Drivers of land-use change in the Southern Nations, Nationalities and People's Region of Ethiopia

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Abstract

The present study employed an econometric framework of land-use shares at the scale of a district to analyse the effects of different socio-economic, bio-physical and climatic factors on land-share allocations to agriculture, forest and grass shrubland in the Southern Nations, Nationalities and People's Region of Ethiopia. The results of the empirical analysis confirmed the significant role played by access to credit, access to markets, population density and road density in the allocation of land to competing uses. The results have important implications for the sustainability of current agricultural intensification policies and rural development strategies in Ethiopia, such as the sustainable land management (SLMP) initiative. For example, it is important to include densely populated regions in the SLMP target areas, as high population pressure remains a major cause of land conversion to agriculture and hence needs to be addressed. It will be necessary to create income and employment opportunities outside farming to reduce the pressure of population growth on land. Care must be taken in identifying routes for the construction of rural road networks with minimal environmental impact. Credit provision must consider other, more capital-intensive technologies such as the irrigation needed to reduce pressure on the land through improved productivity. In addition to the promotion of higher adoption of modern technologies to levels that allow the realisation of the land-saving effects of intensification and productivity gains, strategies and policies are needed to encourage intensification of agricultural production in non-forested land. Furthermore, forest policies that facilitate the capturing of forest rents are important for the preservation of forests. Programmes and strategies to exploit multiple benefits from the various forest ecosystems' services, such as clear and secure land and forest property rights, and land use and forest policies that give carbon rights to land users and allow communal administration of forests, are prerequisites to enhance forest benefits as the main incentive for conservation.

Key words: forest; land use; aggregated data

1. Introduction

Land-use and land-cover change (LULCC) are associated with large negative impacts on ecosystems observed at local, regional and global scales. High rates of water, soil and air pollution are the consequences of observed LULCC. Biodiversity is reduced when land is changed from a relatively undisturbed state to more intensive uses like farming, livestock grazing, selective tree harvesting, etc. (Ellis 2011). Land-use change due to deforestation in the tropics was the major contributor to CO_2 emissions in the 1990s, which averaged between 0.5 and 2.7 gigatonne of carbon

(GtC) per year (UNFCCC 2007).These changes alter ecosystem services and affect the ability of biological systems to support human needs, and also determine, in part, the vulnerability of places and people to climatic, economic and socio-political perturbations (Lambin & Geist 2006).

Research on the Ethiopian highlands showed that, between 1860 and 1980, land under cultivation had increased considerably at the expense of shrubland, woodlands and forestlands, especially on steep slopes and in marginal areas. In the highlands of Ethiopia, LULCC has reduced the surface run-off and water-retention capacity and stream flow, leading to a loss of wetlands and the dying of lakes (Muluneh & Arnalds 2011). The south-western part of Ethiopia, which accounts for 18% of the country's forest cover, has seen significant deforestation over the last two decades (Gole & Denich 2001). Decline in forest area, shrubland and riverine tree cover resulted in the loss of fertile soil and biodiversity, and increased landslides as well as sediment loads in rivers, which are used for power generation (Reid *et al*. 2000; Dereje 2007; Mengistu 2008; Dessie & Christiansson 2008; Kefelegn *et al*. 2009).

Several case studies have shown land-use change to be driven by a mix of resource scarcity, changing opportunities created by markets, inappropriate policy intervention, loss of adaptive capacity and increased vulnerability, and changes in social organisation, resource access and attitudes (Lambin *et al*. 2003). Geist and Lambin (2002, 2004) and McConnell and Keys (2005) made attempts to generate better a understanding of the proximate causes and underlying driving forces of tropical deforestation, desertification and agricultural intensification respectively, based on local-scale case studies. The findings of these studies suggest that there is no universal link between cause and effect. Instead, LUCC is determined by different combinations of a number of proximate causes and underlying driving forces in varying geographical and historical contexts.

The importance of understanding the link between land use and land users is emphasised in many land-use studies analysing how people affect land either directly or indirectly. The direct effects are due to the use of lands that are accessed by resource users, whereas indirect effects play through decisions made by people far from the land where the changes take place. The impact of distant consumption decisions on local land use is generally bigger in the presence of developed social organisations and services (Axinn & Barber 2003). Micro-economic studies on land use explain land-use change as a decision made by land owners based on profitability of alternative land uses. Profitability is affected by a number of socio-economic, bio-physical and institutional attributes. The use of remote sensing data on land cover change and survey data has gained importance in showing the link between people and land-use change. These studies, however, mainly consider the direct use of land and ignore the effect of social organisations and institutions like markets, infrastructure, access to financial services, etc. that link people in spatially different locations to changes observed at specific locations (Fox *et al*. 2003).

A number of LULCC studies have been carried in the southwest of Ethiopia at catchment, zone, watershed and village levels (Reid *et al*. 2000; Dereje 2007; Mengistu 2008; Dessie & Christiansson 2008). The studies referred to have applied perception analyses, descriptive statistics, semi-structured and face-to-face interviews to identify the causes of the changes. The combined effects of population pressure, drought and migration, changes in settlement and land tenure policy, changes in the severity of the livestock disease trypanosomosis, poor institutional and socio-economic settings, poor infrastructure development and expansion in large-scale plantations were identified as the major drivers of the conversion of forest and shrubland to agriculture. The above analyses could not produce enough evidence and consensus to generalise the land-use change processes observed in the Southern Nations, Nationalities and People's Region of Ethiopia (SNNPR). The studies carried out so far looked at proximate causes of land-use change, either at village level, catchments or specific zones, and were based on an analysis of the spatial structure of land use and not linked to the behaviour of individuals or sectors of the economy. Most of them did not link remote sensing data with survey data to connect actors of land-use change with the land use change process.

Proximate driving sources reflect aggregate effects that result from the interplay of human and mitigating forces to directly cause environmental transformations and hence conceal the underlying drivers of the land-use change process (Turner II *et al*. 1995). The issue of scale is also important when analysing land-use change. Studies of a large spatial extent invariably have a relatively coarse resolution, often missing features displaying at smaller scales. On the other hand, due to their small extent, local studies often lack information about the context of the case study area that can be derived from the coarser scale data (Entwisle & Stern 2005). The literature on scale issues shows land use to be the result of multiple processes that act over different scales, where different processes have a dominant influence on land use at each scale. Relationships could also be stronger or weaker when they are compared at different scales (Zermoglio *et al*. 2005).

Studies carried out in Ethiopia involved either national level or lower scales (e.g. catchments, watersheds and village) levels and none looked at the dynamics of the land-use change problem at the scale of district and as an economic decision problem. By using remote sensing and survey data, this study made an attempt to analyse the underlying direct and indirect driving factors of land-use change. The study looked at the land-use change problem from an economic decision-making perspective, where decisions about land-use choices made by land owners aggregate to district-level effects. An econometric analysis approach to change in land use shares was used to study the effect of different socio-economic, bio-physical and climatic factors on shares of agricultural land, forest land, and grassland and shrubland uses in the SNNPR.

By identifying the drivers of land-use change at a district level, this study intends to contribute to recent efforts to integrate land-use planning at the municipal, district and provincial levels into low-carbon development strategies. This is believed to be efficient especially in countries where sub-national governments have authority over land management, as is the case in Ethiopia.

2. Study area

The SNNPR is located in the south western part of Ethiopia and shares boundaries with Kenya to the south and Sudan to the west and southwest. The area covers 110 931.9 square kilometres, which is 10% of the area of the country (SNNPR 2010). The population of the area is estimated at 15 million with a density of 136 persons per square metre, and is growing at 2.9% per annum (FDREPCC 2008). The rural population constitutes close to 90% of the total population in the region. The region has 13 zones, subdivided into 126 woredas (districts), which are further divided into 3 714 rural and 238 urban sub-woreda.

Over the past 30 years, the annual rainfall in the region has ranged between 400 mm in the southern parts and over 2 200 mm in the west (Sheka and Kaffa zones) (SNNRP 2010). The SNNPR has arable highlands (*dega*), midlands (*woinadega*) and lowlands (*kolla*), and pastoral rangelands (*bereha*). The region covers the relatively fertile and humid midlands where the rural population of Ethiopia is concentrated (USAID/Ethiopia 2005). Table 1 gives a breakdown of land uses in the SNNPR.

Table 1: Land use in the SNNPR

Land use	Area (000 ha)
Forest	638.43 (5.9%)
High woodland	548.48 (5.1%)
Plantation	237.20 (2.2%)
Low woodland and shrubland	1349.43 (12.6%)
Other land	7780.76 (72.7%)
Water	152.86 (1.4%)
Total	**10 707.16**

Source: FAO (2010)

Enset (*Ensete ventricosum*) is a widely produced staple food in the region. Cereals are dominant in relatively high- or low-altitude areas, together with pulses and oilseeds. Annual root crops like sweet potatoes, Irish potatoes, taro and cassava are also common in the region. Important cash crops in the area include coffee, ginger, chilli peppers, chat (*Catha edulis*), honey, bananas, cardamom-like spice (*Aframomum).* Livestock production is common in the area, both in the pastoral rangelands and agricultural areas. Farmers supply butter to and fatten animals mainly for the market (USAID/Ethiopia 2005). The following maps (Figures 1 and 2) show how some of the explanatory variables (e.g. different access, biophysical and climatic variables) are distributed in the study region. Lighter shades indicate lower magnitudes of the variables and, as the shades become darker, they reflect higher values.

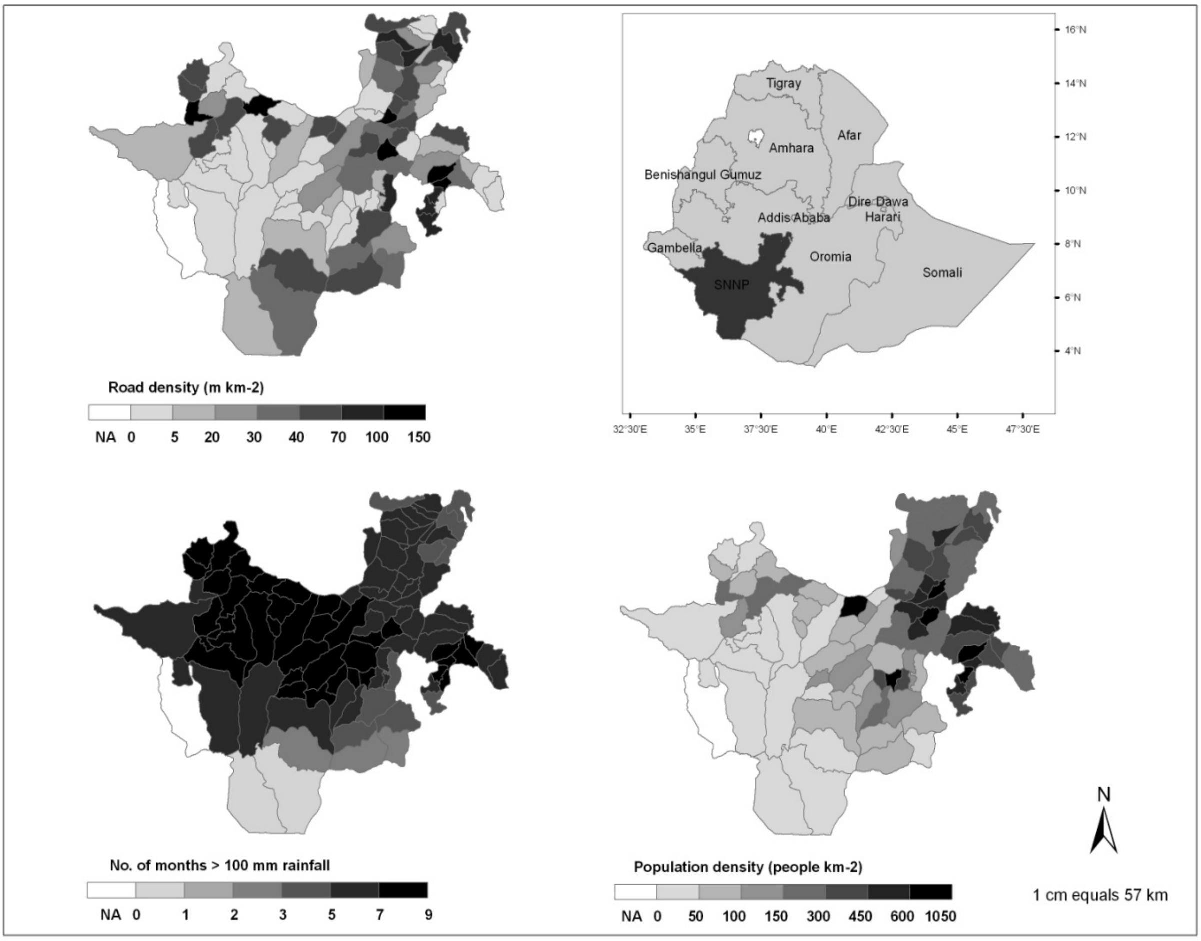

Figure 1: Distribution of road density, rainfall and population density

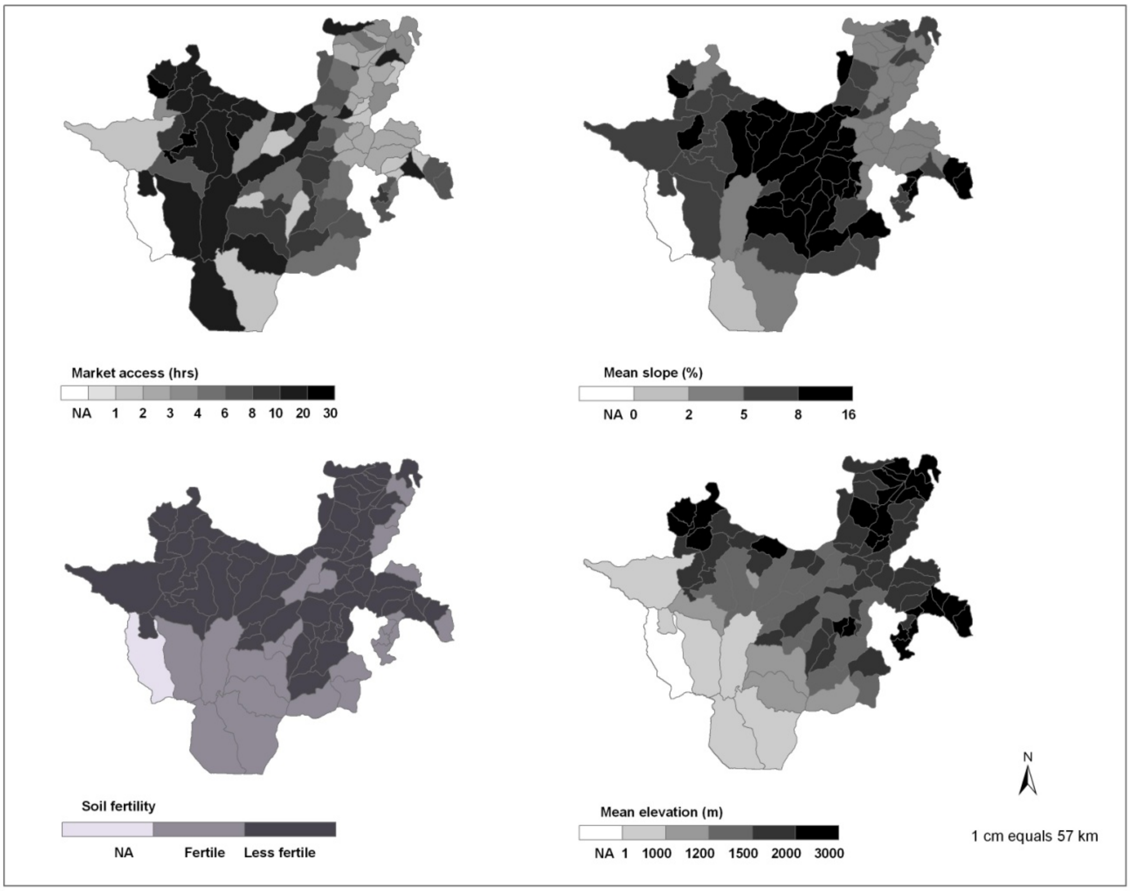

Figure 2: Distribution of market access, soil fertility, slope and elevation

3. The analytical framework

The theoretical basis for the econometric model in our study was the land rent maximisation concept developed by Ricardo (1817), Barlowe (1978) and Von Thunen (1966). This land-use theory has evolved to incorporate land quality differences as determinants of alternative uses of land. Studies by Lichtenberg (1989) and Stavins and Jaffe (1990) demonstrate that existing aggregate land-use allocations are strongly dependent on land characteristics. Recent empirical works confirmed the importance of including land quality in explaining current allocations (Parks & Murray 1994; Wu & Segerson 1995; Hardie & Parks 1997; Plantinga *et al*. 1999).

In this study we follow the model of aggregate land-use change developed by Miller and Plantinga (1999). The analytical framework is static profit maximisation under risk neutrality, where the landowner is assumed to allocate a fixed amount of land to alternative uses. The solution to the landowner's optimisation problem yields an expression for the discounted rents from each parcel of land. This land-use shares model has been applied in a number of land-use studies (Ahn *et al*. 2001; Yin *et al*. 2009).

Assuming that m_i (m_i =1, ..., M_i) is a land manager in district i (i = 1, ..., I) aiming to maximise the expected profits from land use K (k = 1..., K) on land quality h (h, ..., H), X is a vector of exogenous covariates like prices, costs and other economic decision variables, t is time and a_{hk} is the area of land of quality h allocated to land use k. The restricted profit function for this decision problem is denoted by:

$$\pi_{hk}(X(t,m_i), a_{hk}(t,m_i), m_i) \quad (1)$$

The land owner chooses a mix of land uses for each land quality class to maximise profit, given that, for each land quality type, land allocated to the different uses does not exceed the total available land, A_h.

$$\text{Maximise } \sum_k \pi_{hk}(X(t,m_i), a_{hk}(t,m_i), m_i$$
$$\text{subject to } \sum_k a_{hk}(t,m_i) = A_h(t,m_i) \tag{2}$$

The Kuhn-Tucker solution for the above decision problem gives the optimal allocations:

$$a^*_{hk}(x(t,m_i), A_h(t,m_i), m_i) \tag{3}$$

and the optimal amount of land allocated to use k is:

$$f_k(x(t,m_i),t,m_i) = \frac{1}{A(t,m_i)} \sum_h a^*_{hk}(x(t,m_i), A_h(t,m_i), m_i) \tag{4}$$

The land owner faces output and input prices that are not observable at a plot level but depend on several observable factors. These include access to roads and markets, population size, soil quality and availability of services. These are functions of district, regional and national level output and input prices, in addition to transport costs, which in turn are affected by access to roads and markets. The observed land uses at district level are found by aggregating the above individual land-use allocations:

$$Y_{ik} = \sum_{m_i}^{M_i} \phi(t,m_i)[(f_k(x(t,m_i),t,m_i) + \varepsilon_k(t,m_i)) + \xi_k(t,i)] + \varphi_k(t) = g_k(t,i) + u_k(t,i) \tag{5}$$

where $\phi(t,m_i)$ represents the sample weight assigned to land manager m_i , $\varepsilon_k(t,m_i)$ measures the difference in optimal and actual land allocations, $\xi_k(t,i)$ is the potential sampling error associated with each observation, $\varphi_k(t)$ is the aggregate sampling error (as data is collected through sample survey), $g_k(t,i)$ is the expected amount of land allocated to use k in district I, and $u_k(t,i)$ is the composite error term. It is assumed that the sampling errors are distributed with zero mean and finite variance, and are uncorrelated across districts and individuals and with the decision variables (Miller & Plantinga 1999).

4. Econometric model specifications

In cases where the dependent variable Y is a fractional variable, the conditional expectation of Y given X cannot be explained by linear regression of the explanatory variables, as Y is bounded between zero and one and so the effect of any particular X_i cannot be constant throughout the range of X, unless the range of X is very limited (Papke & Wooldridge 1996; Mullahy 2010).

There have been few attempts to resolve this problem. For the linear model the predicted values from an OLS regression are not guaranteed to lie in the unit interval. Modelling the log-odds ratio of Y as a linear function of X works, as long as Y varies between 0 and 1, but if Y takes values of 0 or 1 the equation cannot be true. And even if the model is well defined, recovering the conditional expectation is a problem without invoking further assumptions. By assuming a particular distribution for Y given X, it is possible to estimate the conditional expectation and the parameters of the conditional distribution by maximum likelihood. One common distribution assumption is the beta distribution, but this is difficult to apply in cases where some portions of the sample are at the extreme values of 0 or 1 (Papke & Wooldridge 1996).

Direct specification of a conditional mean structure embedded in an exponential family of quasi-likelihood distribution functions provides consistent estimates of the conditional mean structural parameters, as long as the conditional first moment is specified correctly (Papke & Wooldridge 1996; Mullahy 2010). The Bernoulli quasi-likelihood method is a good example used in estimating parameters of such specification of the conditional mean structure (Papke & Wooldridge 1996).

We follow Mullahy's (2010) extension of the above univariate case for the estimation of the multivariate fractional outcomes: Let Y_{ik} represent the k^{th} land use in district i, n the number of land-use types, X_i, I = 1, …, m be the vector of exogenous covariates and B the total land use in a district (the upper bound). The data can be characterised by the following:

$$Y_{ik} \in [0, B_i], \Pr(Y_{ik} = 0 / X_i) \succ 0 \, and \, \Pr(Y_{ik} = B_i / X_i) \succ 0 \text{, and } \sum_{n=1}^{N} Y_{in} = B_i \quad (6)$$

Here the parameters of concern in the analysis are the set of conditional means, which are specified to satisfy:

$$E[Y_k / X] \in (0, B), \, k = 1,...,N \, and \sum_{n=1}^{N} E[Y_n / X] = B \quad (7)$$

The above specification allows the conditional means to span the open interval (0, B), but not the closed interval [0,B], where the boundary values are excluded in the case of the open interval. But this is limiting in cases where, for some values of X, the probability of Y_k taking the values of 0 and B is one. Hence, to accommodate this, normalised outcomes or shares are used where the shares S range in the closed interval [0,1] (Koch 2010; Mullahy & Robert 2010).

Assume there are N quantities $Y_k = g_k(x, \sigma_k) + u_k$, $k = 1,..., N$ that are derived from the profit maximisation, and $g(.)$ are conditional means. The shares are calculated as follows:

$$S_k = \frac{Y_k}{\sum_{n=1}^{N} Y_n} = \frac{g(x, \sigma_k) + u_k}{\sum_{n=1}^{N} g(x, \sigma_n) + u_n} = \frac{g(x, \sigma_k) + u_k}{Y} \quad (8)$$

where Y_k is total land under use K, $\sum_{n=1}^{N} Y_n$ is total land use , g(.) are the conditional means and u_k is the set of error terms.

The conditional mean of the above share equation is given by (see detailed derivations regarding this in Addendum 1):

$$E[S_k / x] = \omega_k(x, \sigma). \quad (9)$$

Our interest is in an estimation of the conditional mean structure $E[S_k / x] = \omega_k(x, \sigma)$. As interpretations of the σ_s are not straightforward due to the normalisation, the interest is in the partial effect of a change in one of the explanatory variables on the expected conditional mean of the share. In the case of continuous explanatory variables, the partial effect of the change in share S_{ik} due to a change in X_i is calculated from a derivation of the conditional moment with respect to X_i:

$$\frac{\partial E[S_{ik} / X_i]}{\partial X_{i1}} = \sigma_{n1}\omega_n - \omega_n \sum_{n=1}^{N-1} \omega_n \sigma_{ni} \qquad (10)$$

And, when the explanatory variable is discrete, the partial effect is calculated as a difference (Koch 2010; Mullahy 2010).

5. The data and model variables

The data are taken from the Atlas of the Ethiopian Rural Economy, which has spatial information on the rural environment of Ethiopia at three aggregation levels: regional, zonal and district (Woreda). Work on the Atlas started in 2005 and it was made available for public use in 2006. The data is based on information at the district (Woreda) level. This Atlas was developed using data from the 2001/2002 Ethiopian Agricultural Sample Enumeration (EASE) and various other secondary data sources, like satellite imagery and global climatic databases, demographic data, and administrative data from government ministries and agencies (private and government banking and micro-finance institutions, the national cooperative commission, the national telecommunications agency, the postal service, and the Ministries of Health, Education and Agriculture and Rural Development). The EASE covers 464 of the 583 districts of Ethiopia and contains 450 000 households across Ethiopia (about 1 000 households, on average, in each district) (Tadesse *et al*. 2006). The Atlas provides maps that describe biophysical characteristics, accessibility measures, rural demographic characteristics, crop and livestock production variables, the farming practices applied and implements and technologies used. EASE data generated by the Central Statistics Authority of Ethiopia was assembled into a geographical information system (GIS)-enabled database by the Ethiopian Development Research Institute (EDRI). The other non-spatial data were collected from different sources and digitised into a map (Tadesse *et al*. 2006). For the purpose of this study, the land-use information, soil data and market access variables have been transformed from digital maps to match with the other numerical data using GIS software. Data from 93 districts in the SNNPR are used in our study.

The dependent variables for this study are land-use shares under agriculture and forest, grassland and shrublands, which are calculated as the ratio of land under each land use to total land area (Table 2). Explanatory variables are chosen to explain observed changes in land use at the level of the study (i.e. district). Land-use change is assumed to be a function of profitability, determined by changes in prices, economic conditions, policies or infrastructure development. Other determining variables used in the analysis include elevation, slope, rainfall, access to market and roads, population, income, conservation policy and access to credit facilities.

Table 2: Summary statistics of land-use shares and explanatory variables

Share/explanatory variables	Units	Mean	Std. deviation	Min	Max
Agriculture	Share of total land	0.56	0.32	0	1
Forest	Share of total land	0.19	0.26	0	1
Grassland & shrubland	Share of total land	0.25	0.27	0	1
Market access	Hours to nearest market	8.18	6.20	1.5	29.00
Access to credit	% receiving credit	5.47	7.71	0	52.68
Mean elevation	Metres (above mean sea level)	1 770.7	491.3	429.5	2 840.1
Mean slope	% incline	7.07	3.21	0.70	15.46
Mean rainfall	# of months with > 100 mm	6.36	1.70	0.45	9.00
Road density	Metres/km^2	33.05	36.2	0	145.1
Population density	Total population/km^2	241.6	221.9	4.00	1 036.0
Main income source	Cash crops (yes, no)			0	1
Protected areas	Presence of a protected forest area			0	1

The following hypotheses were tested on the relationships between land-use shares under agricultural and forestland, shrubland and grassland, and the explanatory variables given in Table 2:

(i) Access to credit. Credit delivery to purchase yield-increasing technologies has mixed effects on land allocation decisions. The literature shows that intensification of agriculture has mixed effects on forest clearing, depending on the type of technology used and assumptions about factor and output markets. The Borlaug hypothesis emphasises the role that technology can play in sparing cropland and increasing forestland by increasing productivity. Although this may be true at aggregate production at the global level, its application at the local level, especially at the forest frontier, is questionable. This is due to the fact that technological change at the forest frontier often has minimal impact on agricultural prices. Therefore, the increased profitability effect may dominate and lead to greater agricultural expansion (Rudel *et al*. 2009). The study will test the effect of access to credit for agriculture on land allocation decisions at our scale of analysis, i.e. district level.

(ii) Population density. Many farmers in the tropics practise unsustainable farming methods, as continuous cultivation results in a loss of soil fertility and weed problems, which force them to move on and clear additional forest somewhere else. Such shifting-cultivation systems may be sustainable when population densities are low, but with high densities this practice will more likely lead to land degradation unless new technologies are found to allow farmers to maintain productivity without degrading resources. This should reduce their need to abandon land and clear additional forests for new plots to cultivate (Angelsen & Kaimowitz 2001).

Higher population density is expected to lower wage rates and hence reduce the cost of labour relative to land, leading to higher labour intensity in agriculture (Boserup 1965). Higher labour intensity can take the form of production on more marginal lands, less use of fallow, and the adoption of more labour-intensive methods of cultivation (Pender 2001). Labour-intensive technologies are expected to have negative impacts on forest and other non-agricultural land uses. At the same time, while some intensification technologies, such as the use of draught animals, are labour saving and hence induce opposite effects on forestland, other modern farming methods like the use of fertiliser may be labour intensive. Thus, how higher capital input use affects the demand for labour and hence land conversion to agricultural use depends on which type of capital farmers adopt (Angelsen & Kaimowitz 2001).

Depending on the available technology, cost of inputs, government policies and level of discount rates, sustainable intensification might be a difficult choice for farmers and lead them to ignore the long-term effects of land degradation on productivity. This is in line with Boserup's (1965) hypothesis that, as long as potential farmland exists, in this case with low rent, farmers will generally expand cultivation into new areas before they intensify. Accordingly, population density was found to have mixed effects on land conversion decisions, depending on the availability of and adoption of technologies that increase the productivity of land and input-use intensity. This study tested for the population density effects on land use.

(iii) Access to markets and road infrastructure. Higher agricultural productivity increases the profitability of forest clearing and thus is expected to promote forest conversion to agricultural use, but high transportation costs have the opposite effect (Kaimowitz & Angelsen 1999). Better access can increase labour and/or capital intensity by increasing output-to-input price ratios (Binswanger & McIntire 1987). Better access also promotes the production of higher-value crops and more intensive use of inputs. But if the costs of factors increase as a result of constrained supply, a reduction in agricultural area is possible, as productive factors are concentrated in the most profitable lands (Pender *et al*. 2003).

(iv) Income. Higher levels of income, like increased wages, are associated with less land conversion to agricultural use. This is either because of the ability to finance purchased inputs or investments that increase land productivity, and/or through substitution effects on demand for agricultural and forest compared to higher-value consumer goods (Kaimowitz & Angelsen 1999).

(v) Land with lower slopes (flat land) is expected to lead to higher land conversion for agricultural use, since landholders will prefer to use easy and cheaper ways to develop lands.

(vi) Demarcation of protected areas is expected to discourage forest clearing (Krutilla *et al.* 1995), and this relationship is analysed in the study.

6. Empirical results and discussion

The results of the estimated average partial effects of the explanatory variables on land-use shares are reported in Table 3 below. Only five of the explanatory variables have been found to significantly affect land-use change in the region. The Lagrangian multiplier (LM) specification test was performed to test the null of no omitted variables in the conditional mean function, and the result failed to reject the null of no omitted variables (p = 0.9319).

The five explanatory variables showing statistically significant effect on agricultural land-use share are market access, access to credit, mean elevation, road and population density.

Table 3: Average partial effects of explanatory variables on agricultural land-use shares

Explanatory variables	Average partial effects	P > z
Market access	-0.0077373*	0.089
Access to credit	0.0000361*	0.062
Mean elevation	0.0002721***	0.000
Mean slope	0.0053234	0.506
Mean rainfall	0.0024032	0.866
Road density	0.0011797**	0.048
Population density	0.0003203**	0.040
Income	0.0499062	0.231
Protected areas	-0.0463113	0.309

Notes: significance levels: * = 10%; ** = 5% and *** = 1%; sample size = 93

As expected, distance to the market decreased the share of agricultural land and hence increased land allocated to forests, shrublands and grasslands. Similarly, higher road density had the expected sign promoting the conversion of forest land into agriculture. One of the objectives of the Sustainable Land Management Programme (SLMP) of the country is an environmentally sustainable increase in agricultural productivity through applying soil and water conservation measures and developing community infrastructure, including roads. Although this contributes to improving the livelihoods of farmers through generating income from agricultural production, the construction of roads can have negative effects on sustainable land use. Hence care must be taken in identifying locations to construct roads. Credit use for our case study area was found to have a positive impact on share of agriculture in land use, but with a very small magnitude (0.003%). This result is consistent with the findings of previous studies in the area that revealed low adoption rates of fertilisers and improved seeds, and attributed this to the absence of medium- and large-scale loans that would have been used to buy complementary inputs like irrigation equipment, fertiliser and improved seeds.

The effect of elevation shows high statistical significance in conversion of forest land to agricultural use in the study area. This is contrary to expectations and may be attributed to the specific agro-ecological attributes of the study region. The case study area mostly falls in the mid-altitude agro-ecological zone (mean elevation of 1 770 m above sea level), which receives more than 1 400 mm of rainfall and has relatively deep soils. These, together with a temperature range of between 18 and 20 degrees Celsius, seem to provide conditions that favour agricultural production.

Higher population density was also found to increase the share of agricultural land. This is understandable in the study area, as investment in capital-intensive technologies is minimal to reduce the pressure on the land through improved productivity. Moreover, it is important to note that moderately populated areas are targeted by the SLMP interventions. This is because the programme is designed in the belief that areas under high population pressure are fragmented and problematic for sustainable land management, and they hence are left out of any intervention. This remains a big challenge for the country's SLMP, however, as high population pressure is a major cause of the conversion of forests and other lands and it needs to be addressed.

Slope does not seem to have significance in land-use allocation decisions, but shows an unexpected positive impact on conversion to agricultural use. This may also be attributed to the specific agro-ecological attributes of the study region. While the effect of income was not statistically significant, it tends to increase the share of agriculture in land use. This results suggest that higher incomes in the study area do not seem to reach the levels of financing intensification sufficient to realise the effect of productivity gains on land saving. The presence of protected areas showed the expected sign on conversion to agriculture. The low statistical significance can be attributed to the high costs of enforcing protection to deter land users from encroaching into forests and other ecosystems.

Capturing forest rents, both extractive rents and payments for environmental services, are incentives that encourage land owners to preserve forests. A number of studies conducted in Ethiopia, specifically in the study area, show that single-benefit streams from the sale of non-timber forest products (NTFPs) have not been enough to protect forests from being converted to agricultural use. As a result there is a need to consider multiple forest benefits, including benefits from environmental services. Due to the absence of clear property rights, benefits from timber extraction have also been blamed for promoting deforestation.

The reduction of emissions from deforestation and forest degradation (REDD+) is the current common financial incentives-based strategy to compensate national governments and sub-national actors for demonstrated emission reductions. But the absence of national REDD+ policy, strategies, and legal and management frameworks on benefit sharing, carbon rights and responsibilities to manage credits prevents the country from benefiting from this initiative.

Allocation of benefits from emission reductions among actors depends among other things, on the state sector specific programs and policies to provide a system of incentives and law enforcement that achieves the emission reduction targets. The Federal Forest Development, Conservation and Utilisation Proclamation No. 542/2007 (article 4:1) recognizes the ownership of rural lands by governmental and non-governmental organizations and associations and private individuals as long as they follow regional land administration and utilization laws (FDRE, 2007). At the sub-national level also a number of regional proclamations are in place to implement the federal law. But the SNNPR Forestry Proclamation does not have a favourable pre-condition for implementing REDD+ at landscape level as it does not extend the definition of forest ownership to include community forests.

In addition, the right to sell carbon is not yet established. Only the needs of forest communities to access and use state forests for household and subsistence use are recognised in the Federal Proclamation (articles 10:3 & 11:6). The utilisation and administration of state and protected forests depends on whether or not the local community follows an approved management plan and received forest development and conservation training and technical support (FDRE, 2007). In the light of the above, the implementation of REDD+ in the SNNPR requires the establishment of management systems that guarantee ownership rights to the forest products.

The implementation of REDD+ policies and projects should be done carefully, as these might have a negative influence on biodiversity and possible negative impacts on local livelihoods. This is because the different land-use choices made by users to gain carbon credits may lead to the replacement of low-carbon density native forest, savannah and grassland ecosystems with high-carbon density monocultures of tree plantations.

Another issue that needs consideration is related to the development of a market that links emissions-reducing private and public-sector programmes with greenhouse gas (GHG)-emitting companies to comply with the cap-and-trade regulations. Efficiency in the delivery of finance and scale makes the regulated market attractive compared to official development assistance type of funding, which depends on political situations and bureaucratic inefficiencies. But, in the absence of clear tenure rights, the regulated market for forest carbon can lead to the displacement or exclusion of local communities by commodifying carbon. This is particularly important in the SNNPR, as land ownership is unclear and complicated.

7. Summary, conclusion and recommendations

This study analysed determinants of LULCC as an economic decision-making process in which aggregated decisions about land-use choices are made by individual land owners at district level. The land-use shares econometric framework was employed to study the effect of different socio-economic, bio-physical and climatic factors on the share of agricultural land, forest land and grassland and shrubland uses in the study area. The results of the empirical analysis confirmed the significant role access to credit, access to markets, population density and road density play in the allocation of land to competing uses at the district level in the SNNPR of Ethiopia.

Higher population density, proximity to and dense road infrastructure reflecting better access to markets, together with availability of credit services, were found to be important causes of land conversion to agricultural use in the study area. These have important implications for the sustainability of current agricultural intensification policies and rural development strategies in the study region and in Ethiopia. Initiatives like the SLMP being implemented to increase the productivity of small-scale farmers should take into account the negative effects that road construction and improving access to markets have on sustainable land use. It therefore is necessary to design land-use policies that improve the incentive structure so that forest clearing is reduced as access factors are improved.

For instance, care must be taken in identifying routes for the construction of rural road networks that have minimal environmental impacts while contributing to decreasing transport costs to sell outputs and access inputs. Credit provision should not focus only on the delivery of fertilisers and improved varieties, but must consider other, complementary investments like irrigation in water-stressed areas and conservation practices in areas prone to soil erosion. Investment in such, more capital-intensive technologies is currently minimal so as to reduce the pressure on land through improved productivity. Moreover, it is important to include densely populated regions in the SLMP target areas, as high population pressure remains a major cause of land conversion to agriculture and hence needs to be addressed. Options and strategies for the creation of income and employment opportunities outside of farming will be necessary to reduce the pressure of population growth on land.

In addition to the promotion of higher adoption of modern agricultural technologies to levels that allow realising the land-saving effects of intensification and productivity gains, strategies and policies to encourage the intensification of agricultural production in non-forested land are needed. In addition, forest policies that facilitate the capturing of forest rents are important for the preservation of forests.

Programmes and strategies to exploit multiple benefits from the various forest ecosystems' services, such as clear and secure land and forest property rights, and land-use and forest policies that give carbon rights to land users and allow for the communal administration of forests, are prerequisites for enhancing forest benefits as the main incentive for conservation.

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Addendum 1: Assumptions and specifications of the multivariate fractional logit (MFLOGIT) conditional mean of the share equation

Assuming there are N quantities $Y_k = g_k(x,\sigma_k) + u_k$, $k = 1,...,N$ that are derived from the profit maximisation, and $g(.)$ are conditional means. The shares are calculated as follows:

$$S_k = \frac{Y_k}{\sum_{n=1}^{N} Y_n} = \frac{g(x,\sigma_k)+u_k}{\sum_{n=1}^{N} g(x,\sigma_n)+u_n} = \frac{g(x,\sigma_k)+u_k}{Y} \quad \text{(A1)}$$

where Y_k is total land under use K, $\sum_{n=1}^{N} Y_n$ is total land use, g(.) are the conditional means and u_k is the set of error terms.

By assuming a non-stochastic exogenous constraint (i.e. B, which is the total land use in each district), the above equation becomes:

$$S_k = \frac{g(x,\sigma_k)+u_k}{\sum_{n=1}^{N} g(x,\sigma_n)} = \frac{g(x,\sigma_k)}{\sum_{n=1}^{N} g(x,\sigma_n)} + \upsilon_k = \omega_k(x,\sigma)+\upsilon_k \quad \text{(A2)}$$

This is because, when $\sum g(x,\sigma_n) = B$ is enforced in the denominator of the share equation, then $\sum_{n=1}^{N} u_n = 0$

The conditional mean of the share equation then becomes:

$$E[S_k / x] = \omega_k(x,\sigma). \quad \text{(A3)}$$

Particular functional forms for the conditional mean structure, like logit, probit or other cumulative distribution functions, are required to overcome estimation problems associated with fractional outcome variables. Other conditional first-moment functional forms like the Dirichlet are estimable, but the predicted shares could lie outside the [0,1] interval. Although the above formulation is common, alternative forms can be tested empirically using conditional moments tests. Consistent inferences usually require bootstrap covariance estimators, as share data will be under-dispersed relative to the nominal Bernoulli model (Mullahy 2010).

The fractional logit version of the fractional regression (FREG) model, which is the univariate foundation of the multivariate FREG estimator, is:

$$E[s/x] = \omega(x;\sigma) = \frac{\exp(x\sigma)}{(1+\exp(x\sigma))} \quad \text{(A4)}$$

According to Mullahy (2010), the extension to multivariate fractional logit (MFLOGIT) is given by:

$$E[s/x] = \omega_k(x;\sigma) = \frac{\exp(x\sigma_k)}{\sum_{n=1}^{N}\exp(x\sigma_n)}, K = 1,...,M \quad \text{(A5)}$$

Our interest is in the estimation of the conditional mean structure $E[S_k / x] = \omega_k(x, \sigma)$. A multinomial logit quasi-likelihood function Q(σ), embedding the functional form in equation A5 and using the shares $S_{ik}\,\varepsilon[0,1]$, gives consistent estimators of the parameters (Mullahy 2010).

$$Q(\sigma) = \prod_{i=1}^{M} \prod_{n=1}^{N} \omega_n(x_i; \sigma)^{s_{in}} \qquad \text{(A6)}$$

The log quasi-likelihood is:

$$L(\sigma) = Log(Q(\sigma)) = \sum_{i=1}^{M} \sum_{n=1}^{N} S_{in} \times \log(\omega_k(x_i; \sigma). \qquad \text{(A7)}$$

The corresponding $P \times (N-1)$ estimating equations are:

$$\frac{\partial L(\sigma)}{\partial \sigma_k} = \sum_{i=1}^{M} x_i^{\,T} [s_{ik} - (\frac{\exp(x_i \sigma_k)}{1 + \sum_{n=1}^{N-1} \exp(x_i \sigma_n)})], k = 1,..., N-1 \qquad \text{(A8)}$$

The correctness of the functional form is tested using conditional moments' tests. One way to check if the conditional moment is valid is by considering other functions of the explanatory variables and seeing if they are also conditionally uncorrelated with the estimated residuals. Here, quantiles of the fractional multinomial regression model are considered to be those functions. This shows whether the moment condition holds across the multinomial logit distribution within each category (Koch 2010).