With the CCC scenario, the exogenous and endogenous outcmes

are the same. In this scenario, it is likely that there is limited switching across farm types and so the flexibility to switch does not matter.

6. Concluding Remarks

This paper examined climate change impacts on South American agriculture using farmland values collected through household surveys across the continent. Economic impact estimates were measured both for the whole sample and for the limited samples. The three limited models capture crop-only farms, mixed farms, and livestock only farms.

The analysis revealed that both a temperature increase and a precipitation increase would be harmful to farmland values in South America. The models with country fixed effects made little difference in the estimates of climate change.

When the sample is limited to rainfed farms, temperature and precipitation elasticities measured at the mean of the sample were magnified. Constraining further to crop-only or mixed rainfed farms increased the magnitude of the damage from temperature increases slightly, but increased substantially the magnitude of damage from precipitation increase. On the other hand, livestock-only farms were highly vulnerable to marginal increase in temperature at the mean of the sample.

We then simulated climate change impacts for the coming century based on a set of AOGCM climate scenarios. The full adaptation model predicts the damage is about -50% under the CCC scenario but there is a slight gain of 8% under the PCM scenario by 2100. The analysis also reveals that both crop-only and mixed farms would be vulnerable to large climate changes but that livestock only-farms were particularly vulnerable. Finally, comparing the results for the entire sample with the partial samples, the analysis suggests that switching farm types is very important in the PCM scenario but not the CCC scenario. In some scenarios, farmers will not profit from changing farm types and so will remain as they are.

In conclusion, the magnitude of climate damage to agriculture in South America will depend upon which climate scenario unfolds. If climate becomes hot and dry, farms will lose half of their incomes by 2100. On the other hand, if climate warms only slightly, farms will gain slightly.

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Resumo: Este trabalho analisa os impactos de mudanças climáticas na agricultura sul-americana por meio de um conjunto de regressões ricardianas estimadas a partir de diferentes amostras de propriedades rurais da América do Sul. As regressões foram "rodadas" para o total da amostra e para sub-amostras (produção de grãos, mistas e produção de animais). Os resultados indicam que há grande variação entre tipos de propriedade em resposta às mudanças climáticas. A análise revela também que os impactos variarão substancialmente na América do Sul. A Amazônia e regiões equatoriais serão, provavelmente, as mais afetadas nos cenários de aquecimento (elevação da temperatura) enquanto as regiões mais ao sul da América do Sul provavelmente ganharão com a elevação da temperatura.

Palavras-chave: Mudança climática, agricultura, América do Sul.

Appendix

Table 1 - Descriptive Statistics, July 2003-June 2004

Var.	All Farms	Crop Only Farms	Mixed Farms	Livestock Only Farms
Number of Farms	2035	643	1131	261
Land value USD/ha	1848	2680	1531	1168
Temperature °C	16.4	15.7	16.7	16.4
Precipitation mm/mo	100.6	98.7	102.6	97.1

Table 2 -   Ricardian Regression on Land Value for All Farms With and
Without Country Fixed Effects

	Without Country Fixed Effects	
Variable	Coef.	t stat.
Intercept	-419.1	-0.55
Temperature summer	310.8	3.81
Temperature summer squared	-13.21	-5.55
Temperature winter	373.1	8.55
Temperature winter squared	-9.37	-6.63
Precipitation summer	-2.22	-0.48
Precipitation summer squared	-0.03	-1.40
Precipitation winter	-31.36	-5.09
Precipitation winter squared	0.13	3.32
Cambisol Soil	-3.48	-0.86
Luvisols Soil	9.09	2.90
Verisols Soil	2.25	0.73
Electricity	588.7	4.52
Flat land	337.0	3.22
Clay soil	-447.6	-3.26
N	2035	
Adjusted R-sq	0.14	

Table 3 - Marginal Climate Impacts and Elasticities of Ricardian Regression on Land Value With and Without Country Fixed Effects for Entire Sample

	Marginal Effects	Elasticities
Temperature	-76.0	-0.68
Precipitation	-22.5	-1.22

Table 4 - Ricardian Regression on Land Value for Three Farm Types (USD/ha)

	Crop-Only		Mixed		Livestock-Only	
Variable	Coef.	t stat	Coef.	t stat	Coef.	t stat
Intercept	-7427.9	-3.24	2798.4	2.60	-4006.0	-0.93
Temperature summer	669.2	2.86	-471.9	-3.95	433.9	0.91
Temperature summer squared	-25.16	-3.70	7.16	2.13	-22.44	-1.87
Temperature winter	346.2	2.80	483.9	8.85	554.9	3.52
Temperature winter squared	-4.58	-1.19	-12.86	-6.97	-9.07	-2.10
Precipitation summer	84.84	3.59	63.73	6.07	-6.32	-0.48
Precipitation summer squared	-0.38	-4.39	-0.27	-6.80	0.03	0.57
Precipitation winter	-35.28	-2.33	-52.21	-6.72	59.38	1.67
Precipitation winter squared	0.05	0.53	0.22	4.19	-0.48	-1.58
XXX Soil	-21.79	-1.90	4.59	1.02	17.89	0.85
Luvisol Soil	7.34	0.85	12.50	3.73	7.39	0.20
Verisol Soil	-13.94	-1.19	10.69	1.92	67.19	3.81
Electricity	746.2	2.15	453.4	2.51	86.4	0.32
Flat land	298.3	1.05	613.0	4.52	-152.8	-0.39
Clay soil	-526.1	-1.57	-201.4	-1.25	-540.1	-1.26
N	643		949		261	
Adjusted R-sq	0.13		0.28		0.56	

Table 5 -   Marginal Climate Effects and Elasticities Across All, Crop-
Only, Mixed, and Livestock-Only Farms

Farm Type	Marginal Effects Temperature USD/ha/yr/°C	Marginal Effects Precipitation USD/ha/yr/mm/mo	Elasticities Temperature	Elasticities Precipitation
All	-76	-22.5	-0.68	-1.22
Crop-only	-74	-49.9	-0.53	-2.16
Mixed	-88	-34.6	-0.99	-2.32
Livestock-only	-175	-1.9	-2.47	-0.15
Expected	-94.7	-35.2	-0.85	-1.91

Table 6 - AOGCM Climate Scenarios

	NOW	2100
Temperature Summer		
	°C	Change
CCC	19.9	+5.0
PCM	19.9	+1.4
Temperature Winter		
	°C	Change
CCC	16.4	+5.2
PCM	16.4	+2.6
Precipitation Summer		
	mm/mo	Change
CCC	162	-12.3%
PCM	162	+1.9%
Precipitation Winter		
	mm/mo	Change
CCC	75	+1.3%
PCM	75	+22.7%

Table 7 - Climate Change Impacts by Farm Types in 2100 (USD/ha)

Land Type	Baseline	CCC	PCM
All	1835	-993	+141
		(-54%)	(+8%)
Crop Only	2344	-1019	-551
		(-43%)	(-23%)
Mixed	1538	-629	-194
		(-41%)	(-13%)
Livestock Only	1271	-2382	+487
		(-187%)	(+38%)
Expected Value	1835	-977	-220
		(-53%)	(-12%)