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An Analysis of Livestock Choice:

Adapting to Climate Change in Latin American Farms[1]

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Abstract

This paper explores how Latin American livestock farmers adapt to climate by switching species. We develop a multinomial choice model of farmer's choice of livestock species. Estimating the models across over 1200 livestock farmers in seven countries, we find that both temperature and precipitation affects the species Latin American farmers choose. We then use this model to predict how future climate scenarios would affect species choice. Global warming will cause farmers to switch to beef cattle at the expense of dairy cattle.

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1. Introduction

This paper uses cross-sectional evidence to explore how farmers adapt to exogenous environmental factors such as climate and soils. By comparing choices of farmers who face different conditions, the model uncovers how farmers adapt. We specifically examine how climate affects which species Latin American farmers choose to own. We test whether climate alters species choice. Understanding species switching (adaptation) is an important goal in itself to assist planning by policy makers and private individuals. However, understanding adaptation is also important if one is interested in quantifying the impacts of climate change. The impacts of climate change not only require understanding how each species will be affected but also how farmers will switch across species.

Climate impact studies have consistently predicted extensive impacts to the agricultural sector from climate change across the globe (Pearce et al. 1996; Tol 2002). The bulk of agriculture studies on the effect of climate change have focused on crops. However, a large fraction of agricultural output is from livestock. Yet there are very few economic analyses of climatic effects on livestock. Most of the livestock studies related to climate change have not explored the economic impacts (Watson et al. 1995; McCarthy et al 2001).

Two important exceptions are the study of the effects of climate change on American livestock (Adams et al. 1999) and the study of climate and African livestock (Seo and Mendelsohn 2006). Individual American livestock are sensitive to climate. For example, beef catle cannot tolerate high temperatures. However, by using cool locations, protected environments (sheds, barns, etc.) and supplemental feed (e.g. hay and corn), the American livestock sector is not sensitive to warming (Adams et al 1999). In Africa, by contrast, the bulk of livestock have no protective structures and they graze off the land. They currently live in the coolest locations available. African livestock, and especially beef cattle, are sensitive to climate (Seo and Mendelsohn 2006). Warmer temperatures cause African farmers to move away from beef cattle causing large damages. Interestingly, small farmers can substitute sheep and goats for beef cattle and would therefore not be vulnerable to warming.

The theoretical choice model is developed in the next section. Section 3 discusses how data were collected from over 2000 farmers in seven countries across Latin America. Section 4 discusses the estimation procedure and the empirical results. Three climate change scenarios from Atmospheric Oceanic General Circulation Models (AOGCM's) are then examined in Section 5. The paper concludes with a summary of results and policy implications.

2. Theory

In this paper, farmers are assumed to maximize their profits. Farmers choose the desired species to yield the highest net profit. Hence, the probability that a species is chosen depends on the profitability of that animal. We assume that farmer *j*'s profit in choosing livestock *i (i=1, 2,…,IJ)* is

$$\pi_{ij} = V_i(K_j, S_j) + \varepsilon_i(K_j, S_j) \quad (1)$$

where K is a vector of exogenous characteristics of the farm and S is a vector of characteristics of the farmer. For example, K could include climate, soils and access variables and S could include the age of the farmer and family size. The profit function is composed of two components: the observable component V and an error term, ε. The error term is unknown to the researcher, but may be known to the farmer. The farmer will choose the livestock that gives him the highest profit. Defining $Z = (K, S)$, the farmer will choose animal *i* over all other animals *k* if:

$$\pi_i^*(Z_j) > \pi_k^*(Z_j) \text{ for } \forall \text{ k} \neq i.[\text{or if } \varepsilon_k(Z_j) - \varepsilon_i(Z_j) < V\ (Z_j) - V_k(Z_j) \text{ for k} \neq i] \quad (2)$$

More succinctly, farmer j's problem is:

$$\underset{i}{\arg\max}[\pi_1^*(Z_j), \pi_2^*(Z_j), ..., \pi_I^*(Z_j)] \quad (3)$$

The probability P_{ji} for livestock (i) to be chosen by farmer (j) is then

$$P_{ji} = \Pr[\varepsilon_k(Z_j) - \varepsilon_i(Z_j) < V_i - V_k]\ \forall \text{ k} \neq i \text{ where } \mathrm{V_i} = \mathrm{V_i}(\mathrm{Z_j}) \quad (4)$$

Assuming ε is independently Gumbel distributed and $V_k = Z_{kj}\gamma_j + \alpha_k$,

$$P_{ji} = \frac{e^{Z_{ji}\gamma_j}}{\sum_{k=1}^{I} e^{Z_{jk}\gamma_j}} \quad (5)$$

which gives the probability that farmer (j) will choose livestock (i) among (I) animals (McFadden 1981). This is the standard derivation of the multinomial logit model. The parameters of the model are γ_j.

The parameters can be estimated by the Maximum Likelihood Method, using an iterative nonlinear optimization technique such as the Newton-Raphson Method. These estimates are CAN (Consistent and Asymptotically Normal) under standard regularity conditions (McFadden 1999).

Note that farmers can choose more than one species of livestock among the five animals in our study. That is, there are many combinations of animals that the farmer could choose. In this analysis, we examine only the primary animal chosen by each farmer. The primary animal is the single animal that generates the highest total net revenue in the farm (Train 2003). Given these assumptions, the set of choices are mutually exclusive.

3. Data

The data for this study came from a World Bank project to study climate change impacts on agriculture in Latin America. The project used economic surveys to collect farm level data from the following seven countries: Argentina, Brazil, Chile, Columbia, Ecuador, Uruguay, and Venezuela. The countries were selected to represent the wide range of climate throughout South America and include representatives from both the Southern Cone and Andean regions. Districts within each country were selected to provide as much within country climate variation as possible. The original survey interviewed over 2000 farmers of which 1278 raised livestock.

The data includes information on livestock production and transactions, livestock products, and relevant costs. The five major types of livestock in Latin America are beef cattle, dairy cattle, pigs, sheep and chickens.

Climate data came from two sources: US Defense Department satellites and weather station observations. We relied on satellite temperature observations and interpolated precipitation observations from ground stations (see Mendelsohn et al 2006 for a detailed explanation). Soil data were obtained from the FAO digital soil map of the world CD ROM. The soil data was extrapolated to the district level using GIS (Geographical Information System). The data set reports 26 dominant soil types.

4. Empirical results

In practice, farmers can own more than one type of animal. In this analysis, we focus on the five primary species that generated the most livestock income to each farmer: beef cattle, dairy cattle, sheep, pigs and chickens. Altogether these five animals generated 90% of the total revenue from livestock.

In Table 1, we estimate the probability each species is selected using a multinomial choice model. The dependent variable is the (1, 0) choice of whether each species was chosen. Because every farmer must choose one animal, one choice had to be omitted. The choice of chickens has been left out of the regression as the base case. The regressions are explaining how the independent variable affected each choice relative to choosing chickens. The probability of choosing each animal was assumed to be a function of summer and winter temperature and summer and winter precipitation. Other explanatory variables included a dummy variable for the Andean region, three soil variables, a dummy variable for gender, and a dummy variable for a computer.

The model is significant according to three tests of global significance. Most of the individual coefficients are significant. The second column for each choice describes the chi-squared statistic, χ^2 (a measure of statistical significance). P-values show the probability the coefficient is zero. Positive coefficients imply that the probability of choosing the animal increases as the corresponding variable increases.

The climate variables are mostly significant (χ^2 >**4.0)**. The coefficients on the quadratic terms tend to be positive when significant which implies the response function between the probability of each species being chosen and climate is U-shaped. This is especially true for precipitation. Soils can affect which species is chosen as some soils (such as Acrisols) lead to more productive grazing lands whereas others (Luvisols and Arenesols) are less productive. Households with computers are more likely to pick chickens rather than grazing animals. Female farmers are more likely to pick dairy and sheep. Finally, dairy, sheep, and pigs are more likely in the Andean region.

Figure 1 graphs the relationship between the probability of choosing a species and annual temperature. Note that the mean temperature in Latin America is 18°C. The probability of choosing beef cattle and chickens decline as temperatures rise above 18°C. By contrast, the probability of choosing dairy and sheep increases. With pigs, the estimated probability first rises and then declines. The graph clearly reveals that the choice of animals in Latin America is temperature sensitive.

Figure 2 displays the estimated relationship between the probability of choosing an animal and annual precipitation. The mean annual precipitation in Latin America is 118 mm/month. The probability of choosing beef cattle declines precipitously as precipitation increases above the mean. By contrast, more rain leads to more dairy cattle. The other species exhibit a U-shaped pattern where they first decline and then increase.

5. Climate scenarios

In this section, we simulate the consequences of climate change using the parameter estimates in the previous section. We examine a set of climate change scenarios predicted by AOGCMs. The climate scenarios reflect the A1 SRES scenarios from the following three models: the Canadian Climate Center (CCC) scenario (Boer et al. 2000), Centre for Climate System Research (CCSR) (Emori et al. 1999), and the Parallel Climate Model (PCM) scenario (Washington et al. 2000). We use country level climate change scenarios in 2020, 2060, and 2100 from each climate scenario. The change in temperature predicted by each climate model is added to the baseline temperature in each district. The percentage change in precipitation is multiplied by the baseline precipitation in each district. This gave us a new climate for every district in Latin America for each scenario.

Table 2 summarizes the climate scenarios of the three models for the years 2020, 2060, and 2100. The models predict a broad set of scenarios consistent with the range of outcomes in the most recent IPCC (Intergovernmental Panel on Climate Change) report (Houghton et al. 2001). In 2100, PCM predicts a 2°C temperature increase in Latin America whereas CCC predicts a 5°C increase. Rainfall predictions are noisier: PCM predicts rainfall to increase by 8% by 2100 whereas CCC predicts rainfall to decrease by 8%. Examining the path of climate change over time reveals that temperatures are predicted to increase steadily until 2100 for all three models but precipitation will vary across time.

The parameters from the estimated multinomial logit models are used to simulate the impacts of climate change on the probabilities of choosing a particular animal for each climate scenario in Table 3. The dry and hot CCC and CCSR scenarios predict that farmers would choose beef cattle and sheep more often and dairy cattle, pigs, and chickens less often. With the wetter and milder PCM scenario, farmers will pick sheep more often and beef and dairy cattle less often.

6. Conclusion

This paper uses a multinomial choice model to capture the choice of species made by farmers.

The model is estimated across over 1200 farmers in Latin America. We observe that the choice of species varies with climate. Beef cattle are chosen more often in cooler dryer climates. Chickens are chosen in cooler places. Dairy cattle are preferred in wetter hotter climates. Sheep and pigs appear to be heat tolerant.

These results are completely consistent with observations of where species are currently located. Beef cattle are currently concentrated in the relatively cool and dry regions of Argentina, Uruguay, and southern Brazil. Dairy cattle are seen more often in the hotter and wetter regions of Columbia, Brazil, and Chile. Sheep are located in relatively cool locations in Argentina and Chile. Pigs are primarily concentrated in Brazil and chickens are most common in Ecuador.

The probability response functions for Latin America study are quite consistent with the response functions from Africa (Seo and Mendelsohn 2006). Beef cattle and chickens have a hill-shaped relationship with temperature. Dairy cattle are more heat tolerant. However, because Africa is hotter than Latin America, warming is more harmful to African beef cattle compared to Latin American beef cattle. Further, Latin America and especially Brazil grow pigs which are relatively rare in Africa whereas Africa owns goats which are relatively rare in Latin America. Both of these animals tend to be heat tolerant. The only species which has very different climate effects in the two continents is sheep. In Africa, sheep are often chosen in hot locations whereas in Latin America, they are far more likely in cooler locations.

In interpreting these results, there are several caveats that should be kept in mind. First, this analysis does not include price effects. Large changes in animal prices may alter the results. Second, we assume that adaptations can take place as needed. For example, farmers can switch from one animal to another as temperature increases and rainfall decreases. However, this may not be the case if the adjustment requires a heavy capital investment.

Third, we assume that in forecasting climate change impacts, the only thing that changes in the future is climate. Many things, however, will change over the century such as population, technologies, institutional conditions, and reliance on agriculture and livestock. Future studies should address these issues and provide ever more accurate measure of climate change impacts.

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Table 1: Multinomial logit selection model

	Beef cattle			Dairy cattle		
Variable	**Coefficient**	χ^2	**P-value**	**Coefficient**	χ^2	**P-value**
Intercept	0.599	0.130	0.722	2.021	1.560	0.212
Temperature summer	0.102	0.230	0.629	-0.212	1.040	0.308
Temperature summer sq	0.001	0.010	0.906	0.003	0.170	0.683
Precipitation summer	0.016	13.020	0.000	0.011	6.950	0.008
Precipitation summer sq	0.000	15.870	<.0001	0.000	9.930	0.002
Temperature winter	-0.148	2.140	0.143	0.144	2.090	0.148
Temperature winter sq	0.003	0.670	0.414	-0.001	0.120	0.733
Precipitation winter	-0.008	2.310	0.128	-0.009	4.040	0.045
Precipitation winter sq	0.000	1.010	0.315	0.000	9.440	0.002
Soil Acrisols	0.055	7.580	0.006	0.044	4.820	0.028
Soil Luvisols	-0.026	20.300	<.0001	-0.011	4.510	0.034
Soil Arenosols	-0.022	4.380	0.036	-0.036	10.280	0.001
Computer dummy	-0.566	9.760	0.002	-0.342	3.440	0.064
Female dummy	0.266	2.230	0.135	0.493	7.100	0.008
Andes dummy	0.171	0.680	0.411	0.535	6.720	0.010

Table 1: (continued)

	Sheep			Pigs		
Variable	**Coefficient**	χ^2	**P-value**	**Coefficient**	χ^2	**P-value**
Intercept	-5.047	3.210	0.073	-3.015	1.200	0.273
Temperature summer	0.728	4.740	0.029	0.079	0.060	0.814
Temperature summer sq	-0.016	2.660	0.103	-0.005	0.220	0.640
Precipitation summer	-0.005	0.560	0.454	0.011	2.520	0.112
Precipitation summer sq	0.000	1.680	0.195	0.000	7.200	0.007
Temperature winter	-0.448	8.840	0.003	0.344	4.310	0.038
Temperature winter sq	0.016	10.380	0.001	-0.008	2.130	0.144
Precipitation winter	-0.028	10.080	0.002	-0.021	7.140	0.008
Precipitation winter sq	0.000	8.060	0.005	0.000	9.820	0.002
Soil Acrisols	-0.138	0.000	0.000	0.046	4.460	0.035
Soil Luvisols	-0.014	3.350	0.067	-0.036	5.550	0.019
Soil Arenosols	-0.043	2.530	0.112	-0.016	1.290	0.257
Computer dummy	-0.293	1.550	0.213	-0.628	7.360	0.007
Female dummy	0.997	6.310	0.012	0.118	0.170	0.683
Andes dummy	0.923	7.910	0.005	1.134	11.670	0.001

Note: Omitted choice is chickens. Likelihood ratio test: P<0.0001, Lagrange multiplier test: P<0.0001, Wald test: P<0.0001

Table 2: Latin American Average AOGCM Climate Scenarios

	Current	**2020**	**2060**	**2100**
Temperature (°C)				
CCC	18.1	19.5 (+1.4)	20.8 (+2.7)	23.2 (+5.1)
CCSR	18.1	19.4 (+1.3)	20.4 (+2.2)	21.3 (+3.2)
PCM	18.1	18.7 (+0.6)	19.5 (+1.3)	20.1 (+2.0)
Rainfall (mm/month)				
CCC	119	116 (-2.6%)	107 (-9.5%)	109 (-7.7%)
CCSR	119	120 (+1.5%)	119 (0.0%)	114 (-3.8%)
PCM	119	128 (+8.2%)	133 (+11.9%	129 (+8.4%)

Table 3: Predicted change in the probability of selecting each animal from AOGCM climate scenarios

	Beef cattle	**Dairy cattle**	**Sheep**	**Pigs**	**Chickens**
Baseline	47.9%	33.4%	6.4%	4.6%	7.8%
2020					
CCC	+3.06%	-2.04%	+0.35%	-0.67%	-0.70%
CCSR	+1.79%	-1.13%	+0.47%	-0.58%	-0.55%
PCM	-5.02%	+2.30%	+1.72%	+1.02%	-0.02%
2060					
CCC	+4.63%	-3.56%	+1.26%	-0.99%	-1.34%
CCSR	+3.59%	-2.82%	+1.24%	-1.22%	-0.79%
PCM	-3.51%	+1.16%	+1.96%	+0.32%	+0.07%
2100					
CCC	+6.94%	-5.79%	+3.04%	-1.94%	-2.26%
CCSR	+5.50%	-4.14%	+1.09%	-1.61%	-0.84%
PCM	-1.85%	-0.53%	+2.61%	-0.06%	-0.18%

Figure 1: Estimated probability of selecting species given annual temperature

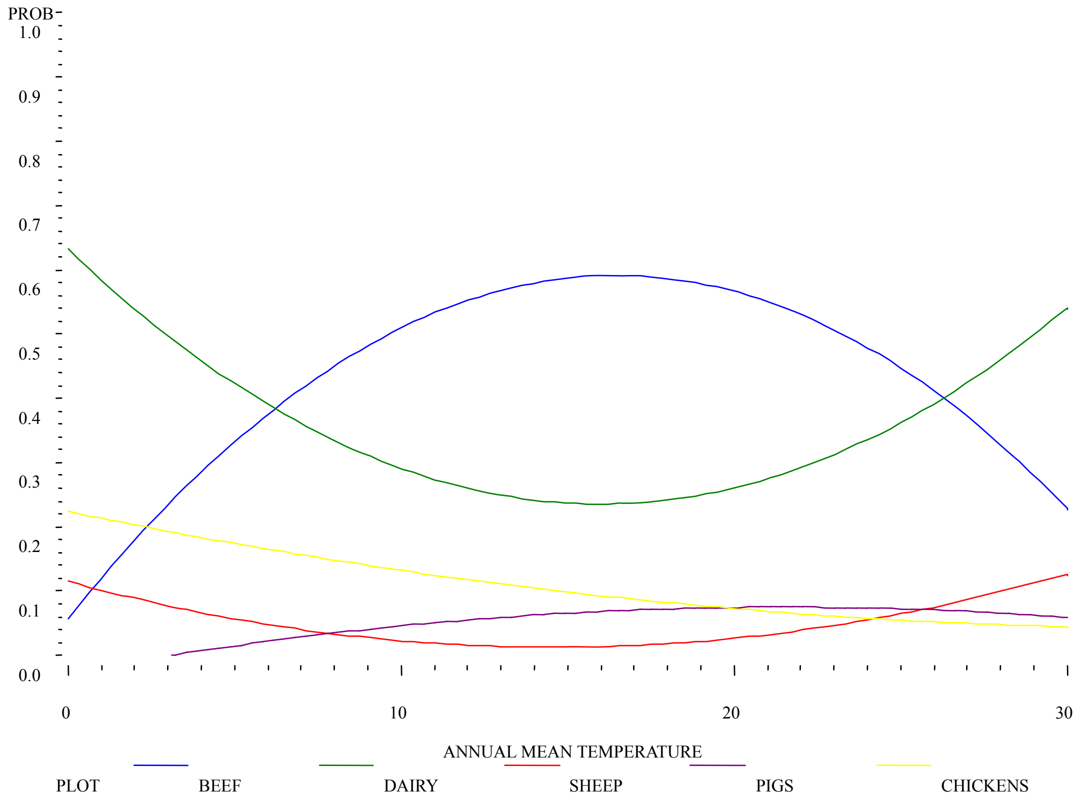

Figure 2: Estimated probability of selecting species given annual precipitation