Nexus between socioeconomic dimensions, population movements and deforestation in the Brazilian Amazon

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LBA

The incorporation of the human dimensions into models of deforestation still represents a great challenge.

Given the complex nature of interrelationships, it is difficult to distinguish effect from cause as well as to measure quantitatively the influence of socioeconomic drivers.

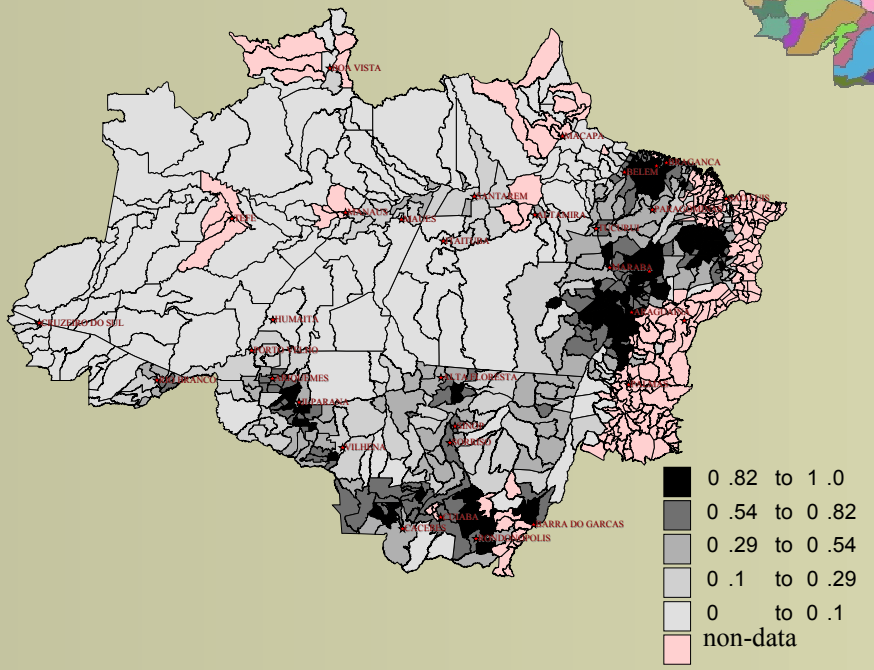
A <- C

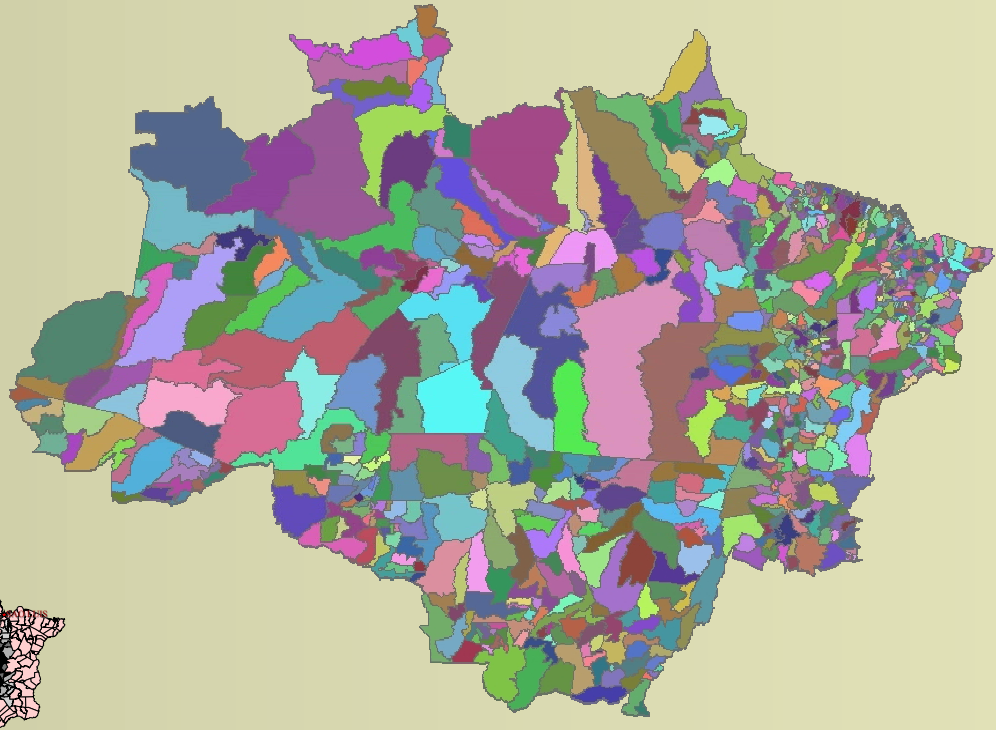
B <- C

A+B=C

To develop a spatial econometric model of deforestation for the Brazilian Amazon that analyzes the influence of a series of socioeconomic and demographic variables

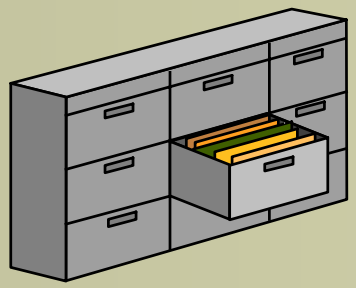
Inpe's Prodes data 1997-2001





IBGE 1996 population tally, 2000 census, as well as other economic and social surveys carried out within 1996-2000 period at municipal level.

Database

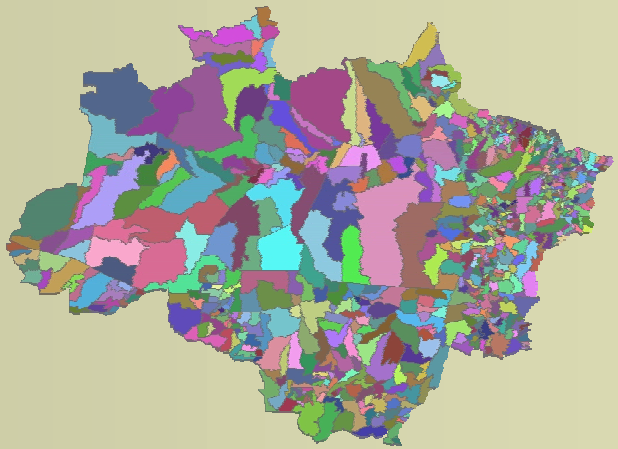


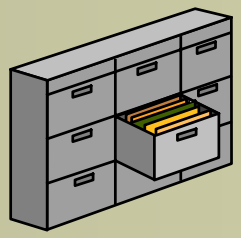
deforestation

three models

% deforested land by 1997
% deforested land by 2001
% deforestation 1997-2001

***All variables normalized by county's area**



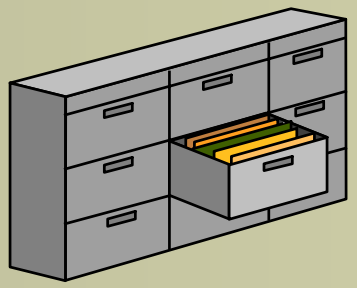


Socioeconomic and demographic variables

Model	n.	Variable
all	1	Mean distance to paved roads
all	2	Mean proximity to urban centers
all	3	Number of cattle heads per Km2
all	4	Income from agriculture per km2
all	5	% of planted area
all	6	Total population density
all	7	Rural population density
all	8	Rural population density adjusted by agrarian concentration index
all	9	Urbanization level
all	10	Social development index
all	11	Economic development index
all	12	Infrastructure agrarian index
all	13	Timber and Agriculture production index
all	14	Primary sector domestic product
all	15	Secondary sector domestic product
all	16	Tertiary sector domestic product
all	17	Gross domestic product
all	18	% protected area
2001	19	Migration rate (1995/2000)
2001	20	Migration balance (1995/2000) /km2
2001	21	Migratory volume/ Km^2
2001	22	Income per capita from agriculture /km2
2001	23	Working population in rural activities /km2
2001	24	% of Working population in rural activities

All variables normalized by county's area

Source: 3 - IBGE - PPM, 1997; 4 and 5, IBGE - PAM, 1997; 6 to 9 1996 IBGE Population tally and IBGE 2000 demographic census; 10-13 Garcia et al, 2004, 14 -17 Andrade and Serra, 1999. 20-24 IBGE 2000 demographic census.



Fuzzy cluster

GOM

Synthetic indices

Economic Development

Domestic Gross Product (1996) [5]
Domestic Gross Product: primary sector (1996) [5]
Domestic Gross Product: secondary sector (1996) [5]
Domestic Gross Product: tertiary sector (1996) [5]
Number of Banks (1998) [3]
Total Deposits in Bank - thousand *Reais* (1998) [3]
Total Investments - thousand *Reais* (1998) [3]
Municipality Revenue (1997) [3]
Municipality Total Expenditure (1997) [3]
Share in the Federal Funds of the Municipality (1998) [3]
Land Taxes- (1998) [3]

Agrarian Infrastructure

Agricultural Aggregated Value (1995-1996) [6]
Number of tractors (1995-1996) [6]
Sowing Machines (1995-1996) [6]
Harvesters (1995-1996) [6]
Number of Trucks (1995-1996) [6]
Total of Farming Machinery (1995-1996) [6]

Agricultural and Timber Production

Total Area of Agricultural Establishments with less than 200 hectares. (1995-1996) [6]
Total Area of Agricultural Establishments with 200 hectares or more. (1995-1996) [6]
Land Tenure Concentration (1995-1996) [6]
Livestock (2000) [7a]
Annual Rate of Increase of the Livestock (1997-2000) [7a, 7b]
Density of Cultivated Area (2000) [8a]
Annual Rate of Increase of the Cultivated Area (1997- 2000) [8a, 8b]
Number of Milling companies (1997) [9]
Timber Log volume per year (1997) [9]
Area Affected by logging (1997) [9]

Social Development

Years of Schooling - population at age 7 to 14 (1996) [2]
Years of Schooling - population at age 15 to 24 (1996) [2]
Years of Schooling - head of the household (1996) [2]
Hospitals per 1000 Population (1999) [3]
Hospital beds per 1000 Population (1999) [3]
Ambulatories per 1000 Population (1999) [3]
Health Posts per 1000 Population (1999) [3]
Health Centers per 1000 Population (1999) [3]
Medical Doctor Offices per 1000 Population (1999) [3]
Dentist Offices per 1000 Population (1999) [3]
Ambulatories in General Hospitals per 1000 Population (1999) [3]
Posts of Medical Care per 1000 Population (1999) [3]
Hospital Bedridden Patients per 1000 Population (1999) [3]
Number of Households (2000) [1]
Improvised Private Household (2000) [1]
Collective Household (2000) [1]
Water Supply (2000) [1]
Bathroom or Sanitary Installation (2000) [1]
Garbage Collection/Destination (2000) [1]
Electricity (2000) [1]
Average Number of Television per Household (2000) [1]
Telephone in the Household (2000) [1]
Paved Streets (1999) [4]
Streets with Illumination (1999) [4]

Source: [1] IBGE 2000 demographic census; [2] IBGE 1996 population tally; [3] IBGE 1999 municipal database; [4] IBGE 1999 profiles of the Brazilian municipalities; [5] Andrade and Serra (1996); [6] IBGE 1995-1996 agricultural census; [7a] IBGE 2000 municipal cattle herd survey; [7b] IBGE 1997 municipal cattle herd survey; [8a] IBGE 2000 municipal agricultural survey; [8b] IBGE 1997 municipal agricultural survey; [9] Verissimo *et. al.*, 2001.

Methodological steps

- **Algebraic manipulation**
- **ORDINARY LEAST SQUARES (stepwise model)**
- **OLS model with outliers control (heteroskedasticity)**
- **DIAGNOSTICS FOR SPATIAL DEPENDENCE**
- **SPATIAL LAG MODEL**

% of deforested land by 1997

Algebraic manipulation

Variables	Algebraic function	parameters A	parameters B	New Correlation index	former Correlation index
Mean distance to paved roads	Y = A*B**X	0,869	0,982	0,750	-0,545
Number of cattle heads per Km2 in 1997	Y = A*Ln(X+B)	0,188	1,142	0,675	0,546
Social development index	-	-	-	-0,004	-0,004
Total population density in 1996	Y = X/(A+B*X)	4,524	1,109	0,690	0,092
% of planted area in 1997 (%)	Y = X/(A+B*X)	0,011	1,231	0,675	0,353
Income from agriculture per km2 1997 (1000 Reais)	Y = X/(A+B*X)	0,424	1,341	0,541	0,306
% protected area	Y = 1/(A*X+B)	0.120	1.561	0.521	-0.453

Incorporating the neigborhood influence

Linear model (stepwiswe)

$$y = X\beta+\varepsilon$$

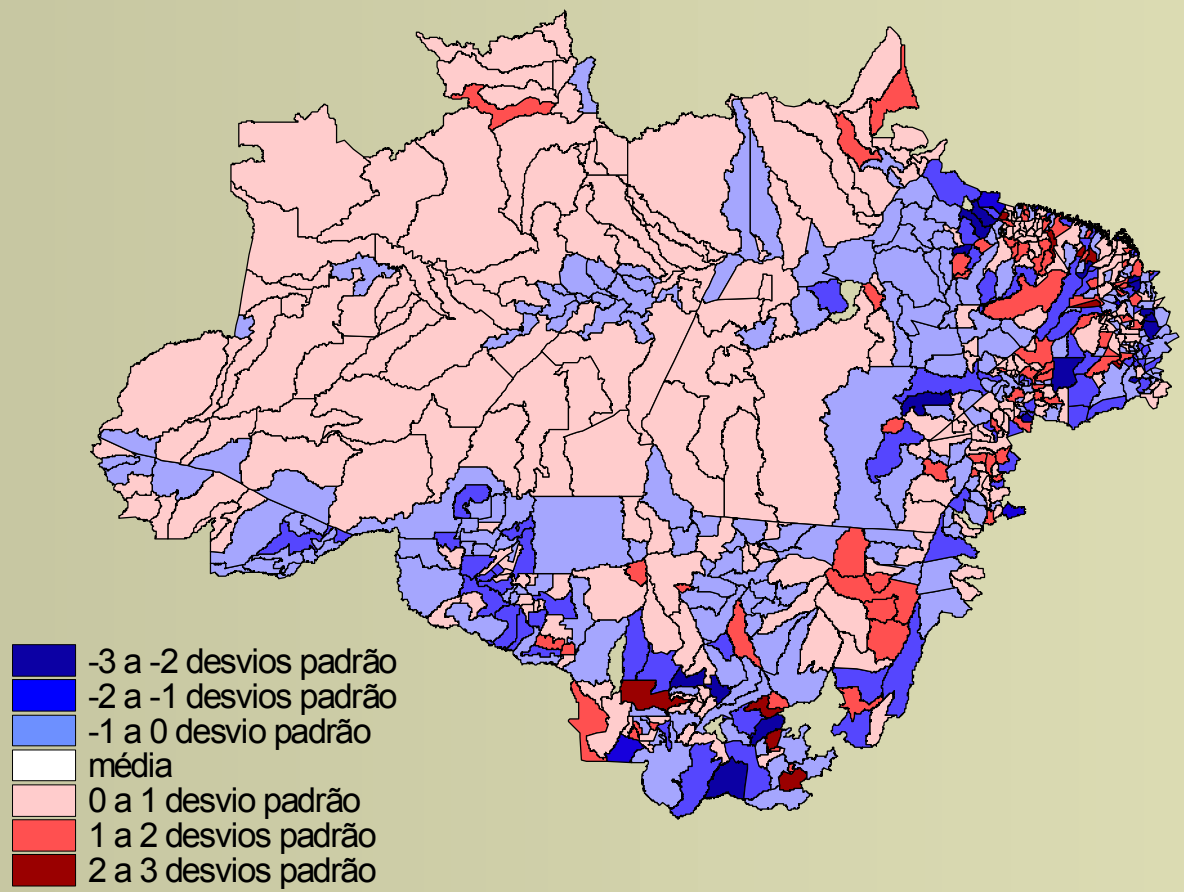
Spatial lag-model

$$y = \rho Wy+X\beta+\varepsilon$$

W is the neighborhood matrix

Note that: $y =(I-\rho W)^{-1} X\beta+(I-\rho W)^{-1}\varepsilon$ **thus** W **affects both** X **and** ε **. The model is auto-regressive**

Outliers


-3 a -2 desvios padrão
-2 a -1 desvios padrão
-1 a 0 desvio padrão
média
0 a 1 desvio padrão
1 a 2 desvios padrão
2 a 3 desvios padrão

DIAGNOSTICS FOR SPATIAL DEPENDENCE

Test	MI/DF	VALUE	PROB
Moran's I (error)	0.367194	15.421626	0.0000
Lagrange Multiplier (error)	1	220.46015	0.0000
Robust LM (error)	1	38.179857	0.0000
Kelejian-Robinson (error)	10	291.99265	0.0000
Lagrange Multiplier (lag)	1	259.29463	0.0000
Robust LM (lag)	1	77.014338	0.0000
Lagrange Multiplier (SARMA)	2	297.47449	0.0000

All models show spatial dependence

Model summaries

Model	heteroskedasticity control	R	R^2	Log-likelihood
% deforested land by 1997				
Linear (MAXIMUM LIKELIHOOD)	no	0.847	0.717	173.80
Linear (MAXIMUM LIKELIHOOD)	yes	0.904	0.817	311.32
Spatial (2SLS)	yes	0.923	0.852	
Spatial (MAXIMUM LIKELIHOOD)	yes	0.932	0,869	445.81
% deforested land by 2001				
Linear (MAXIMUM LIKELIHOOD)	no	0.852	0.727	178.61
Linear (MAXIMUM LIKELIHOOD)	yes	0.899	0.809	291.06
Spatial (2SLS)	yes	0.930	0.864	
Spatial (MAXIMUM LIKELIHOOD)	yes	0.934	0.872	440.06
% deforestation 1997-2001				
Linear (MAXIMUM LIKELIHOOD)	no	0.557	0.310	824.92
Linear (MAXIMUM LIKELIHOOD)	yes	0.774	0.599	933.17
Spatial (2SLS)	yes	0.819	0.671	
Spatial (MAXIMUM LIKELIHOOD)	yes	0.819	0.671	982.37

Increase in model fitness

2SLS – two stages

% deforested land by 1997

(Lag spatial - Maximum Likelihood)	Coefficients	standard error	z value	Significance (P)
Constant	-0.114	0.016	-7.311	0.000
Mean proximity to paved roads	0.093	0.031	2.960	0.003
Number of cattle heads per Km2 in 1997	0.266	0.029	9.043	0.000
Social development index	-0.053	0.013	-4.197	0.000
Total population density in 1996	0.265	0.032	8.310	0.000
% of planted area in 1997 (%)	0.287	0.065	4.416	0.000
Income from agriculture per km2 in 1997 (1000 Reais)	-0.256	0.066	-3.847	0.000
Inverse (% protected area)	0.103	0.029	3.568	0.000
Ou tlier (+)	0.035	0.005	7.358	0.000
Outlier (-)	-0.285	0.026	-10.841	0.000
Lag spatial	0.535	0.029	18.748	0.000

% deforested land by 2001

(Lag spatial - Maximum Likelihood)	Coefficients	standard error	z value	Significance (P)
Constant	-0,332	0,035	-9,494	0,000
Mean proximity to paved roads	0,114	0,032	3,591	0,000
Number of cattle heads per Km2 in 1997	0,238	0,031	7,688	0,000
Rural population density	0,144	0,033	4,308	0,000
Income from agriculture per km2	0,217	0,034	6,448	0,000
Inverse (in-migration rate (1995/2000))	0,405	0,070	5,820	0,000
Social development index	-0,056	0,013	-4,353	0,000
% of planted area	0,070	0,031	2,238	0,025
Outlier(+)	0,262	0,042	6,193	0,000
Outlier(-)	-0,287	0,026	-10,875	0,000
Lag spatial	0,550	0,027	20,067	0,000

% deforestation 1997-2001

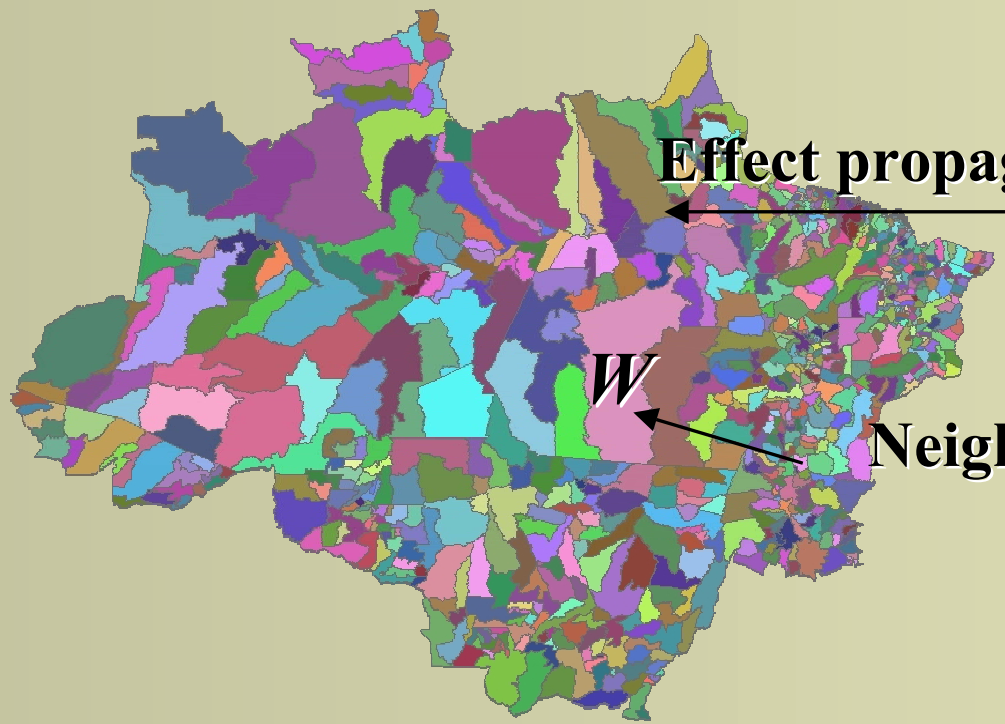
(Lag spatial - Maximum Likelihood)	Coefficients	standard error	standard Coefficients	z value	Significance (P)
Constant	-0,008	0,003		-2,500	0,012
Increase in number of cattle heads per Km2 in 1997	0,000	0,000	0,196	6,824	0,000
Migratory volume/ Km^2 (1995/2000)	0,367	0,078	0,180	4,701	0,000
In-migration rate (1995/2000)	0,016	0,005	0,090	3,071	0,002
Inverse (% protected area)	0,194	0,090	0,077	2,142	0,032
Increase in % of planted area	0,083	0,045	0,053	1,856	0,063
Outlier(+)	0,079	0,005	2,134	15,487	0,000
Outlier(-)	-0,048	0,015	-1,305	-3,231	0,001
Lag spatial	0,433	0,042	0,433	10,406	0,000

conclusions

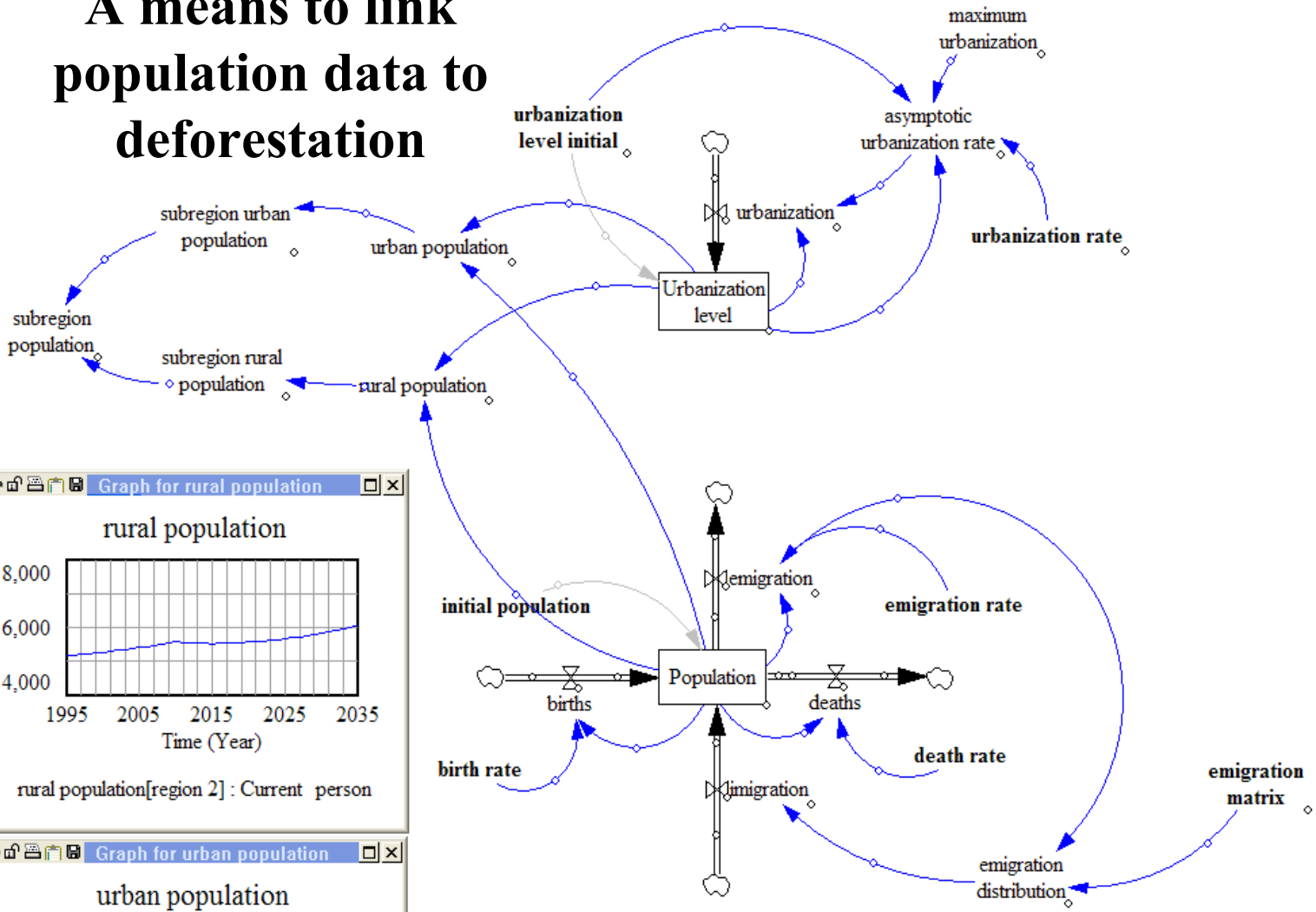
• Proximity to paved roads, cattle herd, and population density (both rural and total) were the most important variables to explain stocks of deforested land, while increase in cattle herd and migratory volume related most closely with the deforestation rate. There is a reversion in the in-migration rates as deforested land increases.

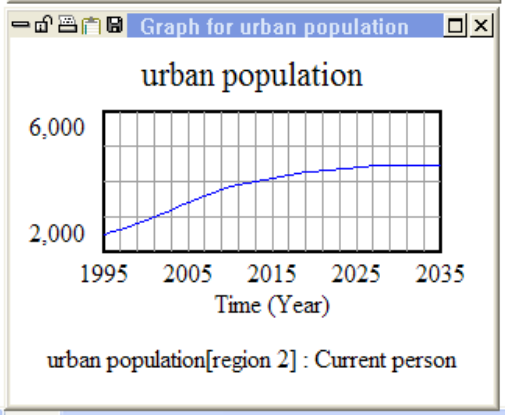
• Worthy of mention, social development and percent of protected area were the only variables to present a negative correlation with stocks of deforested land.

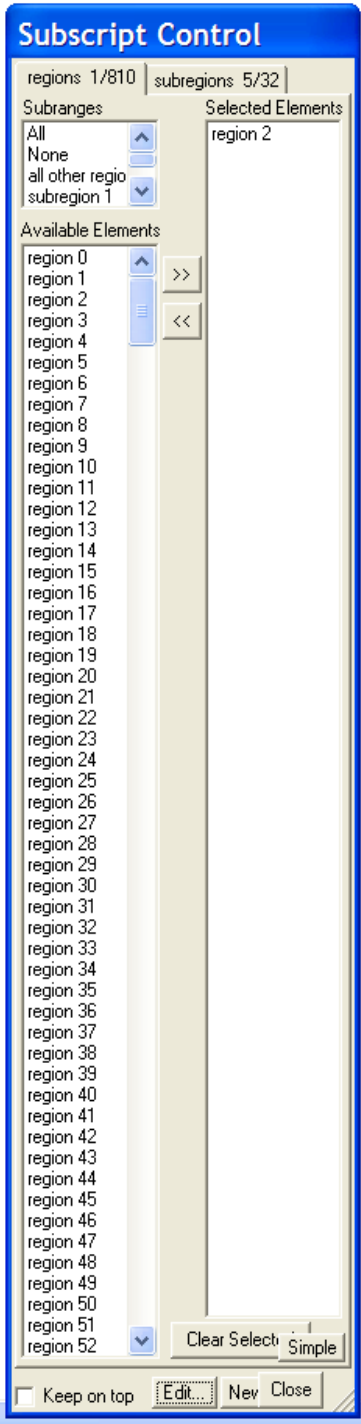
- The obtained spatial econometric model can be used to infer the potential for future deforestation from changes in the socioeconomic and demographic context, not only within a specific Amazon county, but also from its neighboring regions.



A means to link population data to deforestation







Scenarios of migration, urbanization, and population growth

Thank you

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