Modeling Land Use Allocation with Mixed-Level Data:

An Econometric Analysis for the Democratic Republic of the Congo

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Introduction

The Democratic Republic of the Congo (DRC) has 125 million hectares of tropical forest, the second largest in the world after the Amazon. The DRC forests play an important role in the cycling of the greenhouse gases acting as both sink and source of these gases (Houghton 2005). As the third-largest country in Africa, the DRC's natural agricultural potential is immense due to its vast land resources and favorable water supply. Despite that, the DRC has experienced the severe economic depression from the 1960s to 1990s. The vast agricultural sector has suffered even worse.

The DRC government and its development partners (e.g., China, the World Bank and the UK Department of International Development) are investing heavily in transport infrastructure with projects totaling US$8.5 billion. Many of these roads and river rehabilitations cut through or near to the DRC's tropical forests, and will obviously significantly improve the viability of both the agricultural and logging sectors. Besides, the DRC has pursed large scale farming projects and significant foreign investments in agriculture. These policies are affecting the spatial distribution of cropland. Currently, the rates of deforestation in the DRC are low relative to those experienced in South America and Southeast Asia. However, the ongoing and potential investments in infrastructure and agricultural sector are likely to result in deforestation and forestation degradation. A comprehensive analysis of land use in the DRC will provide credible estimates for the deforestation trends in the coming decades, as well as valuable information to policymakers responsible for the design of development strategies.

This paper develops an econometric model to identify the determinants of land use for the DRC. This approach allows for recovering crop decision at a very disaggregate level using the mixed-level land use data. Most previous econometric models of land use choices and land use change, particularly those implemented in sparse data environments, treat agriculture as a single land-use category. As a consequence, some of the more complex interactions in the set of available choices that can lead to changes in landscape cannot be captured. The method proposed in this study addresses this problem.

Data and Econometric Estimation

The analysis uses cross-sectional geo-referenced data. In the upper-level model, data on land cover are from Global Land Cover 2000 Project; data on rural population density are from Global Rural-Urban Mapping Project; data on transport costs are from Global Accessibility Map; topographical variables are from the GLOBE product; climate data are from the WorldClim product. We use 5km pixel as the unit of the econometric analysis. In the lower-level model, we collected national data on crop price and district-level data on crop area from the local governments in the DRC, coupled with crop yield potential calculated using the agro-ecological zones method. Therefore, this econometric method relies on

Econometric Land Use Model

Assume land use decision is made by a representative risk-neutral agent with static expectation of future utility. The optimal allocation rule is to put a homogeneous land plot to the use generating the greatest present discounted value of utility (Plantinga 1996; Stavins and Jaffe 1990).

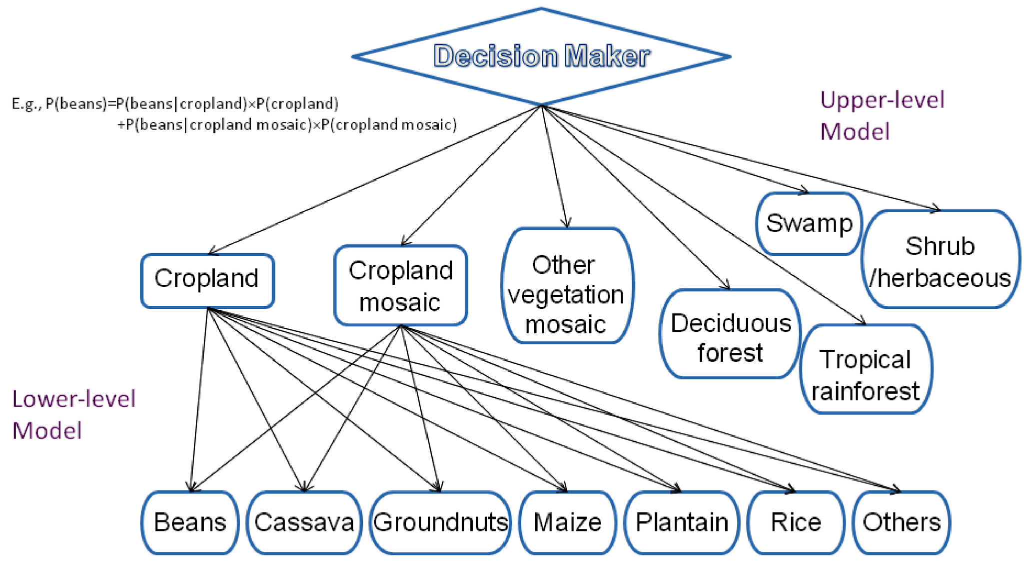

Figure 1. Hierarchy land use decision process

Fundemental equations:

$$(1)\ U_{nkj} = \mathbf{x}_n \boldsymbol{\beta}_k + \mathbf{y}_{nkj} \boldsymbol{\gamma}_{kj} + \varepsilon_{nkj},\quad (2)\ P_{nkj} \equiv \Pr\left(U_{nkj} > U_{nk'j'}, \forall k' \text{ and } j \neq j' \text{ if } k = k'\right) = P_{nk} P_{nkj|k},$$

where

$$P_{nk} = \frac{\exp\left(\mathbf{x}_n \boldsymbol{\beta}_k + \lambda_k I_{nk}\right)}{\sum_{k'=1}^{K} \exp\left(\mathbf{x}_n \boldsymbol{\beta}_{k'} + \lambda_{k'} I_{nk'}\right)},\quad P_{nkj|k} = \frac{\exp\left(\mathbf{y}_{nkj} \boldsymbol{\gamma}_{kj} / \lambda_k\right)}{\sum_{j'=1}^{J_k} \exp\left(\mathbf{y}_{nkj'} \boldsymbol{\gamma}_{kj'} / \lambda_k\right)},\quad I_{nk} = \ln\left[\sum_{j'=1}^{J_k} \exp\left(\mathbf{y}_{nkj'} \boldsymbol{\gamma}_{kj'} / \lambda_k\right)\right],$$

and

n – land parcel index, k – index of major land use in the upper level,

j – index of major crop choice in the lower level ($j \in k$),

$\mathbf{x}_n, \mathbf{y}_{nkj}$ – explanatory variables, $\boldsymbol{\beta}_k, \boldsymbol{\gamma}_{kj}$ – unknown parameters,

ε_{nkj} – error term with generalized extreme value distribution.

remotely sensed data and other relatively inexpensive ancillary data and can easily be applied to land-use analyses constrained by lack of data.

Ideally, if we observe all land use choices at pixel level, the nested logit model can be estimated using a standard maximum likelihood method. However, we lack pixel-level observation of crop choice. To overcome the problem, we assume 1) each crop choice represents an outcome, 2) area of each crop is the frequency of outcome in a given district, 3) crop areas follow a *mixed* multinomial distribution, with parameters being functions of information for each pixel in that district. We estimate the model in a sequential fashion, by beginning with the lower-level model and using the estimates as explanatory variables to enter the upper-level model. An expectation-maximization algorithm is applied.

Estimation Results

To assess the model performance, we calculate several indicators, including McFadden's likelihood ratio index (0.54), the rate of prediction accuracy for each pixel (66%), etc.. Overall, the model performs and predicts moderately well. The preliminary results suggest that estimates are generally consistent with economic interpretation. In the lower-level model, we find that the frequency of most crop choices has positive significant own-elasticity with respect to crop suitability and crop price, indicating that the improvement of the productivity potential for a given crop may increase the net returns to that crop and hence increase the probability of choosing it (table 1). In the upper-level model, we find 1) reducing travel time to major cities tends to cause both crop expansion and deforestation; 2) population density growth has positive effects on cropland expansion but was not a major cause of deforestation; 3) geophysical variables also land use in the DRC, e.g., other things being equals, a land parcel with smaller slope and lower elevation is more likely to used for crop production and less likely to be forest.

Table 1: Estimated Own Elasticity of Crop Choice

Crop choice	Cropland		Cropland mosaic	
	Suitability	Price	Suitability	Price
Bean	0.038***	0.055	0.004***	1.801***
Cassava	0.446	0.258	-0.090	0.592*
Groundnuts	0.216***	0.476**	0.110***	1.250***
Maize	0.236***	1.352***	-0.050	1.335*
Plantain	-0.416***	-1.437***	0.204	1.040***
Rice	0.482	1.239***	0.570	0.297***

Note: (1) *, **, and *** indicate statistical significance at the 10, 5, and 1% levels, respectively. (2) Elasticity is evaluated at the mean of the data and are the percentage change in the probability of crop choice for 1% change in crop suitability and in crop price, respectively.

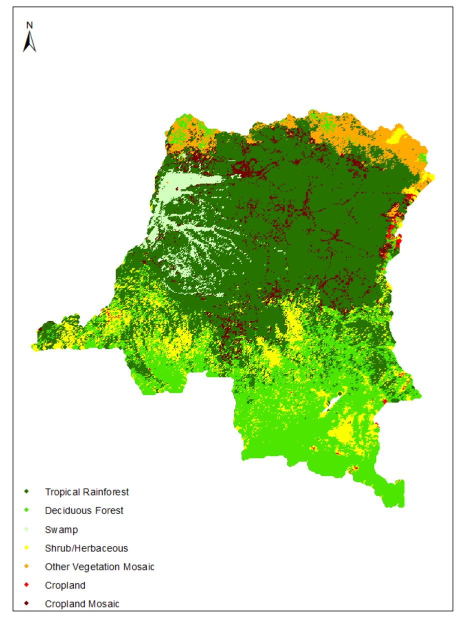

Figure 2. Global land cover 2000 project for the DRC

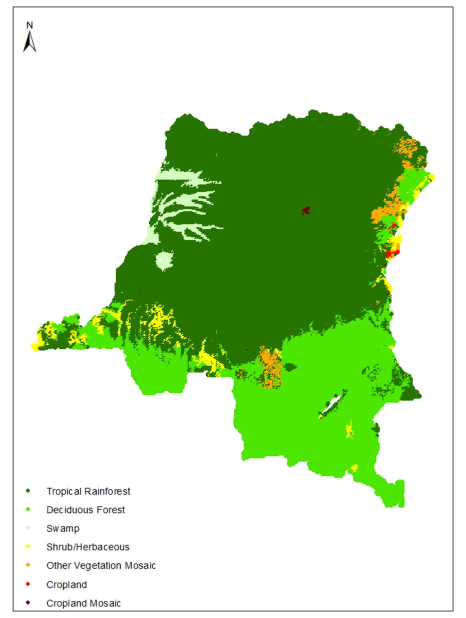

Figure 3. Predicted land cover for the DRC (baseline)

Table 2: Scenario by Road Category

	Baseline: Current network (km)	Projection: Government's plan (km)
Paved roads (80km/hr)	1,611	8,500
4WD roads (30km/hr)	26,500	25,875
Loose gravel (25km/hr)	59,500	53,236
Trails (3km/hr)	87,200	87,200
Ferry crossing (5km/hr)	239	239
Ferries, boats, etc. (10km/hr)	1,486	3,200
Estimated cost (US$ millions)	n/a	US$2,064

Source: Ulimwengu *et al*. 2009. Table 11, page 32.
Note: The government's plan is based on the World Bank, U.K. Department for International Development, and Chinese government documents.

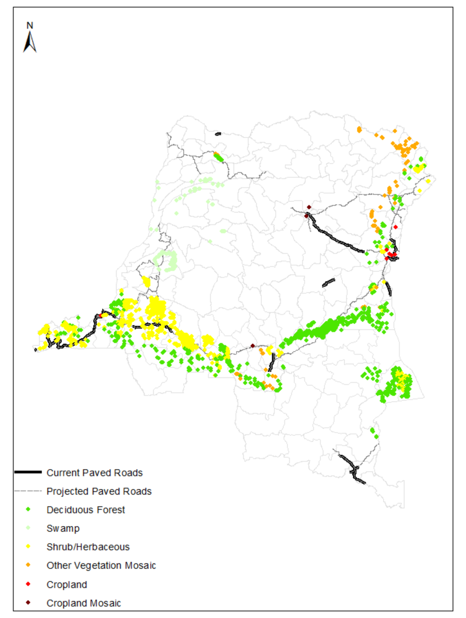

Figure 4. Deforestation of tropical rainforest under the "government's plan"

Policy Discussion

The World Bank and the British government have signed a five-year agreement for the rehabilitation and upgrading of 1,800 kilometers of high-priority roads, while China and the DRC government are planning to rehabilitee some 5,800 kilometers of roads and an equally long railway network. To inform this issue, Ulimwengu *et al*. (2009) has estimated the effect of proposed infrastructure investments on market access. We integrate Ulimwengu *et al*.'s (2009) results into the land use model developed in this paper to assess the potential impact of road construction (table 2) on deforestation and forestation degradation. The simulation results suggest that the total acreage of tropical rainforest would decrease by approximately 2.1 million hectares. Specially, the encroachments of deciduous forest and shrub/herbaceous are predicted to account for 57% and 33% of the reduction, respectively (figure 4). The results of this study should provide valuable information to policymakers and stakeholders to design plausible development scenarios for the DRC and to plan for the use of forest resource.

Reference

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