TECHNOLOGY, CLIMATE CHANGE, PRODUCTIVITY AND LAND USE IN BRAZILIAN AGRICULTURE[*]

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Abstract

The Ricardian model of climate change impacts is extended to include technological services from private and public agricultural research programs and climate change impacts on land use. The extended model is estimated for Brazil and the climate-land value, climate-land use, the technology-land value and the technology-land use linkages estimates are used to simulate both climate change and technology service impacts. Two sets of implications for policy emerge from the estimates of climate and technological change for Brazilian agriculture. The first set is indirect regarding the urgency and importance of policies designed to slow climate change. The second set is direct regarding

policies to compensate for and ameliorate climate change.

1. Introduction

T he "Ricardian" model of land productivity has been applied to Brazil by Sanghi, et al., (1997) and Sanghi and Mendelsohn, (1998). Since land productivity is associated with land use (i.e., the use of land for crops, pasture and forestry) there is a natural extension for the Ricardian model to a land use analysis.[1]

The original application of the Ricardian model to land productivity did not explicitly consider spatial differences in technology. Implicitly the climate change estimates obtained assumed that the technology available to farmers at the time of the census observations would continue to be available during the climate change simulation period. Sanghi, et. al.,(1997) and Sanghi and Mendelsohn,(1998) examine how climate in different places of Brazil affects the net rent or value of farm land. Doing so enables them to account for both the direct impacts of climate on yields of different crops as well as the indirect substitution of different activities, introduction of different activities, and other potential adaptation to different climates. Using Brazilian municipio level data they estimate the effect of climatic variables and a variety of geographical, soil, economic, and demographic factors to determine the intrinsic value of climate on farmland. Their analysis suggests that climate has a systematic impact upon agricultural rents and thus costs through temperature and precipitation. They also suggest that these effects tend to be very non linear and quite different by season. Studies of agricultural productivity in Brazil (Avila and Evenson, (1995), and da Cruz, et al., (1998)) have developed procedures for associating agricultural productivity with investments in both public and private sector R&D, with extension program investments and with infrastructure investments.

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[1] Land use is implicit in the product supply and factor demand systems. That is, the choice of output supplies and inputs implies a land use allocation. See Merrick (1978) for an early land use study in Brazil.

In this paper we report two extensions to the original Ricardian studies. The first is to combine the methodology of the agricultural productivity studies with the Ricardian methodology to achieve dynamic estimates of climate change impacts on agricultural productivity in Brazil. The second extension is to bring both the Ricardian and the productivity methodologies into a land use analysis. It is very important to understand how climate change will affect farmland value or productivity as well as to estimate the possible effect on land use and more specifically on the natural forest share on total agricultural land in Brazil. Not less important is to shed some light on the relation between climate change and technology change. Technological change is affected by private as well as by public resources allocation. These extensions enable us to examine climate-technology interactions and to assess the prospects for offsetting climate change impacts through investments in research and extension. The estimates are based on farm data from the 1975, 1980 and 1985 Brazilian Censuses of Agriculture, supplemented by climate, institutional and technological data.

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In part II we review the methods underlying our empirical specifications. In part III we describe our data and variables. Part IV reports our estimates. Part V reports computations of climate, technological and infrastructural change on land use on farms in Brazil. Part V reports estimates of climate, technological and infrastructural change on farm land productivity. In the concluding section we discuss the policy implications of our estimates.

2 Methodology

We describe production options for each land use with a general transformation function:

(1) $F_i(Y_i, X_i, L_i, C, G, E, T, I, W)$, $i = 1,..,6$

where:

i is land use

Y_i is a vector of outputs produced on land use i

X_i is a vector of variable inputs used on land use i

L_i is land area in land use i

C is a vector of normal or expected climate variables (temperature, rainfall, etc.)

G is a vector of geographic variables (altitude, etc.)

E is a vector of edaphic variables measuring soil characteristics

T is a vector describing available technology

I   is a vector describing market infrastructure

The maximized profits function associated with (1) for each the land use category is

(2) $\prod_i^* = \sum P_{yi} Y_i^* - \sum P_{xi} X_i^* = \prod_i (P_y, P_x, L_i, C, G, E, T, I, W)$

and the system of product supply and factor demand equations is[2]

(3) $\partial \prod_i^* / \partial P_{yi} = Y_i = Y_i (P_y, P_{xi}, L_i, C, G, E, T, I, W)$

$\partial \prod_i^* / \partial P_{xi} = X_{ij} = X_{ij} (P_{yi}, P_{xi}, L_i, C, G, E, T, I, W)$

Note that expressions (2) and (3) state that farmers choose profit maximising output and input combinations in response to climate (and other variables).

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See Merrick (1978) for an early land use study in Brazil.

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We define land use categories as follows:

APC: Area in perennial crops

AAC: Area in annual crops

ANP: Area in natural pasture

APP: Area in planted pasture

ANP: Area in natural forests

APF: Area in plantation forests

Within each of these land use categories we argue that farmers can change areas planted to particular crops or type of pasture and forests at low cost. Significant investments are required, however, to convert land from one of these categories to another.[3]

Total land in farms in a Brazilian municipio is relatively fixed and determined by past road building investments, industrial development and infrastructure. A considerable amount of Brazilian land in farms is actually in the forest use categories (see below). Total land in farms also includes fallow land and unproductive land. These uses are treated as the residual category in our empirical work.

Land use investments will be based on expected profits for each type of land (as noted in (2)). Expected profits are governed by the C,G,E,T and I vectors as well as relative prices. Using the argument that total land in farms in a municipio is relatively fixed, we argue that land use shares in each municipio are related to the C,G,E,T and I variables.

(4) $S_i = S_i(C,G,E,T,I)$

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[3]   *We are thus acknowledging that within each land use class farmers shift between different crops from year to year.*

where S_i is the share of total land in farms in land use category i. We also use the argument that relative price differentials between regions are effectively determined by the C,G,E,T and I variables and can be eliminated from (4). In the next section we define the variables that we use to estimate (4). we note here that while, in principle, there are cross-equation restrictions associated with commodity prices and with investment goods prices, we have not utilised them because of the price endogeniety argument.[4]

The relationship between land productivity and climate, technology and infrastructure is essentially based on the same arguments. The average profits per hectare of land will be reflected by (2) in the short run for each land use. In the longer run, land use will respond to changes in technology, climate and infrastructure. Potential buyers and sellers of land will capitalise expected future profits from the most valuable land use and we thus expect land values in a cross-section to be related to the C,G,E,T and I variables

(5) Value/Hectare = V_L(C,G,E,T,I)

We argue, as did Mendelsohn, et al. 1994, that cross-section (or multiple cross-section) differences in land use and land values can be utilised to estimate (4) and (5) and identify the effects of climate on land use and land values enabling us to compute the following expressions:

(6) $\partial S_i / \partial C, \partial S_i / \partial T$ and $\partial^2 S_L / \partial C \partial T$

and

(7) $\partial V_L / \partial C, \partial V_L / \partial T$ and $\partial^2 V_L / \partial C \partial T$

Expression (6) shows the impact of climate and technology on land use shares. It also shows the interactive effect of technology on the climate impact. (These computations are reported in Part V.) Expression (7) shows the impacts of

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[4]   *The profits function system (3) has cross-equation price terms.*

climate and technology on land values and indirectly on land productivity. (These computations are reported in Part VI.)

Expressions (4) and (5) allow for farmer adaptation in Y and X to climate change and to technical change. This adaptation includes investments in farm level irrigation and drainage and in farm practices. There is, however, potential adaptation by the organizations producing technology and infrastructure for farmers to be considered and these create technology-climate interactions. The technology and infrastructure organizations include private firms who conduct R&D to develop improved factors to be supplied to the agricultural sector and the public sector agricultural research and extension organisations who also develop improved technology for agriculture. They also include public sector units providing for and maintaining infrastructure.

We know that researchers do consider climate conditions in their research programming. Plant breeders are continually seeking genetic traits to change the length of growing seasons and to endow plants with "host plant tolerance" to cold and warm temperatures, to drought and flood stresses, and related climate effects. Their motivation for seeking to incorporate these traits in crop varieties is to allow superior genetic material (e.g., the semi-dwarf wheat and rice varieties) to overcome climate and edaphic barriers to their "migration,' to new areas. This cross-section motive is likely to be good proxy for a time series motive, i.e., to respond to increases in temperature.[5]

Implicitly, this suggests that there may be important "expected" C x T and C x I, interactions in (4) and (5). It may be argued that since climate has changed little over the past 25 years or so, the developers of technology (both public and private) and investors in infrastructure have not responded to

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[5]   *These motives aren't necessarily the same as those that would be generated by an explicit recognition that temperatures were using and that growing seasons were changing, but the research techniques for developing heat tolerant cultivars, etc. would be similar to those employed for crop migration motives.*

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climate change. However, the underlying premise of the estimates obtained from cross-section data in the Ricardian model where C varies over locations, is that these do measure farmers responses to C. Similarly one can argue that T and I reflect responses to C and that C x T and C x I interactions in (4) and (5) provide estimates of future net effects of climate on land use and productivity.

Suppose, for example, that we have two regions (1 and 2) which differ in temperature (t_l and t_2, and edaphic factors (E_1 and E_2))- Suppose that a rise in temperature damages crops in both regions if crops do not migrate from one region to the other. If t_1 rises to the former level of t_2 region 1 can escape this damage if the crops suited to region 2 migrate to region 1. This migration will be affected by edaphic barriers. Plant breeders engage in host plant tolerance breeding for edaphic stresses to facilitate this migration.[6]

Brazil has a large public sector system of agricultural research centers. It also has industrial R&D where technology is produced to be used in the agricultural sector. Avila and Evenson (1995) and da Cruz et al. (1997) have undertaken productivity studies of both the public and private sector research systems. The public system consists of state research centers and experiment stations and a federal system, EMBRAPA. In these prior studies, research "stock" variables were constructed to reflect the regional and timing dimensions of this research. Private sector R&D stocks were constructed from invention data. (See da Cruz, et al. (1997) and the appendix for more details.) These technology variables are suited not only to the productivity analyses conducted by da Cruz, et al.1977, but they are also suited to the present study.[7]

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[6]   *See Avila and Evenson (1995).*

[7]   *The actual variables are "capital stock," variables constructed to reflect the productivity contributions in each region.*

3 Data

Table 1 provides an overview of the data on which the study is based. (See the Appendix for more detail.)

TABLE 1

Variables Description and Means: 1985

		Description	Means
I.	**Endogenous Variables**		
	AAC/LIF	Acreage in annual crops	.07
	ARC/LIF	Acreage in perennial crops	.22
	ANP/LIF	Acreage in natural pasture	.30
	APP/LIF	Acreage in planted pasture	.19
	ANF/LIF	Acreage in natural forests	.17
	APF/LIF	Acreage in planted forests	02

LIF = APC + AAC + ANP + APP + ANF + APF areas in fallow + areas unsuited to production VLNA = VLAND/LIF

II.	**Exogenous Variables**		
(A) Climate (C)			
	RN DEC	Normal December rainfall	172.9
	RN JUN	Normal June rainfall	73.6
	RN MAR	Normal March rainfall	173.1
	RN SEP	Normal September rainfall	64.5
	TC DEC	Normal December temperature	24.4
	TN JUN	Normal June temperature	20.0
	TN MAR	Normal March temperature	24.3
	TN SEP	Normal September temperature	22.2

Note: **Squared values and rain and temperature interactions are included in the estimation**.

(B) Geographic Variables (G)			
	ERS1* - ERSS*	Dummy variables for the two	
		dummy predisposition to	
		erosion indexes in the	
		municipios	
	ALT'M	Altitude in meters	428.9

LATMN	Latitude in degrees	-16.2
DSEAM	Distance from sea	230.9

(cont...)

(continued)

	Description	Means
(C) Edaphic Variables (E)		
SCCB* - STBR*	Dummy variables for two dominant soil types in the municipios	
DCATION	Dummy if cation soil restriction	.93
DORG	Dummy if organic matter restriction	.45
DSAL	Dummy if salinity restriction	.30
DTEXT	Dummy if soil texture restriction	.78
(D) Technology variables (T)		
S-R	Public sector research stock	
S-RSC	Public research stock times state size	
PRIVT	Private sector research stock (relevant to agriculture)	352.6
(E) Infrastructure Variables (I)		
POP_ ARE*	1980 Population/square km.	128.20
POPSQ*	POP_ARE squared	-
URB _TOT*	1980 Urban Population/TotalPopulation 1980 Rural Population/Total	.37
POPDEN85	Farm Land Area	.37
ROADS70*	Km of roads (1970)/total farm land area 1970	.02

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	Description	Means
(F) Interactions		
CxG	ERS1TEMD -+ ERS5TEMP, ERS1RAIN - ERS5PAIN	
CxE	TEMPSCrB - TEMPSTBR, PAINSCrB --- RAIN STBR	
CxT	ST_ RDEC2 – ST_RSE02, ST_TDEEC2 --- ST_TDEC2(Public Research)	
	PRTRDEC2 - PRTRSEP2, PRTTDEC2 PRTTDEC2 RIAVATE Research)	
TxG	STATERS1 -- STATERSS, PRTERS1 -- PRTERS5	
TxE	STATSCCB -- STaTSTBR, PRTSCCB -- PRTSTBR	

Note: C-XG, CxE with average of 4 months rainfall and temperature

CxT with squared values of monthly rainfall and temperature

Data from three census cross-sections (1975, 1980 and 1985) were utilised in the analyses. The dependent variables include the land use shares and the farmer-based estimates of land value in each municipio (municipality).

We estimate a jointly determined system of land use shares and land values based on (4) and (5). Thus we have six land use equations and one land value equation. We used OLS procedures since we have a common set of erogenous variables for the land share equations. The regression estimates are weighted by total land in farms.

Exogenous variables include climate, geographic, edaphic, technology and infrastructure variables. The climate, geographic and edaphic variables are the same as used in the original Ricardian analysis (Sanghi et al. (1997)). Climate was measured by normal (30 year mean) levels of rainfall and temperature. These measures were available for weather

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stations and predicted for each municipio (see Sanghi et al. (1997)). The enable non-linearities, squared values of each rainfall and temperature and rainfall-temperature interaction variables were included.

Edaphic variables were obtained from several sources. These variables capture physical properties of soil, aquifers and topography. One of the major challenges in studies of this type is to distinguish the effects of climate on land values from edaphic effects. It is also important that these edaphic variables not be climate (or hidden climate) variables.[8]

The technology variables include a public sector research "stock" variable and a private sector research stock variable. These variables are constructed in such a way as to be consistent with the "service flow" concept associated with capital variables in production studies. The effects of investment in research have both time and spatial dimensions. Investments in time t have effects distributed through future years. Consequently a research stock associated with a productivity index in a given period is based on investments in previous periods (that are having effects in the current period). The research stock variable is thus constructed using estimated timing weights for past investments (and allowing for depreciation).

The spatial dimension is similar. Research conducted in one location affects productivity in other locations. This spatial "spillover" of research effects requires that spatial weights be estimated allowing for the research stock variable for a given location to include past investments made in other locations. (See the Appendix and da Cruz, et al. (1998) for more details.)

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[8] *Variables that reflect climate may be highly correlated with actual climate variables and create biased estimates of climate effects.*

Infrastructure is proxied by population density, urbanization, and road\ density.[9]

Table 1 also describes the interaction variables used in the study. Note that we define C x G, C x E and C x T interactions as well as T x G and T x E interactions. We do this to capture crop "migration" effects. As climate change occurs, these interactions will limit the movement of crops from one region to another.

4 Estimates

Evenson and Alves (1997) reports estimated coefficients and heteroscedasticity corrected standard errors for the all six land use share equations (note that fallow and unproductive land is the residual share) and the land value equations.

All equations have good statistical fits as indicated by "F" tests. All clusters of climate, geographic and edaphic variables are jointly significant in all equations. All clusters of interaction terms are also significant in all equations. Because of the large number of interaction variables it is difficult to place interpretations on any single coefficient. In the sections to follow we report "partial" effects of key variables evaluated for each data point and summarized in tables for all of Brazil and in map form for regions within Brazil.

5 Computed Estimates of Climate and Technology on Land Use

We report computed partial effects of climate change (rainfall and temperature) and technology (public sector and private sector R&D) on land use shares in this section.

These effects are computed as follows. The partial derivatives (eq. 6) from the estimates are evaluated for each municipio utilizing municipio level values for all interaction terms. The

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[9]   *These variables were developed for the productivity studies of da Cruz et al. (1997).*

national mean effects are summarized in Table 2. Spatial climate change effects are shown in Figures 1 and 2.

These partial effects can be interpreted as simulations. The partial effect of a one degree temperature rise is the change in the dependent variable that would occur if all temperature variables in the estimated equations were increased by one degree Celsius. Thus in Table 2 the national mean (over all municipios) effect of a rise in temperature by 1^0 C on the annual crop land use share is .50. This means that the annual crop share would rise from 22 percent to 22.5 percent. This effect takes into account all estimated coefficients on temperature variables.

For climate effects we compute both rainfall and temperature change effects. For rainfall we compute the effects of increasing each of the 4 monthly rainfall variables by 3 percent (i.e., 3 percent of the normal monthly rainfall in the municipio). For temperature effects we compute the effects of a rise in normal temperature by one degree Celsius in each month in all municipios. These computations are thus for relatively modest climate changes.

For the R&D effects we compute the effects of a doubling of the investments in both private and public sector R&D. Given the relatively low level of R&D investment in Brazil this calculation presumes that Brazil will expand its R&D investments to approximately the levels of North America.

We turn first to the national mean level effects summarized in Table 2. Note that we have estimated 6 land use share equations. The residual land use category accounting for 3 percent of land in farms is fallow land and land considered to be unproductive. The first row in Table 2 reports land use shares for the six classes of land. Subsequent rows report the partial effects of changes in climate or technology on land use shares. (Since these changes sum to zero the effects on the residual category can be inferred from the estimated effects.)

We begin by noting that the term ,"land in farms" in Brazil has a broader scope then in many other countries. It covers cropland, pasture land and forest land. The 19 percent in forests constitutes a significant part of the forest land in Brazil and represents the forest land that is threatened by cropland and pastureland expansion. (Non-farm forest land is threatened by logging and industrial and urban uses.)

We first consider the effect of a 3 percent rainfall increase on land use shares. The mean effects for Brazil are shown in Table 2 (row 2). A rainfall increase is calculated to lead to an increase in land in annual crops of .35 and a decrease in land in perennial crops of .09, but a net increase in the cropland shares (from 29 percent to 29.26 percent). A rainfall increase will lead to a decrease in natural pasture of .78, an increase in planted pasture of .33 and a net decrease in pasture land shares (from 49 to 48.55 percent). A rainfall increase will lead to an increase in land in forest uses (from 19 percent to 19.1 percent). These rainfall effects can be considered to be modest in magnitude and they do not imply a threat to forest habitat.

The same cannot be said for the computed effects of a one degree Celsius temperature rise (row 3). A temperature rise is projected to lead to an increase in both the annual and perennial cropland shares. The largest effect is for pasture land where the natural pasture land share is projected to increase from 30 percent to 33.5 percent. This is only partially offset by the projected decrease in the planted pasture share. The temperature-induced increase in cropland and pastureland comes at the expense of forest land. Both natural and plantation forest shares decline and the total forest landshare is projected to decline from 19 percent of land to less than 17 percent. This estimated temperature effect does raise concerns about biodiversity and habitat loss associated with the conversion of farm forest land to pasture and cropland.

TABLE 2

Estimated Partial Effects of Climate and Technological

	Crop Land		Pasture Land		Forest Land	
	Annual	**Perennial**	**Natural**	**Planted**	**Natural**	**Plantation**
1985 Shares (Percent)	22	7	30	19	17	2
Climate Effects						
3% increase in rainfall	**0,35**	**-0,09**	**-0,78**	**0,33**	**0,14**	**-0,04**
1º C increase in temperature	**0,5**	**0,17**	**3,54**	**-1,07**	**-1,98**	**-0,14**
Combined increases in rainfall and temperature	**0,85**	**0,08**	**2,76**	**-0,73**	**-1,84**	**-0,18**
Technology Effects						
Doubling Private R&D	**0,04**	**0,07**	**-0,006**	**-0,002**	**-0,1**	**-0,01**
Doubling Public R&D	**0,22**	**0,08**	**-0,55**	**0,07**	**0,14**	**-0,01**
Combined doubling of private and public R&D	**0,26**	**0,15**	**-0,56**	**0,07**	**0,04**	**-0,02**
Sacondary Effects of Technology on Climate Effects						
3% increase in rainfall	**-0,0019**	**0,0062**	**-0,0088**	**0,0031**	**0,0018**	**-0,0024**
1º C increase in temperature	**-0,001**	**-0,0153**	**0,0152**	**0,0338**	**-0,0037**	**0,0058**
Combined increases in rainfall and temperature	**-0,0029**	**-0,0091**	**0,0064**	**0,0369**	**-0,0019**	**0,0034**

The combined rainfall and temperature effects are dominated by the temperature effects. The modest climate change associated with a 3 percent rainfall increase and/or 1 degree Celsius temperature rise is projected to raise the cropland shares from 29 percent to 30 percent. This climate change will also raise pasture shares from 49 to 51 percent. Forest shares will decline from 19 percent to a little over 17 percent. (The geographic and regional dimensions of these effects are discussed below.)

Next we consider the technology effects on land use. These can be summarized as follows:

Private R&D effects are smaller than public R&D effects. Both public and private sector R&D effects are positive on cropland shares. Since much public sector R&D is directed toward crop (especially annual crop) improvement, this is as expected.

Private sector R&D has minimal effects on pasture shares. Public sector R&D leads to a lower natural pasture share and a higher planted pasture share.

R&D effects on forest land are small.

Private sector R&D has a negative effect. Public sector R&D has a positive effect. Neither has an effect on plantation forests.

The general impact of expanded investment in agricultural R&D is to increase the cropland shares largely at the expense of natural pasture. Improved agricultural technology is thus expected to expand the climate change effects on cropland with both climate and technological change. The cropland shares will increase from 29 to 31.4 percent. Improved agricultural technology will be counter to the climate effects on pasture land. Technology favors planted pastures and counters the climate induced conversion of natural forest land to natural pasture land. Technology has small positive effects on natural forest land use. Neither climate change nor technological change favors plantation forestry.

The third set of calculations in Table 2 reports the secondary or interaction effects between climate change and technology change. They can be interpreted as the modification to the climate effects that would occur if both climate and technology change occurred. These are generally small except for the temperature effects on pasture land shares. The largest effect is on planted pasture where technology is friendly to planted pasture.

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The spatial dimensions of climate-induced land use changes are displayed in Figures 1 and 2. Recall that the effects of a 3 percent increase in rainfall were positive on annual crops for all of Brazil. In Figure 1 we see that these effects were not uniform spatially. The effects were negative in many municipios including municipios in the southern region where cropping intensity is highest. The spatial effects of rainfall on perennial crops were negative for all Brazil but as noted in Figure 1 there were important and large positive effects in municipios in the Cerrado region.

Rainfall effects were negative for natural pastures and positive for planted pastures. We note, however, that in many municipios the natural pasture effects were positive. Most municipios did show a positive planted pasture effect for rainfall.

Rainfall effects on natural forests were generally positive and inversely related to rainfall levels. That is, municipios in low rainfall areas tend to have positive effects while those in high rainfall areas had negative effects. Similar effects on plantation forests are shown.

Figure 2 shows the temperature effects. As noted in Table 2, the mean effects for Brazil were quite strong. A rise in temperature induces increases in annual crop shares. The spatial dimensions of these effects are quite uneven, with many municipios with significant annual cropped areas showing negative effects. The temperature effects on perennial crops shares were positive for all Brazil, but we note strong regional effects in Figure 2. we observe some response to an extension of the frost-free zone southward, but for most regions with significant cropped area we observe a negative effect.

Among the largest impacts of a temperature rise for the Brazil means computations were a positive increase in natural pasture shares and a decrease in planted shares. Figure 3 shows these strong impacts to be regional, with the expansion of natural pasture areas being relatively low in the

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southern states. Similarly, planted pasture shares were positive in many municipios in the Center and South.

We also noted that a temperature rise had a negative impact on both planted and natural forests. In Figure 3 we see that this "on-farm deforesting" effect is strongest in the north. It is negative in most municipios in the Center-East and South and is positive in parts of the Cerrado and the Northeast.

It is not possible with the methodology used in this study to identify trade-offs in land use where it can be said that an increase in one reduces another. Some insights can be gained from the spatial correlations, however. Perhaps the strongest of these is the correlation between the increased natural pasture shares and the decreased natural forest shares.

4 Computed Estimates of Climate and Technological Change on Land Values and Land Productivity

We now turn to the estimated effects of climate and technical change on land values. These are summarized in Table 3 and spatially displayed in Figure 3. These estimates are roughly comparable to the climate change estimates reported in Sanghi, et al. (1997a), and Sanghi et al.(1997).

As noted in Table 3, the estimated rainfall and temperature effects on land values are substantial for the all Brazil means. We estimate that a 3 percent increase in rainfall would have a positive 4.59 percent impact on land values. A one degree Celsius increase in normal temperature would have a negative 5.36 percent effect on land values. The combined rainfall-temperature effect is a negative 1.23 percent. (Note that since variable inputs account for roughly half of the costs of production for agricultural commodities in Brazil, the implied effect of climate change on land productivity is roughly half of the estimated effect on land values.)

TABLE 3

Estimated Partial Effects of Climate and Technological Change on Farm Land Values in Brazil (Express in Percentages)

Climate Effects	
3% Increase in Rainfall	4.59
1' C Increase in Temperature	-5.36
Combined Increase in Rainfall and Temperature	-1.23
Technology Effects	
Doubling Private R&D	1.40
Doubling Public R&D	1.58
Combined Doubling of Private and Public R&D	3.98
Secondary Effects of Technology on Climate Effects	
3% Increase in Rainfall	01
1º C Increase in Temperature	.001
Combined Increase in Rainfall and Temperature	.011

Before turning to an assessment of the spatial or regional dimensions of the climate change effects we will discuss the technology change effects on land values. These are positive for both public and private R&D. It is difficult to relate these effects to absolute changes in productivity because the coefficient estimates are based on relative differences in land values (as in the case for climate change). Since equilibrium prices are affected by technological (and climate) change these estimates understated the actual effects of technological change on TFP. (See da Cruz et al. (1997) for estimates of R&D on TFP.) Since both climate and technological change have similar price effects we can compare the 2.98 percent increase in land values for technical change with the 1.23 percent decrease for climate change. It appears that the negative effects of climate change

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can be and will be offset by technological change in Brazilian agriculture.

We note further from Table 3 that technological change is "friendly" to both rainfall and temperature change in that these effects are made more positive by technical change.

Figure 3 shows the spatial effects of a 3 percent rainfall increase and a 1^0 C temperature increase. Spatial differences are quite important.

Rainfall effects, while positive for Brazil as a whole, are actually negative for many municipios in Brazil. The net positive effect for all Brazil is the result of relatively high positive impacts in a few municipios and relatively low negative impacts in many municipios.

Temperature effects also have very strong spatial or regional effects. They are strongly negative throughout the North, Northeast and much of the Center-West. They are positive in much of the Center-East (especially Minas Gerais) and the South.

The combined rainfall and temperature effects and the combined effects of public and private R&D on land values are exhibited in Figure 4. Here we note first that the negative effects of climate change are largely seen in the North and Northeast regions. Much of the Center-East and most of the South benefit from climate change. We also note that technological change is positive in most municipios and that its spatial pattern is inversely correlated with the spatial pattern for climate change. This inverse correlation further supports the suggestion that the positive effects technological change is likely to compensate for the negative effects of climate change.

7 Implications for Policy

Two sets of implications for policy emerge from the estimates of climate and technological change for Brazilian agriculture.

The first set is indirect regarding the urgency and importance of policies designed to slow climate change. The second set is direct regarding policies to compensate for and ameliorate climate change.

Regarding the first set of implications for policies to slow global climate change, our estimates do not have implications for achieving the most cost effective slowing of climate change. They do, however, have implications for income distribution and related equity considerations and for environmental concerns.

The income distribution and regional equity implications emerge from ourland value effects estimates. These estimates show that climate change will have significant negative impacts on a large part of Brazil notably most of the North and Northeast and part of the Center-West. These parts of Brazil are currently generally "disadvantaged" in terms of soil resources, rainfall and temperature. They are also disadvantaged in terms of per capita income.

By contrast, many municipios in the Center-East, South and Coastal regions will benefit from climate change. These regions are currently advantaged regions in terms of soils, climate and income.

The fact that there are gains from climate change probably reduces the urgency of policies slowing climate change for much of Brazil. The fact that climate change will exacerbate existing income distributional inequities should result in an increase in the urgency for and support of policies slowing climate change.

The second set of policy implications are more direct. They speak largely to agricultural technology policy in Brazil (and also to schooling, migration and infrastructure policy). Our finding that technological change is not only positive but compensatory is important. our estimates show that if Brazil brings its investment levels in both public-sector and private sector research relevant to agriculture up to developed

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country standards, productivity change can largely prevent climate change losses from occurring in most regions (and many regions will benefit from both technical and climate change).

Investments in schooling, retraining and infrastructure to reduce regional inequities have been given high importance in recent years. Our estimates call for maintaining these policies.

Finally, our land use estimates have implications for both sets of policy concerns. Many policy makers will find the land use implications of climate change (especially warming) alarming. The conversion of forest land to pasture and crop land will be of particular concern to those who wish to protect biodiversity habitats. This will increase the urgency and support for policies slowing climate warming.

Our estimate regarding the compensatory potential of technical change are similar, but of lessor magnitude. Higher investments in private sector R&D, and especially in public sector R&D, will modify and reduce the estimated "deforestation" effect of climate change. Our estimates do not suggest that technological change can actually prevent this deforestation effect although they do suggest a positive effect of technology on natural forest land use. Concluding we can say that R&D do not harm natural forest and they might slow down thr rate of deforestation.

Appendix A: Agricultural Research Stock Variables

Brazil has a complex system of public sector research institutions. Table A.1 lists the Federal EMBPAPA research units and State research units. The State research variable S - R (Table 1) was constructed as follows:

Each municipio, i, in period, t, was assigned a state research stock variable of the following form:

$$(A.1) \quad S\_R_{it} = \sum_{t,j} W'_t \, S_{ij} R_{cj}$$

were

W'$_t$ is a set of time shape weights

S$_{ij}$ is a set of spatial weights

and R$_{tj}$ is research spending (in constant currency units) in region j, time t.

There is a time lag between the conduct of research activities and the development of improved technology. Experiments require time and evaluation and sequences of experiments and tests must be designed before new technology is developed. Then the technology must be diffused to farmers. Some of this diffusion requires embodiment in farm inputs (seeds) and some is diffused as information (improved practices). Farmers must experiment and evaluate as they adopt technology and modify it for their farm conditions.

The "time-shape" of these lags is thus similar to the classic technology diffusion lag with a period of little research impact after investment, rising to a peak some years later. However, a second factor, depreciation, plays a role in the time-shape also. It is important to distinguish between depreciation and obsolescence in this regard. Technological obsolescence occurs when new technology (say a variety of rice) is superior to an existing technology and displaces it. If the new technology was developed as an extension of existing technology (i.e., it was an "add-c)n" to an existing technology) then the investments associated with the development of the existing technology did not depreciate even though the technology becomes obsolete.

Depreciation occurs when (a) there is incomplete additivity in technology development and (b) when there are "exposure" effects to reduce the value of technology after it has been exposed to use. Host plant genetic resistance to plant insects and diseases is often reduced by use exposure and this is an

example of depreciation. Changes in prices can reduce (or enhance) the value of technology and this is a source of depreciation as well (e.g., a rise in energy prices may reduce the value of technology that is highly dependent on energy).

The formula used to build the research stocks in this study is:

(A.2) $S_tR_t = (ExpRE_{t-4}.0.2)+(ExpRE_{t-5}.0.4)+$

$+ExpRE_{t-6}.0.6)+(ExpRE_{t-7}.0.8)+\sum_{t=8}^{20} (ExpRE_{t-2}.1.0)$

where $ExpRE_{t-4}$ is spending in year $t-4$, etc.

We built in a time lag of four years between the initial investment in agricultural research (ist year of the research project) and the impact on agricultural production at the farm level. The full impact is realized after eight years. Given the relatively recent development of ENBRAPA research we did not built in a depreciation component. These estimates are based on previous studies (Evenson et al., (1987); Evenson et al., (1989)).

Research conducted in one location will produce technology that is useful in other locations. But it is not necessarily equally useful in all other locations. We know that plant and animal performance is sensitive to climate and soil factors. The natural selection model of Darwin tells us that genetic diversity is associated with a high degree of location specificity of plants and animals to environmental niches. Modern plant animal breeding programs have only partially overcome this "Darwinian" phenomenon. Research systems in Brazil have incorporated Darwinian targeting into their structure.

The problem that we face in this study is to assign the research stocks from the National Centers, Regional Centers and State Programs to specific micro-region and municipios (our unit of analysis). In practice, there are two methods for doing this. One is the technology distance method where research conducted in region in region "I" is assigned to

region "ill in proportion to a technology distance index between them. Technology distance indexes are measures of the relative performance of regions i's best technology in region i relative to region i's best technology in region i.

The second method, used in this study, is to "test" alternative assignments of research based on geo-climate and priority zone evidence. For example, in the work reported below we construct three alternative assignments for EMBRAPA National Program research. They are:

1) Assignment I where all micro-regions in the country are assigned the National Program research stock. This is consistent with complete full "spill-over" of National Program research from the National Product Center to other locations.

2) Assignment 2 where National Program research is assigned to "Priority Zones" as identified by National Product Center staff. This is a sub-set of the 92 agro-ecological zones (on average 40 percent). This assignment is consistent with spill-overs limited to these priority zones.

3) Assignment 3 where National Program research is assigned only to micro-regions in the Agro-ecological zone in which the National Research Center Program is located. This is consistent with very limited spill-over of research benefits.

A similar procedure is applied to EMBRAPA Regional Center Research where a test is made between assignment to the Region as defined by EMBRAPA and assignment 3.

Mean square error tests are performed to select the assignment most consistent with the data. As we note below, these tests show that assignment 1 was best for National Program livestock research. Assignment 2 was best for crop and agricultural research generally. For Regional Center research, assignment to the region was best. State research assignment to all microregions in the State was best.

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Appendix B: Brazilian Agricultural Research System

1) EMBRAPA Decentralized Units

a) Agroforestry or Agricultural Ecoregional Research Centers

CPAA - Agroforestry Research Center for Western Amazonia

CPATU - Agroforestry Research Center for Western Amazonia

CPAC - Cerrados Agricultural Research Center

CPAF-AC - Agroforestry Research Center of Acre

CPAF-RO - Agroforestry Research Center of Rondonia

CPAF-RR - Agroforestry Research Center of Roraima

CPAF-AP - Agroforestry Research Center of Amapa

CPAP - Pantanal Agricultural Research Center

CPAMN- Center for Agricultural Research in the Mid-North

CPAO - Center for Agricultural Research in the Mid-West

CPATC - Center for Agricultural Research in the Coastal Tablelands

CPACT- Agricultural Research Center for Temperate Climate

CPATSA- Semi-arid Agricultural Research Center

CPPSE   - Center for Research on Cattle Raising in the Southeast

CPASUL - Center for Research on Cattle Raising in the Southern Fields

b) National Commodity Centers

CNPA - National Research Center for Oleaginous and Fibrous Plants

CNPAF - National Rice and Beans Research Center

CNPC - National Goat Research Center

CNPF - National Forestry Research Center

CNPGC - National Beef Cattle Research Center

CNPGL - National Dairy Cattle Research Center

CNPH - National Vegetable Crop Research Center

CNPMF- National Cassava and Tropical Fruit Research Center

CNPMS- National Corn and Sorghum Research Center

CNPSO- National Soybean Research Center

CNPT - National Wheat Research Center

CNPSA- National Pig and Poultry Research Center

CNPUV- National Grape and Wine Research Center

c) Basic Theme Research Centers

CENARGEN- Nat.Genetic Resource and Biotechnology Research Center

CNPAB- National Agro-biology Research Center

CNPAT- National Research Center for Tropical Agro-industry

CNPDIA- National Center for Research and Development of Agri. Instrumentation

CNPMA - Nat. Res. Center for Monit. and Assessment of Environmental Impact

CNPS - National Soil Research Center

CNPTIA - National Center for Technological Research on Information in Agriculture

CTAA - National Agro-industrial Food Technology Center

d) Special Services

SPI **-** Informational Production Service

SPSB **-** Basic Seed Production Service

NMA **-** Nucleus for Satellite Monitoring of Environment and Natural Resources

1. State Research Institutions

a) South Region

IPAGRO - Agricultural Research Institute, RS State

IRGA - Rio Grande do Sul Institute of Rice, RS State

FUNDACEP - Agricultural Research Center Foundation, RS State

EPAGRI - Agricultural Corp. for Research and Development, SC State

IAPAR - Agricultural Research Institute of Parana, PR State

OCEPAR - Cooperative Organization of Parana (Agric. Research Units), PR State

b) Southeast Region

IAC - Agronomic Institute of Campinas, SP State

IB - Biological Institute, SP State

IZ - Zootecnical Institute, SP State

PESAGRO **-** Agricultural Research Corp. of Rio de Janeiro, RJ State

EMCAPA **-** Corporation of Espirito Santo for Agric. Research, ES State

EPAMIG - Corporation for Agric. Research of Minas Gerais, MG State

b) Northeast Region

EBDA - Agricultural Research and Development Corp. of Bahia, BA State

EMDAGRO - Corporation for Agricultural Development, SE State

EPEAL - Corporation for Agricultural Research of Alagoas, AL State

IPA - Agricultural Research Corporation of Pernambuco, PE State

EMPAR - Agricultural Research Corp. of Rio Grande do Norte, RN State

EMEPA - Corporation of Parafba for Agricultural Research, PB State

EPACE - Corporation of Ceara for Agricultural Research, CE Stste

EMAPA - Corporation of Maranhao for Agricultural Research, MA State

c) North Region

The states in this region don't develop agricultural research. EMBP,APA research centers are responsible for the agricultural research.
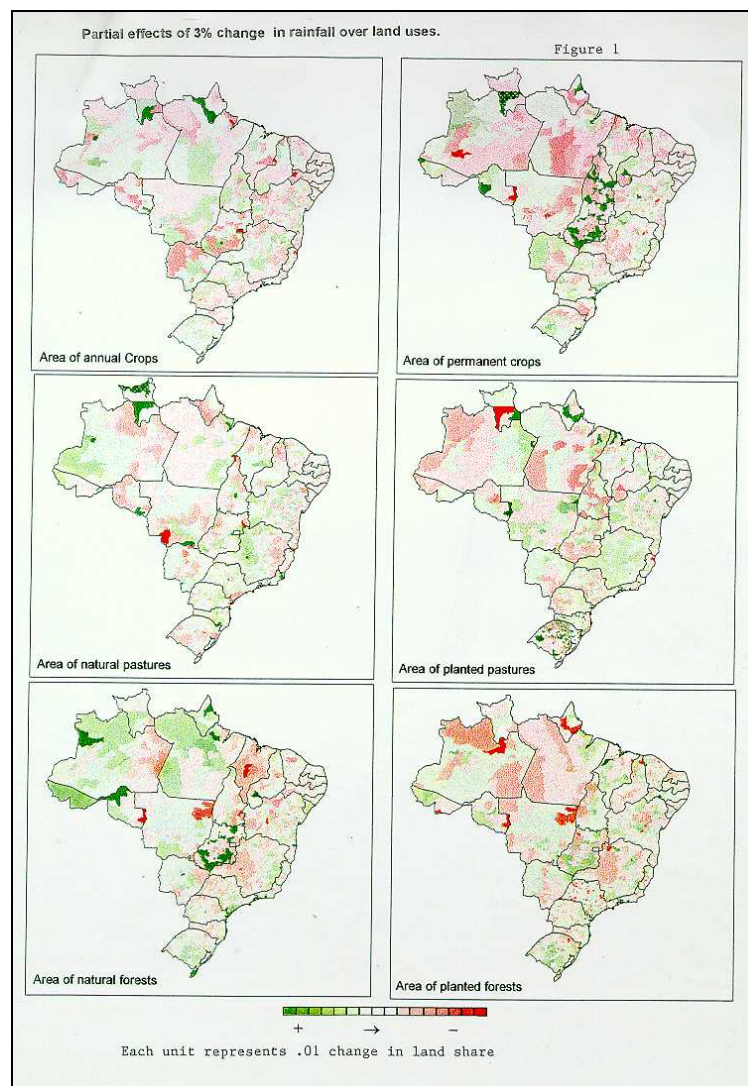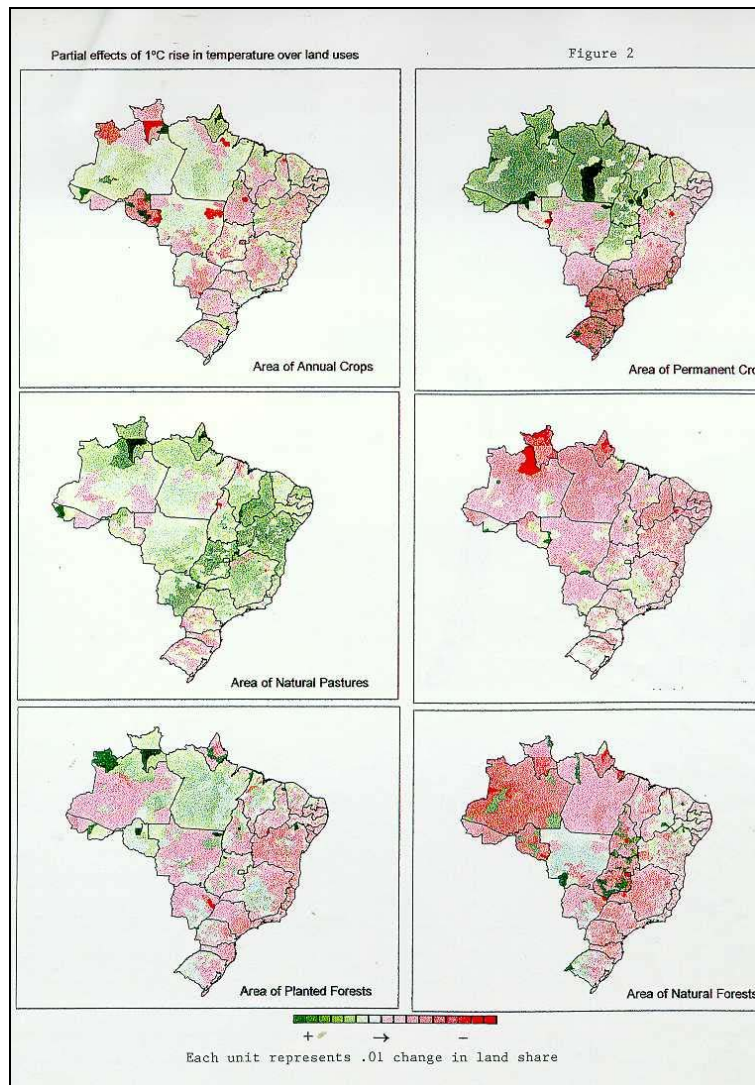
d) Center-west Region

EMGOPA - Agricultural Research Corporation of Goias, GO State

EMPAER/MT - Corp. fpr Agric. Research and Rural Ext. of Mato Grosso, MT State

EMPAER - Corp. for Agric. Res. and Rural Ext. of Mato G. do Sul, MS State

Partial effects of 3% change in rainfall over land uses.

Figure 1

Area of annual Crops

Area of permanent crops

Area of natural pastures

Area of planted pastures

Area of natural forests

Area of planted forests

Each unit represents .01 change in land share

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Partial effects of 1ºC rise in temperature over land uses

Figure 2

Area of Annual Crops

Area of Permanent Cro

Area of Natural Pastures

Area of Planted Forests

Area of Natural Forests

Each unit represents .01 change in land share

Figure 3

Partial effect of 1oC change temperature over land values (log)

Partial effect of 3% change in rainfall over land values (log)

Each unit represents one percent change in land values

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Figure 4

Total effect of research (private - 1% - and state - 1%) over land values (log)

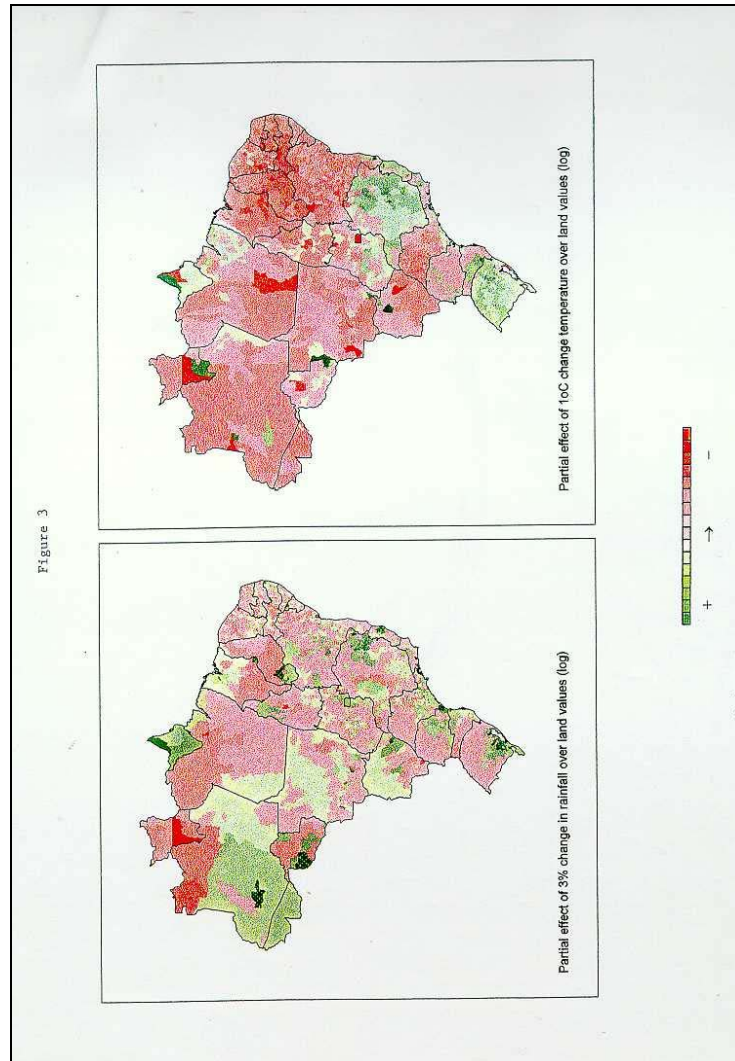Total effect of climate (rainfall - 3% - and temperature - 1°C) over land values (log)
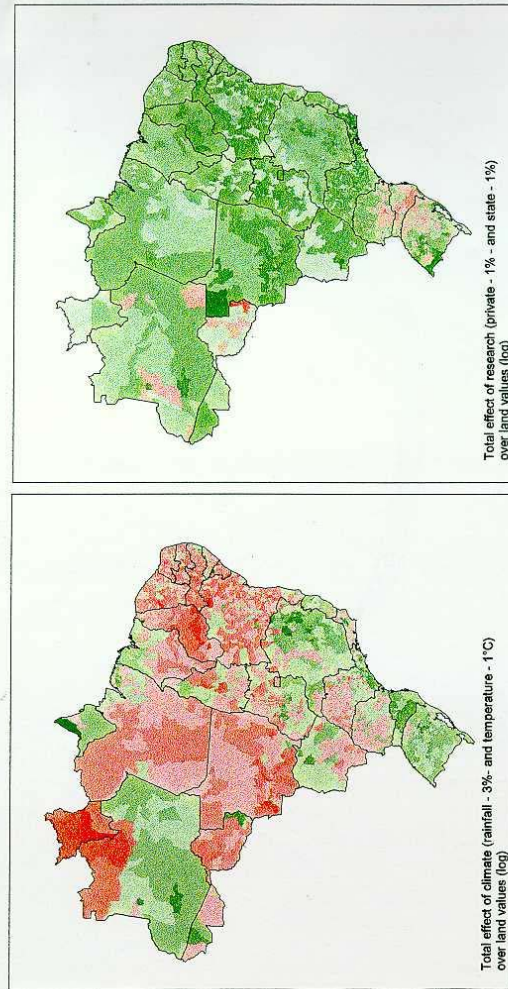
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