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CHAPTER 1

INTRODUCTION

1.1 Preamble

Land use and land cover change (LULCC) is the human modification of the earth's surface to expand production of many ecosystem services and economic benefits. Currently the rate of land use change (LUC) is causing undesirable effects on ecosystems observed at local, regional and global levels. LULCC is responsible for global warming through the emission of greenhouse gases (GHGs). High rates of water, soil and air pollution are the consequences of LULCC. Biodiversity is reduced when land is changed from a relatively undisturbed state to being used for more intensive purposes such as farming, livestock grazing, selective tree harvesting, etc. (Ellis, 2011). LUC due to deforestation in the tropics was the major contributor to carbon dioxide (CO_2) emissions in the 1990s, averaging between 0.5 and 2.7 Giga-ton of carbon (GtC) per year at an average rate of 1.6 GtC/annum (LULCC, 2007). These changes alter ecosystem services and affect the ability of biological systems to support human needs, which also determines, in part, the vulnerability of places and people to climatic, economic and socio-political perturbations (Lambin & Geist, 2006).

Globally, different causes of LUCs have been identified. Though the factors may be different for different areas, a combination of results of case studies shows that land-use change is 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, access to resources, and attitudes (Lambin et al., 2003).

The literature also reveals the dependence of the driving forces of deforestation on the scale of the analysis (Cassel-Gintz et al., 2004). Geist and Lambin (2002, 2004) and McConnell and Keys (2005) attempted to generate better understanding of the proximate causes and underlying driving forces of tropical deforestation, desertification and agricultural intensification based on local-scale case studies. The proximate causes are human activities and actions at the local level, such as agricultural expansion, which has a direct impact on forest cover. The findings of these studies suggest that there is no universal link between cause and effect. Instead Land Use and Cover Change (LUCC) is determined by different combinations of a number of proximate causes and underlying driving forces in varying geographical and historical contexts.

Forests as one form of land use that provides ecosystem services such as watershed protection, biodiversity conservation, carbon sequestration and the consequent reduction in GHG stocks/loading, which are of enormous value to society, are being lost at alarming rates. The Food and Agriculture Organisation (FAO, 1997) reported that 14 x 10^6 ha of tropical forests had been lost annually worldwide. The global expansion of croplands since 1850 has converted some 6 million km^2 of forests/woodlands and 4.7 million km^2 of savannahs/grasslands/steppes. Land cover modifications are also widespread (Ramankutty, 1999). The Intergovernmental Panel on Climate Change estimates that tropical deforestation was responsible for 20 to 30% of global, anthropogenic GHG emissions during the 1990s *(*Kremen et al., 2000*).*

A review of research on the Ethiopian highlands showed that from the1860s to the1980s there was a decline in shrubland, woodland and forestland, whereas cultivated land increased considerably. This decline worsened between the 1980s and 2000s owing to expansions in

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cultivated areas, especially on steep slopes and in marginal areas. In the highlands of Ethiopia land use and cover change have reduced surface run-off and water retention capacity and stream flow, leading to loss of wetlands and drying up of lakes (Alemayehu & Arnalds, 2011).

Particularly the south-western part of Ethiopia has faced LUCs mainly due to deforestation. According to Gole and Denich (2001), LUC due to deforestation in the last two decades has been significant in this area, which accounts for 18% of the country's forest cover. A decline in forest area, shrubland and riverine tree covers and an expansion of croplands have also been observed in the area (Robin et al., 2000; Daniel, 2008; Dereje, 2007; Dessie & Christiansson, 2008). These changes resulted in loss of fertile soil and biodiversity and increased land sliding and sediment loads in rivers, which are used for power generation (Kefelegn et al., 2009).

A number of LULCC dynamics studies have been carried out in the south-western part of Ethiopia at catchment, zone, watershed and village levels. In Gibe Valley the LUCs were perceived to be caused by the combined effects of drought and migration, changes in settlement and land tenure policy and changes in the severity of the livestock disease, trypanosomosis (Robin et al., 2000). High population pressure, which in turn leads to increasing demand for land and trees, poor institutional and socio-economic settings, lack of land tenure security and poor infrastructure development were identified as the reasons for the changes in the Silte zone (Daniel, 2008). These village case studies in parts of the south-west of Ethiopia identified large-scale plantation expansion, communities' crop field expansion, lack of a clear land use plan and change in farming systems due to population growth as the causes of these changes (Dereje, 2007). In Awassa watershed, which is located

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in the south-central rift valley of Ethiopia, forest LUC was studied from the perspective of socio-political and geographical factors. The causes of the decline were attributed to geographic properties, socio-political changes, population growth, unstable land tenure principles, agricultural development and the improvement of transport capacity (Dessie & Christiansson, 2008).

In spite of the recent efforts and policy reforms promoting prudent development and use of the country's natural and environmental resources, environmental issues remain secondary in priority compared to economic growth and development objectives. For example, privatisation of natural resources has been advocated as one of the vehicles of growth without considering its environmental impact. This has been implemented in the dense south-western tropical rainforests (including wild coffee genetic diversity hotspots) where large tracts of these forest areas are given to private investors to develop coffee, tea and rubber plantations. This strategy clearly emphasises the short-term benefits of export revenue from the commercial farming sector (MCKEE, 2007; Aseffa, 2007).

Net annual forest loss has been observed to increase dramatically after these investments, particularly since investment in tea started. Expanding tea production has resulted in complete removal of the forests in the area, as no buffer zones have been reserved for riverine vegetation along the Baro River, which is the main tributary to the Blue Nile and has huge potential for irrigation development (Bedru, 2007; Tadesse & Masresha, 2007). The East African and Bonga Tea Plantation companies, which are the main investors in tea production, had cleared about 6 000 hectares of the south-western forests in Ethiopia by 2001 and this deforestation process is continuing (Tadesse et al., 2002).

Some researchers have identified the underlying reason for the deforestation process as the underestimation of the value of many goods and services provided by the forest (Lette, 2002). One reason for this undervaluation is market failure. According to Kramer et al. (1995), markets only exist for some products, such as timber, fuel wood and certain non-timber forest products (NTFPs). Other services provided by forests, such as carbon storage, biodiversity protection and recreation, are not traded in markets, hence their economic value is often ignored (Hassan, 2003).

Though the value of the goods and services provided by tropical forests in their natural state is not well known compared to the value of timber and agricultural products, it is expected that thorough and more focused scientific research will contribute significantly to improved understanding about their ecosystem service value (Graham-Tomasi, 1998). Efforts have been made by forest conservationists to protect natural forests from liquidation and conversion to non-forest uses through ecotourism, certification of wood products from sustainably managed forests and the sale of NTFPs. In response to global efforts to address climate change, there is increased interest in the benefits of carbon sequestration that accompany forest conservation (Bonnie et al., 2000). A case study in Madagascar analysed the costs and benefits associated with preserving a 33 000-ha area of tropical forest versus authorising large-scale industrial logging and concluded that establishing the park would be financially feasible if the state received compensation for the reduction in GHG emissions associated with the forest conservation project (Kremen et al., 2000). Both the convention on biodiversity and framework on climate change signed in 1992 and recent concerns about global warming provide many developing countries' governments with strong incentives for conserving their forests. The carbon market is one major mechanism through which developing countries will be rewarded financially by the developed nations for sustaining and improving the carbon sink capacity of their forests (Lovera, 2009).

1.2 Statement of the problem

Valuing forests by incorporating the different ecosystem services they provide to humans is important to reach a decision on the choice of land use. This is of huge importance, especially when deforestation is rarely reversible, as in the case of tropical forests. Recently, with the introduction/creation of markets for different environmental services, the need for consideration of multiple income sources from the forest rather than one benefit stream has started to generate interest in managing forest resources. Different studies have consequently recommended the development of many NTFPs and increasing their value through organic or forest certification and niche marketing, as well as consideration of ecotourism and environmental service payments, which may make the forest sector a better proposition than agriculture (Wunder, 2005; Landell-Mills % Porras, 2002).

Many studies used traditional CBA in evaluating the desirability of investment (forest development) projects, but ignored the option of delay in investment decisions. To invest today, the present value of expected benefits should equal or exceed the present value of expected costs plus the value of the option of waiting. This involves considering critical values that must be reached before making a risky and irreversible investment decision (Conrad, 1999). Ignoring quasi-option value, which is an important component in the decision to invest in irreversible development, will result in biased estimates. Studies also confirm that if a land use decision ignores non-use benefits and quasi-option value, optimal forest stocks will be smaller than current stocks. Complete deforestation is also possible when the trend and uncertainty of benefits are ignored, as in the deterministic case. In addition,

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studies show the sensitivity of the results to the assumptions made about these trends and uncertainty parameters (Bulte et al., 2002).

Conversion of primary forests to agriculture is considered an irreversible loss, particularly regarding its biodiversity functions. As a result, the decision to develop forests should be made cautiously and this becomes even more critical, since the benefits gained from tropical rain forests are uncertain. In most of the studies uncertainty about future environmental benefits and the irreversibility of the development decision were not taken into account. In addition, because of the absence of data, most studies have ignored the benefits of forest use other than as a source of timber. Hence modelling that takes account of the combination of uncertainty and irreversibility in analysing the costs and benefits of forest conversion is necessary (Pearce et al., 2006; Graham-Tomasi, 1995).

Most of the empirical studies of tropical forests have used deterministic frameworks in the analysis of the benefits and costs of forest conservation (Ehui & Hertel, 1989). Few studies have been conducted in Ethiopia to estimate the values of forest products considering environmental and ecological services, using the contingent valuation method (Seyoum, 2007). One of the objectives of this research is therefore to explore the effect of considering the price uncertainty of forest products, particularly NTFPs, in the face of the irreversible nature of the deforestation process on optimal land use choice between forest and tea production. The study will also consider the multiple forest values and the possibility of payment for the carbon-storing benefits of forests.The present study thus intends to incorporate available data on the benefits of forests and the forecast value of carbon from global models to analyse the costs and benefits of an irreversible development, given the

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uncertainty about forest benefits in Ethiopia. This assists in developing optimal land use decisions.

As said above, all studies in Ethiopia on LULCC have been carried out at either national level or lower (e.g. catchments, water shades and village) levels, but have not looked at the dynamics of the LUC problem as an economic decision problem. One of the objectives of the current study is to look at the problem of LULCC and forest conversion from the perspective of economic decision-making, where aggregated decisions about land use choices are made by land owners at the district level. This study has therefore looked at the forces driving deforestation that are important in the forest chains of Ethiopia. Different studies have shown the dependence of the driving forces of deforestation on the scale of the analysis (Cassel-Gintz et al., 2004). Studies conducted in Ethiopia to understand the process focused on national and regional scales and cannot explain the process at other scales. This study has considered factors at the scale of a district to analyse the effect of different hypothesised socio-economic and biophysical factors on different land use choices.

1.3 Objectives of the study

One main objective of this study was to measure and analyse the relationship between various drivers of LULCC and shares of land allocated to different uses in the major forest regions of Ethiopia. A second objective of the study was to determine optimal forest stocks over an infinite time horizon under uncertainty about the benefits from forest conservation. To reach these main objectives, the study intended to:

1. Analyse drivers of LULCC in Ethiopia using the Southern Nations and Nationalities People's Region (SNNPR) as case study area;

2. Compare the benefits from conversion of forest land to agricultural use (tea plantations) with benefits from forest conservation;
3. Calculate the quasi-option value of retaining the forests and determine the optimal mix of land use between forest and agriculture, using the threshold function under deterministic and stochastic scenarios; and
4. Derive conclusions and recommendations for an improved forest policy and better management in Ethiopia.

1.4 Hypotheses of the study

To achieve the above stated objectives, the following hypotheses were tested:

1. Higher soil fertility, lower slopes, access to road and market infrastructure and access to credit favour conversion of forest land to agriculture use.
2. When uncertainty in forest benefits is considered, deforestation ise more excessive than under deterministic valuation of forest ecosystem benefits. In other words, uncertainty about future forest benefits has a negative impact on optimal forest stocks.

1.5 Approach and methods of the study

To test the above hypothesis about the relationship between shares of land allocated to different uses and potential determinants of LUC (objective 1), cross-sectional analysis was conducted using a framework that incorporated many land uses and a number of explanatory variables. A model of aggregate land use data developed by Miller and Plantinga (1999) was adapted to conduct the intended analysis. The analytical framework is static profit maximisation under risk neutrality, where the landowner is assumed to allocate a fixed

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amount of land to alternative uses. The solution to the landowner's optimisation problem yields an expression for the maximum 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).

To test the second hypothesis about optimal land use choices, a continuous-time stochastic dynamic framework, in which the optimal preservation of a resource whose consumption is irreversible in the face of uncertainty about future prices is adopted. The decision to deforest was modelled as a threshold model with an incremental forest conversion process using dynamic optimisation (Bulte et al., 2002). In this formulation the social planner aims at maximising the discounted value of land use for forest or agricultural production activities. Forest clearing can be chosen when forest benefits drop below a certain critical value. Given stochastic changes in per hectare forest benefits over time, the gain may drop below the threshold value, hence increasing land allocated for agricultural use.

1.6 Organization of the study

The next chapter reviews land use development planning and related forest and environmental conservation and agricultural development policies, and institutional and legal issues of land use in Ethiopia. This chapter also analyses the status of forest resources in the country and trends in forest conversion and deforestation, the importance of the forestry sector to the national and household economy, the functions and characteristics of forests and other wooded land in the country and efforts to manage forests in Ethiopia.

Chapter 3 presents a review of relevant literature on theories and models of LUC. Chapter 4 presents methods and results of the empirical investigation of LULCC in the SNNPR of

Ethiopia. Chapter 5 presents methods and results of the analysis of determinants of the optimal mix of land use between forest and agricultural land use under both deterministic and stochastic scenarios. Finally chapter 6 concludes with policy implications and recommendations.

CHAPTER 2

STATUS OF FOREST RESOURCES AND LAND USE DEVELOPMENT PLANNING AND POLICY IN ETHIOPIA

2.1Introduction

The economic contribution of the forestry sector to the total gross domestic product (GDP) in Ethiopia was 11.60% in 1995 and declined to 9.0% in 2005. These figures do not include all the benefits from forests, such as wild edible plants and animals, livestock grazing, spices and the contribution of protected areas to the national economy. This is due to the absence of a forestry-related information system in the country that is sufficient for the construction of physical and monetary stock and flow accounts (Sisay, Menale & Mungatana, 2010a).

Besides its ecological importance as habitat for a multitude of animal and plant life, the forestry sector provides employment opportunities for both urban and rural communities. It has been estimated that it absorbs 0.29% of the nation's total of employed persons (31.44 million) excluding the employment opportunities for households that collect and sell biomass fuel and exudates (Sisay, Menale & Mungatana, 2010b).

Despite the sector's importance, unsustainable land use practices such as deforestation, deterioration of grasslands and croplands are observed in the country. LUC, dominated by deforestation, is the leading cause of species extinction, GHG emissions, water pollution, air pollution and soil erosion, which leads to the impoverishment of rural communities. These are the challenges Ethiopia, like many developing countries, is facing today. Ethiopia being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention to Combat Desertification and Convention for Biological Diversity, many of its policies emphasise the interrelationship among climate change, land degradation and biodiversity (ECSNCC, 2011).

To achieve the goals of a sustainable environment and development, international forest policies and national policies on forests, agriculture and other sectors should be formulated in coordination. The international climate policies assist to protect tropical forests through incentive mechanisms. The broader national development policies should go hand in hand with forest policies. National policies formulated to meet the demand for food and feed affect forest protection and other land use conversions (Searchinger, 2011).

In addition, the existence of a comprehensive land administration and use policy is crucial to combat environmental degradation and climate change. Land use policy formulation is important to secure the best possible productive use of land as a resource to meet human needs. Hence understanding the status of the forest and other wooded lands, management regimes and policies related to these sectors gives insight into the proper management of land resources.

2.2 The Status of Forest and other land uses and cover in Ethiopia

Ethiopia's forest resources cover about 50.6% of the country's total land area and fall into the categories of forestlands, woodlands, shrub lands, bush lands, plantations and bamboo (Sisay, Menale & Mungatana, 2010b).

Between 1990 and 2010 Ethiopia had lost an average of 140 900 ha (0.93%) per year of its forest. In total, between 1990 and 2010, the country lost 18.6% of its forest cover, or around 2 818 000 hectare (FAO, 2010). The total land area under different uses is given in Table 2.1.

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Table 2.1 Land uses in Ethiopia and SNNPR in 2005

Land use Categories	Area in hectares	
	Ethiopia	SNNPR
Forest	3 337 988	638427
High woodland area	9 632 616	548480
Plantations	509 422	237198
Low woodland and Shrub land	46 297 530	1349431
Other land	53 899 503	7780755
Inland Water	828 277	152860
Total	**114 505 336**	**10707150**

Source: FAO (2010, 2005)

The land under different uses has shown a number of changes in different periods. The trends of forest and other lands are shown in Table 2.2.

Table 2.2 Trends in Total (Net) Forest Cover of Ethiopia from 1990 to 2010

Forest										Other Wooded Land			
Area in 1000 ha				Annual change rate in 1000 ha						Area in 1000 ha			
1990	2000	2005	2010	1990-2000		2000-2005		2005-2010		1990	2000	2005	2010
				‘000 ha/yr	%	‘000 ha/yr	%	‘000 ha/yr	%				
15,114	13,705	13,000	12,296	-141	-1.0	-141	-1.1	-141	NA	44,650	44,650	44,650	NA

2.3 The ecological functions and characteristics of forest and other wooded land

The vegetation resources of Ethiopia are the world's only gene pool reservoir of 'wild' Arabica coffee (*Coffea arabica*), and the wild relatives of teff (*Eragrostis tef*). They also contain important gene pools of wild and cultivated enset (*Ensete ventricosa*), sesame (*Sesamum indicum*), Niger seed (*Guizotia abyssinica*) and several other globally important crops (Edwards, 1991). Ethiopia also harbours two of the 34 global biodiversity hotspots, namely the Eastern Afromontane and Horn of Africa biodiversity hotspots.

Diverse vegetation types are found in the country. There are 1 027 native, one endangered and 23 vulnerable tree species (FAO, 2005). The vegetation types include the dry evergreen Afromontane vegetation that ranges from dry to very dry *Acacia* and *Commiphora* bushlands in the arid and semi-arid areas of the north-east, east and south to the tropical rainforests in the south-west and the cloud forests on the eastern escarpment and the mountains (Sebsebe, 1996; CSE, 1997; Zerihun, 2000), *Combretum–Terminalia* (broad-leaved) deciduous woodland, *Acacia–Commiphora* (small-leaved) deciduous woodland, the lowland dry forests, the lowland semi-desert and desert vegetation, the evergreen scrub; wetland (swamps, lakes, rivers and riparian) vegetation, the moist evergreen montane forest and Afroalpine and sub-Afroalpine vegetation (Mulugeta Lemenih & Tadesse Woldemariam, 2010).

According to the FAO (2005), the forest and other woodland vegetation cover in the country is categorised as either modified natural or productive plantation. They are further classified for their productive and multipurpose functions. The amount of land covered for these purposes is given in tables 2.3 and 2.4 below.

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Table 2. 3 Designated function of forest and other wooded land

FRA categories	Primary Function (Area '000 hectares)		
	1990	2000	2005
Forest			
Production	491	491	491
Multipurpose	14622	13213	12509
Total forest	**15114**	**13705**	**13000**
Other wooded Land			
Multipurpose	44650	44650	44650
Total other wooded land	**44650**	**44650**	**44650**

Table 2. 4 Characteristics of Forest and other wooded land

FRA 2005 categories	Area (1000 hectares)					
	forest			other wooded land		
	1990	2000	2005	1990	2000	2005
modified natural	14622	13213	12509	44650	44650	45073
productive plantation	491	491	491	-	-	-
protective plantation	-	-	-	-	-	-
Total	**15114**	**14826**	**12526**	**44650**	**44650**	**45073**

The forests and other wooded lands also have significant stocks of carbon in living biomass and dead wood (Table 2.5).

Table 2. 5 Carbon Stock in living biomass and deadwood

FRA 2010 Categories	Carbon (Million metric tonnes)							
	Forest				other wooded land			
	1990	2000	2005	2010	1990	2000	2005	2010
carbon in above-ground biomass	227	200	186	172	172	172	172	172
carbon in below-ground biomass	62	54	50	47	82	82	82	82
carbon in dead wood*	43	38	35	n/a	38	38	38	n/a
carbon in litter	32	29	27	26	94	94	94	94
Soil carbon to a depth of _cm	982	890	845	799	2902	2902	2902	2902

Source: FAO (2010)

*Information on carbon in dead wood is found from FAO (2005)

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2.4 Importance of the forestry sector to National and Household economy

Forests have both socio-economic and ecological importance. They provide diverse and essential environmental protection services that support other economic sectors such as agriculture, construction, tourism and energy. Nationwide natural forests supply a high volume of industrial wood and NTFPs, and plantation forests supply most of the industrial wood. Farm forests supply most of the poles and posts demanded by the construction industry and industrial round wood. In addition, the natural high forests, woodlands, bushlands, industrial and peri-urban plantations and farm forests contribute to meeting the fuel wood demand in the country (Mulugeta & Tadesse, 2010).

In 2000, the total biomass in the forests of Ethiopia (natural and plantation) was estimated at 363 million tonnes (79 t/ha), while the total volume was estimated at 259 million cubic metres (56 m^3/ha). The forests produced 2 459 thousand cubic metres of industrial round wood, 60 thousand cubic metres of sawn wood, 25 thousand cubic metres of wood panels (FAO, 2001), and about 98 million cubic metres of fuel wood in 2000. Because of declining forest cover, the supply of industrial wood production is dwindling. In the 1970s the amounts of lumber and plywood produced were 65 and 1.9 thousand cubic metres, respectively, but in the early 2000s production declined to 16 and 1.6 thousand cubic metres, respectively. To balance the gap between supply and demand, the country has therefore started importing wood. In 2000, 12 000 cubic metres, 7 000 tonnes and 20 000 tonnes of wood-based panels, pulp for paper, and paper and paper boards respectively were imported at a cost of USD 15.3 million (Mulugeta, 2008).

The most important NTFPs in the county include forest coffee, gum, incense, honey and wax. Around 30 to 35% of annual coffee production originates from either wild or semi-managed

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coffee forests (Feyera, 2006). An average quantity of 4 107 tonnes of gums and resins, of which about 2 667 tonnes are exported, are harvested annually from the woodlands (Mulugeta, 2008). Around 56 thousand tonnes of medicinal plants are harvested and used each year. Most of these plants are harvested from wild plant stocks and most of the rural population and 90% of livestock herders depend on traditional medicine (WHO, 1998). About 1000 indigenous plant species with herbal medicine application have been identified to date and these are used in the traditional health care system to treat close to 300 physical disorders, from childhood leukaemia to toothaches and mental disorders (Fekadu, 2001, 2007). In addition to curative roles, herbal medicines help in government expenditure savings; the value added to the economy from traditional medicine in 2005 was estimated at USD 250 million and this industry provides 346 000 job opportunities (Mulugeta & Tadesse, 2010).

The forest sector also plays a huge role in export earnings and import substitution, employment generation and expansion of the GDP base (Mulugeta, 2008). Commercial non-wood forest products such as forest 'wild' coffee, honey and beeswax, gums and incense, spices and civet musk are exported. For instance, honey and beeswax production were estimated at about 26 000 and 3 000 tonnes per year and it is estimated that 10 million bee colonies exist in the country. About 7.5 million of these are confined in hives and the remaining ones exist in the forest in wild form (Hussein, 2000). The sector is also the major supplier of biomass energy.

The forests, woodlands, shrublands/bushlands and other tree resources contribute to the household economy by ensuring food security and provision of sustainable livelihoods for millions of rural people. More than 480 species of wild trees, shrubs and herbs have been

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recorded as important traditional forest-food sources in Ethiopia (Zemede & Mesfin, 2001). Income from forest/woody and other vegetation-based products is the second largest source of non-agricultural income for rural households in the country (Turnbull, 1999; Jagger & Ponder, 2000; Zenebe et al., 2007). At the national level, it has been estimated that fuel wood entrepreneurs receive the equivalent of USD 420 million per year, herbalists USD 216 million per year, wild coffee producers USD 130 million per year and honey and beeswax producers USD 86 million per year (Mulugeta, 2008), but no estimates have been found for furniture makers. All of these are estimated incomes received at individual or household levels.

Forests and woodlands are also valuable resources supporting the broad rural agrarian as well as agro-pastoral populations of Ethiopia. They provide productive virgin land for crop cultivation or serve as rangelands for the large livestock population. Thirty-five percent of rangelands in Ethiopia are covered by bushland and shrubland and animals graze and browse the forest. The forest provides 10 to 60% of livestock feed during dry and wet seasons, respectively (Mulugeta, 2008).

The forest sector also provides large formal and informal employment opportunities. Small and medium enterprises that range from wood-based small furniture-making workshops to non-wood-based production such as herbalists, wild coffee producers and tree farming by private farm households and entrepreneurs, are some of the investment opportunities provided by the sector. A few large forest-based industries include the paper and particleboard, bamboo furniture factories and saw-mill sub-sectors.

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Forest ecosystems also contain buffer stocks of biodiversity. They have been serving as emergency relief for millions of food-insecure citizens through formal and informal immigration and/or resettlement (Mulugeta & Tadesse, 2010).

2.5 Financial performance of the forestry sector

The total value of harvested forest products - firewood, charcoal and construction wood - and non-wood forest products - coffee, fodder, medicinal plants, exudates, honey, bamboo, beeswax, thatch grass - was estimated to be close to Ethiopian Birr (ETB) 10.45 billion[1] in 2005. The watershed benefit of the forest sector was estimated to have reached ETB 11.27 billion and the total value of construction wood and carbon ETB 8.51 billion in 2005 (Sisay, Menale & Mungatana, 2010b).

According to Mulugeta (2008), the total annual gross financial turnover in the forest sector was estimated to be USD 2.02 billion. The financial performance of the forestry sector with regard to some of the products and services (Mulugeta, 2008), production of forest products and services between 1995 and 2005 (Sisay, Menale & Mungatana, 2010a) and the value of wood removal from the sector (FAO, 2005) is shown in tables 2.6, 2.7 and 2.8).

[1] The exchange rate equivalent of 1 USD=8.7075ETB according to a rate prevailed in 15/06/2005

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Table 2. 6 Annual turnover of forest products

Product Type	Estimated annual turnover in USD
Wild Arabica Coffee (average 90,000 tonnes/yr)	130,590
Gums/Incense (Gum arabic, olibanum, myrrh, etc.)	3700
Honey and bees' wax	86,510
Herbal Medicine	2,055,484
Ecotourism (20% of the tourism industry)	15,400
Bamboo	10,555
Forest grazing (fodder)	-
Forest food	-
Essential oils	-
Live wild animals	-
Spices (Average 1208 tonnes/year)	2700
Civet musk (average 400 tonnes/year)	183
Total Value	2,305,123

Table 2. 7 Production of forest goods and services, 1995 and 2005(National Level)

Forest good/forest service (ETB)	1995	2005
Fodder	1,195,571,724	1,732,947,000
Forest Coffee	23,652,200	70,156,800
Semi forest coffee	53,467,297	190,793,827
Honey	85,501,662	108,046,220
Beeswax	16,901,780	42,221,138
Medicinal Plants	435,200,000	569,740,000
Bamboo resources	1,067,640	4,504,272
Exudates	21,157,480	41,924,830
Thatch grass	127,040,000	147,850,000

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Table 2. 8 Value of Round Wood

FRA 2005 Categories	Value of round wood removal (1000 USD)		
	Forest		
	1990	2000	2005
Industrial Round wood	61804	70303	74552
wood fuel	491379	591616	641734
Total for Country	**553184**	**661919**	**716286**

*Round wood price for all years =25 USD/M3

*Price of fuel wood: USD 5.894/ M3*1412236 M3 = USD 8324129

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2.6 Management of forests in Ethiopia

Forest management efforts such as planned logging, enrichment planting, assisted regeneration, tree species improvement programmes and protection against fire, as well as maintaining and improving the overall health and quality of the forests, are limited in Ethiopia (Mulugeta & Tadesse, 2010). The management of the forest sector is characterised by inadequate budget outlay, staffing and facilities to conduct even the minimum operations to manage forests, a low level of transparency and accountability in governance, lack of a basic database on which to base the management policies and regulations, and an industry that employs resource-wasting technologies (Demel & Tesfaye, 2002; Sisay, Menale & Mungatana, 2010a).

Management of forests involves government organisations, local communities, individuals, civil societies and non-governmental organisations (NGOs). Past and present management measures and interventions are directed at preventing further degradation, for example through area exclosure/enclosure, use of protected areas and plantation forests as buffers, or regulating access to forests and harvesting of products through participatory forest management and traditional institutions for forest management, or both (Mulugeta & Tadesse, 2010).

Planation forests include trees of both native and exotic species. These include industrial forests that supply sawn wood and lumber, peri-urban forests supplying poles and firewood to urban centres and catchment protection forests. Small-scale trees are also planted by rural farmers in rows or patches as woodlots, around fields or scattered on farmlands as agro-forestry, in pasturelands or other open areas and near homesteads (Turnbull, 1999; Jagger & Ponder, 2000; Zenebe et al., 2007).

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Area exclosure for forest regeneration is a common management measure in Ethiopia in a few places. It is the practice of land management that excludes grazing livestock and people from openly accessing a degraded area. It prevents further degradation of ecosystems and natural restoration of biodiversity and overall ecological conditions of the area. In some cases management also involves enrichment planting with native and/or exotic species, as well as introducing soil and water conservation structures to supplement and support the rehabilitation.

In the protected (priority) area demarcation and protection system, most of the remnant natural forests and some plantations are designated as national forest priority areas to protect and conserve their biodiversity. These areas cover close to 2.8 million hectares (Demel *et al.*, 2010). Some of the lowland forests and woodlands are included in national parks and wildlife sanctuaries (e.g. Awash, Nechi Sar, Mago, Abijata–Shalla, Yabello, Sinkile and Babile), which are another form of protected area management. However, current conditions evidence continuous human encroachment and other forms of severe disturbance.

The country is also involved in bio-carbon, such as the clean development mechanism-(CDM) based afforestation/reforestation projects, and reduction in emission from deforestation and degradation (REDD+) initiatives (Mulugeta & Tadesse, 2010). In table 2.9 the first five projects are CDM-based while the last two are REDD projects.

Table 2. 9 CDM and REDD Projects in Ethiopia

CDM based /REDD+ projects	Area coverage (hectares)
Humbo Assisted Natural Regeneration	2,728
Abote District Afforestation/Reforestation	2,000-3,000
Ada Berga District Afforestation/Reforestation	4,500-6,000
Sodo Farmers Managed Natural Regeneration & Agro-forestry	2,200
An Afforestation/Reforestation project in Amhara National Regional State	20,000
Bale eco-region	500,000
Yayu & Gedo forests	190,000

In addition, a sustainable land management programme (SLMP) designed within the Ethiopian Strategic Investment Framework for sustainable land management, which is a 15-year (2009-2024) programme, involves multiple sectors with the goal to improve the livelihoods of land users while restoring ecosystem functions and ensuring sustainable land management (Birhan, 2010). With support from the World Bank and Global Environmental Facility, the programme has already been initiated in 35 watersheds that cover about 300 thousand hectares.

Participatory forest management is one of the management measures undertaken to promote sustainable forest management by involving communities that live in and around forests, while improving their socio-economic status. The communities are involved as co-managers and share benefits accruing from the sale of forest products. A number of NGOs such as FARM-Africa, SOS Sahel, GTZ and JICA have been active in promoting and supporting the development of this management system in Ethiopia. They have introduced devolution of certain bundles of property rights from the state to the community, allowed local people to manage the forest resources sustainably and partially use the forest resources for livelihood support (Mulugeta & Tadesse, 2010).

Traditional forest management and conservation practices are also common in a few places in the country. These involve the management of forests using indigenous knowledge through organised indigenous institutions. The *Acacia–Commiphora* woodlands are managed as rangelands by the Borana people with the Gada governance institution (Watson, 2003) and the Afromontane forests in the south-west are managed for the extraction and use of NTFPs by the Kobo system (Dereje & Tadesse, 2007). In addition, there are small private efforts at traditional agro-forestry, such as a home garden agroforestry system in the dry lands of south and south-west Ethiopia, which are estimated to cover 576 thousand hectares (Tesfaye, 2005). These are but a few examples of this traditional management system.

2.7 Institutional and legal issues of land use in Ethiopia

According to the Ethiopian rural land proclamation, land use is defined as "a process whereby rural land is conserved and sustainably used in a manner that gives better benefits." It is a practice where the options that give greater economic benefit without causing land degradation and environmental pollution are determined and implemented from the different use options available for rural land on the basis of physical, economic and social information (ECSNCC, 2011).

The importance of environmental protection and its proper management to use and maximise economic returns from land is recognised in the country. A number of strategies and policies have been established within the framework of sustainable development plans and policies in

Ethiopia, which have direct and indirect effects on the conservation and development of forest resources.

The Federal Land Administration and Use Proclamation No. 456/2005 stipulates that "a guiding land use master plan which takes into account soil type, landform, weather condition, plant cover and socio-economic conditions and which is based on a watershed approach, shall be developed by the competent authority and implemented." The different regions in the country have followed these land administration and use proclamations of the federal land law (ECSNCC, 2011).

The environmental policy of Ethiopia was approved in April 1997; it constitutes 11 sectoral and 11 cross-sectoral policy elements. The overall goal of this policy is "to improve and enhance the health and quality of life of all Ethiopians and to promote sustainable social and economic development through the sound management and use of natural, human-made and cultural resources and the environment as a whole, so as to meet the needs of the present generation without compromising the ability of future generations to meet their own needs" (EPA, 2004). In addition, under the broad environmental policy, sectoral environmental policies on soil husbandry and sustainable agriculture; forest, woodland and tree resources; and genetic, species and ecosystem biodiversity are formulated to ensure sustainable development. This policy in the forest, woodland and tree resources sector addresses the complementary roles of communities, private entrepreneurs and the state in forestry development, integration of forestry development with land, water, energy, ecosystem, genetic resources development and crop and livestock production. The selection of suitable species for afforestation/reforestation is also included in this policy (EPA, 2004).

Ethiopia has a conservation strategy that provides a strategic framework, detailing principles, guidelines and strategies for the effective management of the environment (EPA, 2004).

The Agricultural Development Led Industrialisation (ADLI) policy emphasises increasing agricultural productivity in smallholder agriculture through improved inputs and technologies, diversification of production and the application of conservation practices. This has implications for sustainable land use, as agriculture is the main driver of LUCs, and the demand for new cropland and pastureland can be reduced by increasing the productivity of the sector. This type of land sparing from yield gains is achieved through government-driven and also market-driven measures that boost agricultural productivity on existing lands (Searchinger, 2011). The development of large-scale commercial agriculture and farmers' integration into domestic and international markets also fall under this (ADLI) policy. To use natural resources in a sustainable way the Plan for Accelerated and Sustainable Development to End Poverty considered, in addition to other strategies, proper land use plans by analysing the suitability of lands in a number of watersheds between 2005 and 2011, though no land use plans have been implemented (ECSNCC, 2011). The Growth and Transformation Programme (GTP), which is a five-year (2011/12-2014/15) development strategic plan of the Federal Government of Ethiopia, also focuses among others on expansion of commercial agriculture. To make the development process sustainable, the GTP plans to implement appropriate natural resource conservation measures (ECSNCC, 2011; MOFED, 2011).

Before the 1990s there were no specific forest policy and laws in Ethiopia and forest resource management was vague, required interpretation from various related legal documents such as institutional mandates or similar documents. As said earlier, the forest law enacted in 1994, through Proclamation No. 94/1994, was specifically aimed at contributing to forest

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development and protection for its ecosystem services and economic functions. It introduced the principle of benefit-sharing with the local people and public participation in forest management. The law recognises three types of forest ownership: federal forest, regional state forest and private forest. Private forest ownership applies to planted forests, as according to the constitution all natural resources, including natural forests, are public property (Demel & Tesfaye, 2002). In 2007, a new Forest Management, Development and Utilisation Policy (MoARD, 2007) replaced the previous law. It recognises state and private ownership of forests. This policy recognises communities' rights over natural forests and the need for their participation in managing such forests. The main objective of this policy is 'to meet the forest product demands of the society and increase the contribution of forest resources to the national economy through appropriate management. To achieve the objectives, a number of strategies were identified. These are promoting private forest development and conservation, promoting forest development technologies, strengthening forest product markets, administering and managing state forests, preventing deforestation and establishing an up-to-date information database (Mulugeta & Tadesse, 2010).

Under this policy community forests are recognised under private ownership, though communal right may allow a wide range of rights vested in communities. There are conflicting opinions on this law, as some argue that the term private ownership can refer to the rights of (organised) communities to own natural forests, but others are of the opinion that this might lead to misuse and does not necessarily imply ownership by communities but applies to plantations developed by individuals or private investors (Melesse, 2008: Demel & Tesfaye, 2002; Mulugeta & Tadesse, 2010). The same contradiction is observed in the SNNPR federal rural land administration and land use proclamation, which defines communal holding as "rural land which is given by the government to local residents for common grazing forestry and other social services" (FDRE 2005:Art.2(12)). These holdings given by government are fragmented and are not continuous territorial lands. Article 5(3) of the same proclamation recognises government as the owner of rural land and allows the conversion of communal lands to private lands as deemed necessary.

Regional states are given the power to formulate regional policies, administer land and other natural resources, raise their own revenues and implement their own forest development policies as long as these are in accordance with the federal laws. The decentralisation, governance and management of natural resources have been the responsibility of regional agricultural and rural development bureaus. These bureaus are also responsible for the preparation of plans and budgets for the forestry administration in their respective regions (Mulugeta & Tadesse, 2010).

Contrary to the national agenda, the SNNPR rural land administration and utilisation law, proclamation no. 456/2005 article 12(1) sub-article 2, contradicts sustainable use of land. According to this article, unoccupied land that is suitable for farming and lands in the possession of the government with potential for agriculture may be redistributed to landless individuals, farmers with limited lands, investors and willing settlers in the region. In this proclamation the term unoccupied land includes forestlands. The SNNPR land administration proclamation therefore does not consider the territorial concept of land ownership right of local communities and gives power to the government to lease land (SNNPR 2003: Art. 17(1)).

The responsibility for administering forests is given to a few government organs. The Ministry of Agriculture and Rural Development has the most important powers and duties in determining which plants should be called trees, preparing a list of endangered indigenous

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tree species, coordinating the appropriate federal and regional bodies and providing technical support to them, and initiating the drawing up of policies, laws and strategies. The proclamation vests more power in relation to direct forest administration in the regional states than at the federal level. Nonetheless, there are provisions that are difficult to understand without a regulation and/or directive for the implementation of the proclamation (Mellese, 2010).

The absence of autonomous environmental protection organs in different regions, especially in the SNNPR where the largest part of natural forests is located, is a constraint to forest conservation and development. The environmental protection organ is organised as one structure under the Bureau of Agriculture and Rural Development. This body is expected to be involved in supervising, protecting and developing natural resources and parks, implementing and controlling wildlife protection and utilisation laws, controlling forest fires, initiating a biodiversity protection policy, issuing directives and implementing the directives, as well as issuing and implementing directives that will protect natural resources and the environment. The Agriculture and Rural Development Bureau is also given the mandate to prepare land for investment in agriculture (SNNPRS, 2007).

Most of the policies have been accompanied by regulations for law enforcement. Tworegulatory instruments are employed in the legislation on forest product uses. These are business licensing and permits for the movement of forest products. Penalties for forest offences have been raised to a maximum of ETB[2] 30 000 and/or five years' imprisonment. The enforcement has been conducted by forest guards and forest products movement inspectors. Custom officers and the regular police can also enforce the law in their absence. There is a reward system for informers against offenders (Mulugeta & Tadesse, 2010).

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Despite the growing public concern about natural resources, especially forests, and the formulation of a number of policies, strategies, programmers and management plans and decentralisation in the administration and management of natural resources to address the problems, pressures for social and economic development continue to drive unsustainable use of land resources.

The development programmes and policies underscore sustainable production and conservation of natural resources but do not explicitly mention how these objectives will be achieved and the relevance of the land use plan in the process. The laws do not provide details. Such detail would require land use plans prepared at local levels, which are not available. Similarly, in the SNNPR, land laws are vague and implementation is problematic; the laws give unnecessary discretion to the regulatory authorities and they do not serve the conservation goal of the government (ECSNCC, 2011).

The forestry sector is characterised by frequent restructuring and is understaffed. Local people's right to participate in the management of and ownership of forests and woodland resources is limited. In addition, the sector is considered as a sub-component of the large agriculturally oriented structure, which has implications for budgetary allocations, human capacity building, priority setting and logistic allocation. The economic resources usually allocated to the forest sector are the lowest amount (<10%), and this is usually incapable of ensuring good forest management, as it restricts human and logistic deployment (Mulugeta & Tadesse, 2010).

Law enforcement in the forestry sector is also identified with weak institutions to follow up forest offence cases, poor linkage between law enforcing and forestry institutions, and high corruption owing to the attractive business in the illegal trade in forest products (Mulugeta & Tadesse, 2010).

Non-forest policies such as food security, agricultural development, resettlement, investment and other rural development strategies have reduced the perceived value of the forest sector. This has resulted in direct clearance of large areas of forests and other vegetation. Resettlement and investment in many areas show this.

Problems with the forest resources database is another limiting factor in the generation of appropriate policies and strategies. There are either no data or only unreliable and obsolete data.

2.8 Summary

The contribution of the forestry sector to the Ethiopian economy is significant and still under-estimated. It contributes to GDP and generates formal and informal employment opportunities for a significant portion of society. Ethiopia's forest resources cover a significant proportion of the country's total land area and are classified as forestlands, woodlands, shrublands, bushlands, plantations and bamboo. Recently these covers have been declining significantly. This calls for proper natural resource management through formulating and implementing appropriate policies.

A number of policies, strategies, laws and programmes have been formulated on land use, specifically in the forestry sector, but implementation of these at the local level has proven to be problematic. This is due to weak institutions and institutional arrangements, inadequate budget allocation, frequent restructuring of the sector and lack of coordination between different sectors of the economy. Land use plans prepared to be used at the local level are inadequate and the focus on non-forest policies tends to overshadow the benefits from forest resources.

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CHAPTER 3

REVIEW OF RELEVANT LITERATURE

3.1 Introduction

As stated in chapter 1, this study aims to analyse factors driving LUC in Ethiopia under secure and uncertain conditions. The chapter starts by reviewing approaches to the analysis of LUCC in section 2. Studies considering the effects of an uncertain market and non-market environmental values and the irreversibility of forest conversion are reviewed in section 3. Sections 4 and 5 review LUCC studies conducted in Ethiopia and approaches followed in this study. Section 6 summarises the chapter.

3.2 Approaches to study land use change

Approaches and models of LUC can be classified into many categories, depending on their theoretical bases, spatial and time dimensions of the studies, whether they are based on theory or not, scale of the analysis and whether they explain realities or prescribe solutions. They can consequently be economic or other disciplinary theories; spatially explicit or non-spatial models; dynamic or static models; deductive or inductive models; narrative, agent-based or systematic models; on household or firm level, regional and sub-regional or global models; descriptive or prescriptive models; and analytical, empirical or simulation methods. In each category one finds a number of sub-classes.

3.2.1 Theories of land use change

The main disciplines of scientific research that address LUCC include economics, geography, ecology and anthropology. A number of LUCC theories emerged from these disciplinary perspectives. The different theories often offer different explanations for LUCC, implying that the complexity of the land use system as a whole is not completely understood (Lambin et al. 2001).

Theories of LUC can be broadly labelled as explanatory and normative; individualist (behaviourist) and institutional (structuralist) theories; urban, regional, or global LUC theories; theories of particular types of land use (residential, industrial, agricultural and forestland; theories that prioritise specific determinants of LUC (economic, environmental or particular combinations of these) and static, quasi-static, and dynamic theories of LUC (Briassoulis, 2000; Verburg et al., 2006). Each category can be sub-divided further.

Three categories of LUC theories are generally recognised: 1) the urban and regional economics theorisation tradition; 2) the sociological (and political economy) theorisation tradition; and 3) the nature-society (or human-nature) theorisation tradition (Briassoulis, 2000).

3.2.1.1 Urban and regional economic theories of LUCC

These theories are based on rational utility maximisation by humans and the land use phenomenon is analysed from either micro-economic or macro-economic theories' perspectives. Micro-economic approaches start from the individual consumer and producer's behaviour and aggregate over all individuals to yield socially optimum land use patterns, i.e.

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the aggregate utility of all members of society is maximised (Briassoulis, 2000; Verburget al., 2004). Core examples of this family of analytical frameworks include the agricultural land rent theory developed by Von Thunen (1966; original in 1826), urban land market theory by Alonso (1964), who refined von Thunen's work, and agent-based theories of urban and regional spatial structures (Fujita et al, 1999; Henderson & Mitra, 1996; Krugman, 1995). The agent-based theories differ from micro-economic approaches of urban land rent theory because they stress particular features of agents, which relate to their linkages and interactions in space. The explicit attention to interactions between agents makes it possible to simulate emergent properties of systems. In addition, the decisions and actions taken by agents are influenced by past location decisions, which also influence future location decisions. The resulting spatial pattern is endogenously determined and changes underlying these patterns give rise to LUCs (Briassoulis, 2000; Kanaroglou & Scott 2001).

A number of land use models exist that are based on micro-economic theory [reviewed by Kaimowitz and Angelsen (1998) and Irwin and Geoghegan (2001)]. Modern economic land use theory has been built on the early contributions of Ricardo (1817) and von Thunen (1966) and can be summarised as "given a fixed land base, relative land rents are the key determinants of the allocation of land among competing uses." An addition to land use theory is the realisation that heterogeneous land quality is crucial to determining the alternative uses of land. The initial formulation of the concept of land rent is attributable to Ricardo, who defined rent as "that portion of the produce of the earth, which is paid to the landlord for the use of the original and indestructible powers of the soils." Ricardo introduced the notion that land rent is a function of soil fertility or climate. Later, von Thunen extended Ricardo's theory by adding location and transportation cost components to the model. Barlowe (1978) defines "land rent" as residual economic surplus, i.e., total revenue less total variable cost.

Most economic LUC models begin from the viewpoint of individual landowners who make land use decisions with the objective of maximising expected returns or utility derived from the land, and use economic theory to guide model development, including choice of functional form and explanatory variables (Ruben et al. 1998).

Macro-economic approaches deal with aggregate behaviour and show how aggregate patterns are produced. The LUC model of IIASA developed for China (Fischer and Sun, 2001) is one example of this approach. The spatial and inter-temporal interactions among various socio-economic and biophysical forces that drive LUCC are assessed in an integrated way in this theoretical framework. It is based on applied general equilibrium modelling using input-output accounting tables as the initial representation of the economy and applies a dynamic welfare optimisation model (Verburg et al., 2004).

Spatial economic equilibrium theory applies utility maximisation theory of welfare economics to spatially disaggregated economy and land and land use processes are treated at higher levels of abstraction (Ginsburgh & Keyzer, 1997; Losch, 1954; Takayama & Labys, 1986; Weber, 1929). The static form of this approach does not explicitly address change, as it is concerned with the equilibrium of demand and supply. In the dynamic form change is triggered by economic determinants such as changes in the location of production and consumption and the associated changes in demand and supply, product prices and wage levels, and trade levels among regions. This theory is usually used at regional, interregional, national and international levels (Briassoulis, 2000).

Regional disequilibrium theory considers activities in space as object of analysis and addresses LUC in an abstract and indirect manner. The Keynesian neoclassical theory of multiregional growth analysis, the Harrod-Domar model and export-based models are examples of purely aspatial theories and hence cannot be used to analyse LUC in specific regions and locations (Benet & Hordijk, 1986; Cooke, 1983; Hoover & Giarratani, 1999). However, they can provide directions for macro-economic determinants of LUCs in relation to incomes, investments, consumption, imports and exports with some assumptions (Briassoulis, 2000).

Other approaches in regional science, such as social physics-entropy and fractal growth concepts, are applied to analyse urban growth. They replicate observed patterns and processes but do not show causality of the changes and their explanatory power is poor compared to theories based on economic or sociological principles (Israd, 1999; Stewart, 1950). Urban and regional mathematical ecology is another theory concerned with urban and regional growth that borrows ideas and concepts from ecology and sociology, combined with theories from mathematics. It focuses on aggregate form, behaviour and processes and does not deal with land use explicitly; it hence lacks economic or social theory foundations (Nijkamp & Reggiani, 1998; Wilson, 1981).

3.2.1.2 The sociological theories of LUCC

This theorisation tradition draws on sociology, anthropology, psychology and political sciences thinking. Its focus is on the importance of the human agency, social relationships, social networks, and socio-cultural changes in bringing about spatial, political, economic and other changes. It includes functionalist/behaviourist theories (Burgess, 1925; Chapin, 1965), structuralist (institutionalist) theories (Scot, 1980), core-periphery theories (Hechter, 1975;

Friedmann, 1966), unequal exchange theories (Amin, 1978) and uneven development (capital logic) theories (Smith, 1990).

The nature-society (human-nature) theories of the LUCC theorisation tradition is more diverse compared to the above two traditions. It analyses land use within the broader context of global environmental change. This approach addresses the human causes of environmental change by considering interactions between nature, economy, society and culture, but the behavioural and other assumptions differ from one theoretical scheme to another. This theoretical tradition is based on humanities, natural science, social science and multidisciplinary theories (Briassoulis, 2000).

The humanities-based theories emphasise the culture-specific and variable nature of the nature-society relationship, taking into account the deeper social and personal determinants of LUC, though most of them do not show the direct connection to land use and its change (Lynch, 1960; Richards, 1990). The natural science-based theories treat environment, land and land use concretely and comprehensively as material entities with characteristic properties and particular ways of relating to one another and to the socio-economic forces that impinge on them. They emphasise environmental factors, ignoring or assigning a secondary role to institutional, political and economic factors (Bennet, 1976; Ellen, 1982). The social science-based theories include mass-consumption culture approaches, the ecological revolutions approach and multidisciplinary theories to analyse nature-society relationships (Merchant, 1990; Sack, 1990).

The multidisciplinary theories are applied to various spatial scales but are mostly relevant to larger scales. These theories consider the notion of ecological equilibrium where change in spatial structure in a region is considered to come from changes in equilibrium between

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population, resources, technology and institutions. LUC is brought about by changes in the size and distribution of a population, technological innovation and economic restructuring, social organisation and policy. Interactions among the biophysical and socio-economic determinants of LUCC are also considered in this class of model (Meyer & Turner, 1994).

The multidisciplinary family of theories comprises mostly loose collections of theoretical propositions, mostly descriptive frameworks, and their value lies in considering the role of resources and environmental constraints as factors limiting development and consequently land use. They do not delve into the mechanisms of change and the dynamic interactions between the natural constraints and the socio-economic and institutional regimes governing their utilisation, and hence cannot be of use as explanatory devices of LUC.

3.2.2 Empirical models of land use change

Both static and dynamic models are developed to study causes of LUCC, to predict where, when and how the change is likely to take place, and to assess apriori what interventions can influence the change. Static models are used to identify driving factors and predict future LUCs, but do not take into account feedback and path dependencies (Chomitz & Thomas 2003; Overmars & Verburg 2005). Dynamic models emphasie temporal aspects of LUC and can thus evaluate the irreversible effects of past changes on path dependencies in systems' evolution and LUC trajectories. Many multi-agent models and spatially explicit models such as GEOMOD (Geographic Model) (Pontius et al. 2001) and Conversion of Land Use and its Effects (Veldkamp & Fresco 1996; Verburg et al. 1999) are examples of dynamic models.

LUCC models can be either prescriptive or descriptive models. Descriptive models simulate the functioning of the land use system to explore near future land use patterns. They are based on actual land use systems and processes that lead to the change. They can be used for projecting land use patterns under different scenarios. Prescriptive models calculate the optimal land use allocations that fit the given objectives and use actual allocations as constraints for more optimal land use configurations. Many of these models assume optimal economic behaviour by actors (Lambin et al., 2000; Rabin 1998).

Another classification of LUCC models refers to deductive and inductive models. Inductive model specifications are based on statistical correlations between LUC and a number of explanatory variables that give insight into the change (Veldkamp, 1999). They do not have an all-encompassing theory to guide the change process owing to the complex relationship among the underlying causes that vary across space, time and organisational levels. The range of models includes the ones that consider decision-making by actors as specified as a set of decision rules and interactions based on observations (Parker et al., 2003) and others that analyse correlations between land use patterns and drivers as captured by statistical techniques (Geoghegan et al. 2001; Nelson et al. 2001; Verburg & Chen 2000). Logistic regression is a common approach to estimating the probability of a particular LUC (Bell & Irwin, 2002). This method has been used in modelling deforestation in the tropics (Chomitz & Gray, 1996; Mertines & Lambin, 1997) and in the central highlands of Vietnam (Muller & Munroe, 2004), among others.

Deductive land use models, on the other hand, are based on a theory that predicts pattern change from a process. Theory-based studies have the advantage that they are structured around the important human environment relationships identified in the theory and hence

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help to focus on data required to estimate and test hypotheses about such relationships. However, they only study processes that are likely to explain the observed pattern (Verburg, 2006). Most studies found in the literature are, however, not purely inductive or deductive. Theory and prior understanding of decision-making are used in selecting factors of LUC and suitable functional forms, though the quantification is based on inductive methods (Verburg, 2006).

Prescriptive LUCC models are classified as narratives, agent-based approaches and the systems approach (LUCC, 1998). The narrative perspective attempts to explain the LUC process through historical details and provides empirical and interpretative baselines for other approaches to validate the outcome of the studies. This is beneficial in identifying random events that affect land use processes and yet cannot be addressed by other approaches that employ more limited time horizons (Lambin, 2003).

The agent-based perspective looks at the land use process from the angle of the general nature and rules of individual agents' behaviour in their daily decision-making (Lambin, 2003).

The systems (structure) perspective attempts to understand the process through the organisations and institutions of society that establish the opportunities and constraints on decision-making (Lambin, 2003; Ostrom, 1990). It recognises interactive operation of structures at different spatial and temporal scales, linking local conditions to global processes and vice versa (Moran, Ostrom & Randolph, 1998) and the manifestation of the systems and structures in unforeseen and unintended ways. Inductive, deductive and integrated approaches are applied to understand the process (LUCC, 1999).

Empirical models quantify the relationship between variables using data and statistical methods, while simulation models employ parameters based on stylised facts drawn from various sources to assess scenarios and the impact of policy changes (Lambin, 1994). Based on the purpose of the model, underlying theories, types of land uses modelled, the discipline from which the models originate and the spatial and temporal dimensions, four main categories of LUCC models are identified in the literature, namely statistical and econometric models, spatial interaction models, optimisation models and integrated models (Briassoulis, 2000).

Statistical models include continuous and discrete land use models and are generally applied to explain, describe and predict LUCs as functions of some selected determinants. They assume linear relationships among variables and usually no specific theory underlies the models (Hill, 1965; Hoshino, 1996; Kitamura et al., 1997). They are spatially explicit and most of them are cross-sectional static models. Cross-sectional analysis of the actual land use pattern reflects the outcome of a long history of LUCs, resulting in more stable explanations of the land use pattern (Hoshino, 2001). They show associations among variables but do not capture causal relationships. There is consequently a need for validation of the causality of the empirically derived relations. Most causal explanations, however, are valid only at the scale of the study (mostly the individual agent of LUCC), and hence subject to up-scaling problems. Therefore a combination of methods, including multi-scale analysis and multi-agent models, are suggested for integration of the empirical and individual behaviour approaches (Veldkamp, 1999).

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Most statistical models therefore rely on econometric techniques, mainly regression, to quantify the defined relations based on historic data of LUC (Bockstael, 1996; Chomitz & Gray, 1996; Pontius & Schneider, 2001; Pontius et al., 2001; Mertens & Lambin, 1997; Mertens & Lambin, 2000; Pfaff, 1999; Pijanowski et al., 2000; Serneels & Lambin, 2001; Turner et al*.*, 1996; Veldkamp & Fresco, 1996; Wear & Bolstad, 1998). Most of these models describe historic land use conversions as functions of the changes in driving forces and location characteristics, but these approaches often result in a low degree of explanation because of the relatively short period of analysis, variability over the period and a relatively small sample size (Hoshino, 1996; Veldkamp & Fresco, 1997).

Spatial interaction models are gravity type models and are drawn from efforts to model interaction of human activities based on the analogy of the law of gravity in physics. They represent a mechanistic and deterministic view of aggregate social behaviour viewed according to laws governing the motion of particles. These models do not provide theoretical explanations about the interaction process, but simply represent and reproduce empirical regularities. They usually do not incorporate most of the determinants of land use and change, but are constructed to simulate flows between origin and destination zones, to predict these flows when changes in the origins and/or destinations occur and/or when the accessibility between origins and destinations changes. These are mostly applied in urban/metropolitan areas and not in agriculture, forestry and open space (Batten & Boyce, 1986; Lee, 1973).

Optimisation models derive solutions optimising certain objectives by decision-makers. They are normative or prescriptive models, i.e. they indicate desirable future land use patterns according to the specified objectives, preference structures, decision variables and

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constraints. They are applied in land use planning and land use solutions that contribute to sustainable development and use of environmental and human resources. This model category includes linear programming models, dynamic programming models, goal programming models, hierarchical programming models, linear and quadratic assignment models and non-linear models, utility maximisation models and multi-objective/multi-criteria decision-making models (Briassoulis, 2000).

Linear programming models have either a single objective or multiple objectives. The objectives can be minimisation or maximisation of certain objectives. Their data requirements are very high and are usually applied to development (benefit or cost), income and the environment (Herbert & Stevens, 1960; Stoorvogel et al., 1995).

Dynamic programming models are used in making a sequence of interrelated decisions. They give a systematic procedure for determining the combination of decisions that maximises overall effectiveness (Hopkins et al., 1978).

Goal programming addresses the issue of satisfying more than one goal simultaneously. It works by establishing a goal for each of the objectives, formulating objective functions for each and finally finding a solution that minimises the weighted sum of deviations of these objective functions from their respective goals. It is usually applied to private sector decision-making, as identification of the values of the goals is found to be difficult in the public sector (Lonergan & Prudham, 1994).

Hierarchical optimisation is a multi-objective programming approach and is usually applied to problems where the objective functions can be ranked in ordinal ways (Nijkamp, 1980).

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Linear and quadratic assignment models work on how to match available land-using activities to available sites to optimise an objective such as minimisation of development costs, maximisation of benefits, etc. The analysis is based on a prototype assignment problem (Moore, 1991).

Non-linear programming models assume non-linear relationships between LUC and drivers of change and their computation is often complicated (Adams et al., 1994).

Utility maximisation models include models that share a common theoretical basis that draws on economic theory. The utility theory of the neo-classical economics, based on the principle of consumer sovereignty, is used in this modelling. The analysis of both consumer and producer choice starts from the individual and is then aggregated over all individuals in the economic system to derive the aggregated demand and supply behaviour of an economy. The utility maximisation approach is used as evaluation method in the analysis of the desirability of alternative land use plans (Ruben et al., 1998). Land is considered as a fixed factor of production and as a special form of capital. Land associated with different uses enters the economic analysis of producer and consumer choices, hence changes in the demand and supply of goods and services lead to LUCs. The modelling approaches under this type could be either partial equilibrium (demand or supply oriented) or market equilibrium. Most applications are demand-oriented, assuming land will adjust to any magnitude of market demand. The demand-oriented approaches used mostly draw on the micro-economic theory of consumer behaviour and consider the supply of land, resources, availability of housing, etc. as fixed (Alonso, 1964; Wingo, 1961). The supply-oriented approach is applied in the housing market (Muth, 1969). Blackburn (1971), Beckman (1969), and Muth (1969) considered both the supply and demand side, i.e. the market equilibrium approach. Under

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utility maximisation models the land uses usually analysed are agricultural and forestland uses at the regional level. A study by Bockstael and Irwin (1999) tried to address the issue of incorporating more constraints, such as institutional, socio-cultural and political factors and the heterogeneity of the landscape and environment in land use decisions rather than only considering accessibility, transport cost, etc.

Multi-criteria/multi-objective decision-making models involve the combination of optimisation techniques with elaborate, multidimensional techniques of land use assessment/evaluation in a spatially explicit modelling environment and are data-intensive (Fischer et al., 1996).

Integrated models include econometric type models, gravity/spatial interaction models and simulation models. Econometric type models consider the interactions, relationships and linkages between two or more components of a spatial system. They are mostly large-scale models where the range starts from urban/metropolitan and reach the global. One econometric type integrated model (i.e.. Penny Jersey model) adopts an aggregate macro-economic approach to modelling the components of a metropolitan economic system (Wilson, 1974).

Simulation integrated models involve a set of rules that enable a set of numbers to be operated upon, but the rules and the consequences of applying them cannot be written down as a set of algebraic equations. They are used to derive the behaviour of a system when the system is too complex to be modelled using a more direct analytical approach to find explicit equations representing the behaviour of a system. The effect of possible interventions or shock to the system can be predicted. They are mostly based on either micro- (continuous utility maximisation framework or a discrete, random utility theory framework) or macro-economic theories (Kain, 1986; Putman, 1991).

Another method of quantifying the relations between driving forces and LUC is the use of expert knowledge. Especially in models that use cellular automata, expert knowledge is often used. Cellular automata models define the interaction between land use at a certain location, the conditions at that location and the land use types in the neighbourhood (Clarke & Gaydos, 1998; Engelen et al., 1995; Wu, 1998). However, the setting of the functions underlying these cellular automata is largely based upon the developer's knowledge and some calibration.

To address the difficulties observed in quantified modelling of complex systems, qualitative modelling has been developed in cases where quantitative information is absent. One of the methods is the syndromes approach (Petschel-Held et al., 1999). Though it is not a real LUC model, the approach indicates the extent to which a certain 'syndrome', which is closely related to LUC, is active in an area. Among the different methods the ones that are directly relevant to LUC are an urban sprawl syndrome and a green revolution syndrome. This approach is dynamic and it helps to understand and forecast the intensity of occurrence of the different syndromes in time. Although spatially explicit, the present extent is global with associated coarse resolution (Verburg et al., 2004).

An overview of deforestation models by Lambin (1997), deforestation models based on economic theory by Kaimowitz and Anglesen (1998), integrated urban models by Miller et al. (1999) and U.S. EPA (2000), multi-agent modelling approaches by Parker et al. (2003) and Bousquet and Le Page (2004), agricultural intensification models by Lambin at al. (2000), a number of LUC models based on economic theory by Bockstael and Irwin (2000), models based on spatial, temporal and human choice complexity (Agarwal et al., 2001), and

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general overview of land use models by Briassoulis (2000) and Verburg et. al. (2004), are some of the different land use models following a number of approaches.

3.2.3 Importance of scale in analysis of land use change

In LUCC research, scale dependencies are observed. Coarse scales obscure variability and variability at detailed scales obscures general trends. Local actions do not always give solutions to the problems faced at regional level and studies undertaken at the regional level do not always give insight into problems experienced at local level. The scale of observation influences the result of a study because of the complex interactions among the different biophysical and socio-economic processes. Multi-scale analysis of driving forces of LUC is important. Scale is continuous, so studying a particular scale will give a picture at one point (Turner, 1989).

Different studies provided different conclusions on the magnitude of the effect of scale on the influences of driving forces (Kok & Veldkamp 2001; Veldkamp & Fresco 1997; Walsh et al. 2001).

LUC with varying resolution and extent in six countries of Central America were studied, employing statistical techniques to analyse the relationship between the six land uses and a number of potential determining factors (Kok & Veldkamp, 2001). The results of the said study indicate that the effect of spatial resolution, by aggregating a basic grid to larger units, is small in comparison with other similar studies. The effect of a varying extent, by keeping either national boundaries or analysing the entire region at once, on the other hand, is substantial. Findings strongly suggest that any modelling effort at regional or global level

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should incorporate a thorough analysis of the effects of spatial scale on LUC predictions (Kok & Veldkamp, 2001).

Many papers further addressed the critical issue of distinguishing the different driving processes that influence land use patterns at multiple scales, from the local to the regional and national level (Nagendra et al., 2004).

Although the importance of explicitly dealing with scaling issues in land use models is generally recognised, most existing models only take a single scale of analysis into account. Especially economic models tend to aggregate individual actions but neglect the emergent properties of collective values and actions (Riebsame & Parton, 1994). Approaches that do implement multiple scales can be distinguished by the implementation of a multi-scale procedure in either the structure of the model or in the quantification of the driving variables. The latter approach acknowledges that different driving forces are important at different scales and it takes explicit account of the scale dependency of the quantitative relation between land use and its driving forces.

Two different approaches of quantifying the multi-scale relations between land uses and driving forces are known. The first is based on data that are artificially gridded at multiple resolutions; at each individual resolution the relations between land use and driving forces are statistically determined (De Koning et al. 1998; Veldkamp & Fresco 1997; Verburg & Chen 2000; Walsh et al. 1999; Walsh et al. 2001). The second approach uses multi-level statistics. This technique uses hierarchically structured data that could also be useful for the analysis of land use (if the hierarchy is known), taking different driving forces at different levels of analysis into account (Goldstein, 1995).

Scale of analysis is also important, as different variables are considered endogenous or exogenous, depending on scale and analysis at different scales, allowing the answering of different questions. According to Kaimowitz and Anglesen (1998), economic models of LUC are identified as household and firm-level models, regional or sub-national models and national models. In the household and firm-level models, land allocation is based on exogenously determined prices, initial resources and preferences, policies, institutions and technological alternatives (except in Chayanovian and subsistence models where farm households make trade-offs between consumption and leisure so that they make decisions based on their subjective, endogenously determined, shadow prices, which are at least partially determined by their preferences, rather than market prices).

The regional (meso) level models consider a region as an area that has a distinct characteristic ecology, agrarian structure, political history, local institutions, established trade networks, pattern of settlement, infrastructure and land use. Here some prices, institutions, demographic trends and technological changes are endogenous and others are not. Macro-economic variables, national policies and international prices are largely exogenous. Because of data limitations, most of the empirical models use counties, provinces or states as proxies for regions (Kaimowitz & Anglesen, 1998).

National and global scale models use regression models to establish statistical correlations between LUC and exogenous variables such as population, national policies, macroeconomic trends, prices, institutions, and technology (Kaimowitz & Angelsen, 1998).

Correctly defining the spatial observation unit with respect to decision-making, which usually involves linking a unit and Geographic Information System (GIS) data, is important in land use analysis. In other words, the question, ‘do we link human activities to land or do we link land to people?' is of special importance (Geoghegan et al., 2001). Administrative units or grid cells are not individual agents, but aggregates of these. Inferences as to outcomes in such units require simplifying assumptions about the homogeneity of the decision-makers and the dynamics comprising that aggregate. Proper inference of micro-level spatial behaviour is therefore more appropriately based on survey samples of individual agents, under the general principle of matching the spatial scale of the decision process and the scale at which measurement is carried out (Anselin, 2002). This consideration should be taken into account by linking spatial measures to the perceived real decision-makers, thus matching the spatial and behavioural units.

The linkage of socio-economic household-level data and remote sensing data at the household level in general captures best the actual level of decision-making, except in cases where policy decisions at an administrative unit level are more important determinants. Linked household-level data also allow representation of the heterogeneity between households operating in a spatial unit. However, linking remote sensing and socio-economic data at the household level comes at a cost. Depending on the detail of analysis required, it generally requires geo-referencing every plot of the households interviewed. This is labour-intensive and expensive, as one should travel with the household to every plot to collect GPS coordinates or a detailed map should be available on which the household can identify its parcels (Lambin, 2003).

3.2.4 Drivers of land use change

LUC is typically modelled as a function of a selection of socio-economic and biophysical variables that act as the so-called 'driving forces' of LUC (Turner II et al., 1993). At different scales different driving forces have different influences on the land use system. At the local level this can be the local policy or the presence of small ecological variables, whereas at the regional level distance to the market, port or airport might be the main determinant of the land use pattern.

The selection of the driving forces depends on the simplification made and the theoretical and behavioural assumptions used in modelling the land use system. Most LUC models are related to the land rent theories of Von Thünen and Ricardo. Under these theories any parcel of land, given its attributes and location, is assumed to be allocated to the use that earns the highest rent (Chomitz & Gray 1996; Jones & O'Neill, 1992). Hence individual households optimise their location by trading off accessibility to the urban centre and land rents, whose value increase for areas closer to the centre. In this approach the equilibrium pattern of land use shows concentric rings of residential development around the urban centre and decreasing residential concentrations as the distance from the urban centre increases. The distance to an urban centre is therefore an important variable that drives change in land rent. Other approaches explain the difference in land rent due to differences in land quality, which result from a heterogeneous landscape. Many models that try to explain land values (for example, hedonic models) combine the two approaches by including variables that measure the distance to urban centres as well as specific locational features of the land parcel (Bockstael, 1996).

A number of models incorporate different land uses in the same framework. These models commonly use a larger set of driving forces and include drivers such as land value and transportation conditions, suitability of the land for agricultural production (e.g. soil quality and climatic variables), market access, etc. In addition, the extent of the study area influences the selection of variables. In larger areas it is common for a larger diversity of land use situations to be found, which requires a larger variety of driving forces to be taken into account, whereas in a small area it might be only a few variables that have an important influence on land use.

A model of land-use shares is applied at county level in a number of studies (Ahn, et al., 2000; Parks & Murray, 1994; Plantinga & Buongiorno, 1990; Mauldin et al., 1999). With the assumption of competitive land markets, landowners allocate parcels of land to the use that yields the highest rent. The productive ability of the land is determined by market accessibility (von Thünian's ideas), and Ricardian land rent, or the inherent value of land given soil fertility, topography and other factors. Changes in land use are brought about by the changing profitability of a particular use, which can be caused by changes in prices, economic conditions, policies or infrastructure development.

These studies investigated the drivers of LUCs among agricultural, urban and forestland uses; deforestation and change among specific uses such as land under planted pine, natural pine or upland hardwoods, and agricultural land etc. The studies identified population growth, road density, better soils, terrain, credit, stumpage prices, productivity, economic structures, employment types and zoning as the main drivers of LUCs; some have mixed effects across different studies (Ahn, et al. 2001; Bhattarai et al., 2004; Parks et al., 2000; Pfaff, 1997; Nagubadi & Zhang, 2005; Sohngen & Brown, 2004; York & Munroe, 2009).

One recent land use study in 31 counties in China's upper Yangtze basin used the fractional logit model specification to determine the effects of important economic and institutional variables on changes in cropland, forestland and grassland empirically. The results of this study showed that population expansion, food self-sufficiency and better market access increased cropland share, while industrial development contributed to an increase in forestland and a decrease in other land uses. In addition, stable tenure had a positive effect on forest protection (Yin et al., 2009).

3.3 Land use decisions under uncertainty and irreversibility

In economics literature, evaluating the desirability of an investment project involves using the theory and methods of cost-benefit analysis (CBA). Investment decisions in traditional CBA are based on net present value under the assumption that investment is reversible such that expenditure can be recovered if market conditions turn out to be worse than anticipated. There is no possibility of the option of delay in making the investment. However, in real life irreversibility and the possibility of delaying decisions are the most common phenomena (Conrad, 1999; Dixit & Pindyck, 1994).

In such a case, investing today requires the present value of expected benefits to equal or exceed the present value of expected costs plus the value of the option to wait. Uncertainty and the fact that the project may be economically costly or ecologically impossible to reverse are the aspects that are not easily introduced into the traditional CBA framework.

If investment is irreversible and future returns are uncertain, the uncertainty can be resolved by waiting. The quasi-option value concept used in environmental economics literature (Arrow & Fisher, 1974; Hanemann, 1987; Henry, 1974) is equivalent to the financial economics concept of option value (Fisher, 1999). It is a flexibility premium when future learning is considered in decisions regarding irreversible development and is measured by the expected value of future information conditional on preservation (Hanemann, 1987). According to Conrad (1980), this value is associated with the expected value of either perfect or imperfect information, depending on whether the delay of irreversible action allows individuals to ascertain the true value with certainty or if delay only affords the opportunity for probability revision.

Stochastic processes are the interest when considering the uncertainty and irreversibility concepts in analysing investment or development decisions. They are variables that evolve over time and are at least in part random. They could be stochastic processes continuous everywhere, such as the Brownian motion (Wiener process) or mean reverting processes. To decide whether to model a process as mean reverting or Brownian motion, statistical methods, theoretical considerations and analytical tractability are taken into account. The Wiener process is a continuous time stochastic process with properties of a Markov process, independent increments and normally distributed changes of the process in any finite interval of time with variance increasing linearly with the time interval. It is generalised into a broad class of continuous time stochastic processes called Ito processes (Dixit & Pindyck, 1994). These processes are used to show the dynamics of the value of projects, output and input prices, input costs and a number of other processes that evolve stochastically over time. The stochastic processes do not have conventional time derivatives, so ordinary rules of calculus cannot be used. Instead Ito's Lemma or the Fundamental Theorem of Stochastic Calculus is used to solve stochastic differential equations. Dynamic programming is the technique used, and it divides the whole sequence of decisions into an immediate decision and a value function that includes the effects of all subsequent decisions, starting with the position that results from the immediate decision. The method has the advantage of considering uncertainty and irreversibility (Conrad, 1999; Dixit & Pindyck, 1994; Hertzler, 2009).

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Many studies in the environment and resource economics literature produced policy recommendations for the management of resources but suffered from the shortcomings of treating stochastic phenomena as deterministic. A number of studies (Arrow, 1968; Arrow and Kurtz, 1970; Fisher et al., 1972) investigated the effect of uncertainty concerning estimates of environmental costs of some economic activities. The said studies showed that in certain important cases, uncertainty will lead to a reduction in net benefits from an activity with environmental costs. When development involves irreversible transformation of the environment, and if information about the costs and benefits of both alternatives realised in one period results in a change in their expected values for the next, the implication for an efficient control policy is some restriction on the development activity.

In addition, recent studies provide examples of the importance of considering uncertainty and irreversibility in land use allocation decisions. According to Bulte et al. (2002), too much primary forest is converted to agriculture in Costa Rica, when uncertainty and trends in forest benefits are considered. More of the forest should have been preserved, compared to recommendations made by frameworks that ignore uncertainty and irreversibility.

Valuation of forest stands was conducted using both deterministic and stochastic frameworks in Austria, and the results showed that the optimal rotation period is prolonged in the case where uncertainties in wood and carbon prices are taken into account (Chladna, 2007).

3.4 LUCC studies in Ethiopia

Excessive LUC, especially forest conversion to both large-scale and small-scale agriculture by investors and small-scale farmers, is observed in the country and specifically in the SNNPR, where large tracts of natural tropical forests are found (Reusing, 1998 cited in

Tadesse & Masresha, 2007:4). A number of studies tried to explain these dynamics by looking at the land use decisions made with respect to associated private benefits and the driving forces behind such changes.

Land allocation to commercial farms is done at the expense of forests and no CBA is conducted by the responsible government bodies (Tadesse & Masresha, 2007). A number of studies that looked at land allocation patterns among small-scale farmers assumed conversion under subsistence agriculture, assuming that challenges of development, poverty reduction and environmental preservation can be solved by merely focusing on sustainable management of NTFPs (Mohammed & Wiersum, 2011), ignoring the indirect and non-use values of forests (Reichhuber & Requate, 2007; Schravesande-Gardei, 2006). The said studies focused on livelihood strategies adopted by farmers and the contribution of the NTFPs to household income and believed that as long as households get a certain percentage of income from the diversification, they might as well preserve the forests. Other studies, on the contrary, assumed that farmers convert land to agricultural use in pursuit of profit maximisation motives and that single-benefit streams, especially NTFPs, could not prevail over agriculture to preserve forests (Belcher & Screckenberg, 2007; Wood, 2007). This is the case even in places where there is forest coffee production (Belcher et al.2005; Ros-Tonen & Wiersum 2005).

Studies carried out to identify drivers of LUC in Ethiopia's SNNPR were at catchment, zone, watershed and village levels, based on perceptions, analyses and descriptive statistics, employing semi-structured and face-to-face interviews for data collection. These studies identified the following causes of LUC in the SNNPR: population pressure, lack of land tenure security and poor infrastructure development (Daniel, 2008); drought and migration,

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changes in settlement and land tenure policy, and changes in the severity of livestock diseases (Robin et al., 2000); the expansion of large-scale plantations and community field crop, lack of a clear land use plan, change in the farming system due to population growth (Dereje, 2007); geographic properties, socio-political changes, unstable land tenure principles, agricultural development and the improvement of transport capacity (Dessie & Christiansson, 2008).

3.5 Approach and methods of this study

Sub-optimal land use patterns, particularly conversion of land to agricultural uses, could arise because of the absence of markets for key services of the forest ecosystem and ignoring the uncertainty and irreversibility of the deforestation process. These problems can be addressed by reaching agreement among stakeholders, where compensation is given for the private loss arising from the choice of a socially beneficial land use choice. In addition, by identifying the drivers behind LUC, damaging policies may be modified and a shift may occur in unwanted LUC to other areas (Butler, 2011; Pearce et al., 1999).

Hence there is a need to analyse whether existing forest stocks (and other land uses) are optimal, considering multiple uses of forests and the uncertainty facing the values of some of the forest services, to arrive at an optimal strategy of either developing more forestland or preserving the existing stock. In addition, identifying the drivers of LUC helps with identifying policy instruments that prevent unwanted LUC. This requires employing a stochastic framework for analysing the costs and benefits associated with forestland conversions by considering benefits foregone by protecting forests. In addition to market values, non-market values of regulating forest ecosystem services (together with their uncertainties) and the irreversible nature of forestland conversions are important to take into account in studying land use decisions.

Previous studies conducted in Ethiopia only focused on a few forest use benefits that have market value and others considered only the private benefits of forests in weighing the costs and benefits of LUCs as reviewed above. No study in the country attempted to examine the effects of uncertainty and irreversibility on land use decisions. In addition, in trying to identify the drivers of LUC, no study has tried to analyse the effects of potential socio-economic variables and drivers that are observed at district level (scale).

Hence this study adopted a stochastic dynamic optimisation framework to evaluate the trade-off between forest conservation and conversion to other land uses. The land use share modelling approach is then employed to analyse drivers of LUCs among agriculture, grassland, shrubland and forestland uses.

3.5.1 The Land use shares model

As explained previously, studying the land use process at different scales is important to understand the full dynamics of the change. The LUC drivers are different at different scales and are context-specific, so the studies undertaken can explain the process only at the specific level of analysis (Cassel-Gintz et al., 2004). Hence studying LUC at district level contributes to a better explanation of such changes. For instance, a number of policy variables, such as rural development policies, are implemented at district level in Ethiopia, but no studies have been conducted at that level to capture these dynamics and existing studies have used non-economic frameworks to explain the change at different scales. As a result the effects of important land use decision variables, such as socio-economic factors, are not taken into

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consideration. In this study the land use shares modelling approach is used. This approach addresses the above problems by making use of the economic rent maximisation framework, where in addition to the biophysical factors, socio-economic and institutional factors are taken into account to understand the LUC process. In addition, this modelling approach is appropriate when the focus of a study is on aggregated decision-making by land owners using aggregated data.

The theoretical basis for the econometric model of land use shares is the rent maximisation concept developed by Ricardo (1817), Barlowe (1978) and von Thunen (1966), which has been developed further to incorporate land quality difference as one of the determinants of the alternative uses of land (Hardie & Parks 1997; Stavins & Jaffe, 1990). The basic model was developed by Miller & Plantinga (1999).

In this approach the optimal shares of the different land uses are often specified as logistic functions of a linear combination of the explanatory variables. However, linear regression is unattractive in modelling land use shares, as the effect of explanatory variables on the dependent variable is non-linear and the variance decreases as the mean gets close to either of the share boundaries. To solve this problem, the distribution of dependent variables and modelling how the mean proportion or share is related to the explanatory variables are emphasised in the literature. The beta distribution (betafit), a zero/one inflate beta distribution, and Dirichlet distribution are the distributions used for the dependent variables, and fractional logit and fractional multinomial logit are used to analyse the relationship between land use proportions and explanatory variables. The choice depends on whether a single or multiple proportion is considered, whether the extreme values, i.e. 0 and 1, are included or omitted in the analysis, whether the 0s and 1s follow the same process as the

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other proportions or not, and whether the interest is on the mean and not on other quantities (Buis, 2010). Most land use shares models in the literature apply the multinomial logit structure in modelling the process where ordinary least squares are used in estimation procedures. This results in bias and inconsistency in parameter estimation (Buis, 2010).

The interest in this study is estimation of the conditional mean of the shares, given the explanatory variables. Direct specification of a conditional mean structure embedded in an exponential-family quasi-likelihood, the maximisation of which estimates a distribution function, provides consistent estimates of the mean structure parameters as long as the conditional first moment is specified correctly (Mullahy, 2010; Papke & Wooldridge, 1996). Hence a multinomial fractional logit structure, as described by Mullahy (2010), which incorporates boundary values of the share data, is used to obtain consistent estimates of the parameters.

3.5.2 Stochastic dynamic optimization

As discussed in section 3.3, the use of a deterministic framework to study optimal land allocation between forest and agricultural use assumes current and future benefits and costs of forest conservation to be known with certainty. This may lead to policies biased toward more deforestation. In addition, forest development is an irreversible process where some of the functions of forests, such as biodiversity, are lost forever. Ignoring this also leads to bias towards development and conversion of forestland (Arrow & Fisher, 1974; Fisher, 1999).

The uncertainty observed in forest benefits comes from non-use values of forests such as future carbon prices (Riahi & Roehrl, 2001). The option of delay is considered in the decision framework, as forest conversion is an irreversible process and there is the opportunity of

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delaying this process (Pearce et al., 2006). Hence a stochastic dynamic framework, which incorporates both uncertainty in forest benefits and the irreversible nature of the development process of forestland, provides a better framework for studying optimality of land use decisions.

In this framework the benefit from forest conservation is modelled as a variable following the Wiener process (Brownian motion), i.e. it evolves over time in a way that is at least in part random (Bulte et al., 2002; Chladna, 2007). The Wiener process is a continuous-time stochastic process with the characteristics that (1) it is a Markov process (i.e. future value of the benefit stream depends upon its current value and is unaffected by the past values), (2) it has independent increments (i.e. the probability distribution for the change in the process over any time interval is independent of any other time interval, and (3) changes in the process over any infinite interval of time are normally distributed with a variance that increases linearly with the time interval (Dixit & Pindyck, 1994).

Dynamic programming is used to find the optimisation solutions, while considering both the uncertainty and irreversibility. The technique breaks up the decision problem into an immediate decision and a valuation function that includes all the consequences of subsequent decisions, starting with the position that results from the immediate decision (Dixit & Pindyck, 1994; Hertzler, 2009).

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3.6 Summary

There are a number of theories explaining LUC processes. They belong to different disciplinary backgrounds but have mainly emerged from economics, geography, ecology and anthropology. Theories of LUC generally fall under the urban and regional economics theorisation tradition; the sociological (and political economy) theorisation tradition and the nature-society (or human-nature) theorisation tradition.

The urban and regional economic theories are based on rational utility maximisation by humans and look into the land use choice problem from the micro- and macro-economic theories' perspectives. The sociological theorisation tradition focuses on the importance of the human agency, social relationships, social networks and socio-cultural changes in bringing about spatial, political, economic and other changes. The theory is based on sociology, anthropology, psychology and political sciences thinking. The nature-society theorisation tradition is based on theories of humanities, natural science, social science and multidisciplinary theories. It addresses the human causes of environmental change by considering interactions between nature, economy, society and culture.

Empirical models of LUC can be dynamic or static, prescriptive or descriptive, inductive or deductive. They are further classified into four main categories: statistical and econometric models, spatial interaction models, optimisation models and integrated models.

In quantifying the relationship between the driving forces and LUC process, the selection of variables depends on the simplifications made and the theoretical and behavioural assumptions used in modelling the land use system, and whether the area under study is large or not. In large areas diverse land uses are common and hence large numbers of driving

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factors have significant effects. Different driving forces also affect land use at different scales, hence consideration of multiple scales in studying the land use process is important.

The choice of LUC models is based on the type of LUC considered and its determinants at various spatial and temporal levels, the research or policy question required to be addressed and the characteristics of the study area and availability of data. In addition, using a combination of deductive and inductive approaches has a complementary benefit by improving understanding of the drivers behind LUC.

This study aimed at looking at the dynamics of land allocation to different uses in Ethiopia's SNNPR and the reasons for unwanted or sub-optimal LUCs. As a result, two approaches or modelling techniques are employed. The land use shares model is used to understand the driving forces behind LUCs in Ethiopia and the stochastic dynamic optimisation technique is used to investigate whether land is allocated to different uses in an optimal way.

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CHAPTER 4

DRIVERS OF LAND USE CHANGE IN THE SOUTHERN NATIONS AND NATIONALITIES PEOPLE'S REGION OF ETHIOPIA

4.1 Introduction

LULCC is associated with significant negative effects on ecosystems observed at local, regional and global scales. High rates of water, soil and air pollution are the consequences of LULCC. Biodiversity is reduced when land is changed from a relatively undisturbed state to more intensive uses such as farming, livestock grazing, selective tree harvest, etc. (Ellis, 2011). LUC due to deforestation in the tropics was the major contributor to CO_2 emissions in the 1990s, averaging between 0.5 and 2.7 GtC per year (UNFCCC, 2007).These changes alter ecosystem services and affect the ability of biological systems to support human needs, which 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 loss of wetlands and drying up of lakes (Alemayehu & 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). A decline in forest area, shrubland and riverine tree cover resulted in loss of fertile soil and biodiversity and increased land sliding and sediment loads in rivers, which are used for power generation

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(Robin et al., 2000; Dereje, 2007; Daniel, 2008; Dessie & Christiansson, 2008; Kefelegn et al., 2009).

Several case studies showed that LUC is driven by a mixture of resource scarcity, changing opportunities created by markets, inappropriate policy intervention, loss of adaptive capacity and increased vulnerability, changes in social organisation, access to resources and attitudes (Lambin et al., 2003). Geist and Lambin (2002, 2004) and McConnell and Keys (2005) attempted to generate better understanding of the proximate causes and underlying driving forces of, respectively, tropical deforestation, desertification and agricultural intensification 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 land that is accessed by resource users, whereas indirect effects occur through decisions made by people far from the land where changes take place. The impact of distant consumption decisions on local land use is generally higher when there are developed social organisations and services (Axinn & Barber, 2003). Micro-economic studies on land use explain LUC as a decision made by land owners based on the profitability of alternative land uses. Profitability is affected by a number of socio-economic, biophysical 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 LUC. These studies, however, consider mainly the direct use of land and ignore the effect of social organisations

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and institutions such as 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 out in the south-western part of Ethiopia at catchment, zone, watershed and village levels (Robin et al., 2000; Dereje, 2007; Daniel, 2008; Dessie & Christiansson, 2008). The studies referred to 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 a 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 conversion of forest and shrubland to agriculture. The above analyses could not produce enough evidence and consensus to generalise LUC processes observed in the SNNPR. Studies carried out to date examined proximate causes of LUC, at village level, in catchments or specific zones and were based on analysis of the spatial structure of land use and not linked to the behaviour of individuals or sectors of the economy. Almost none linked remote sensing data with survey data to connect actors of LUC with the LUC process.

Proximate driving sources reflect aggregate effects that result from the interplay of human and mitigating forces to cause environmental transformations directly and hence conceal the underlying drivers of the LUC process (Turner II et al., 1995). The issue of scale is also important in analysing LUC. Studies of a large spatial extent invariably have a relatively coarse resolution, often missing features that are evident at smaller scales. On the other hand, owing to their small extent, local studies often lack information about the context of the case

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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 at each scale different processes have a dominant influence on land use. Relationships could also be stronger or weaker when they are compared among different scales (Biggs & Tianxiang, 2005).

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

By identifying the drivers of LUC at district level, this study intends to contribute to recent efforts to integrate land use planning at municipal, district or 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 in the case of Ethiopia.

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4.2 Study Area

The SNNPR is located in the south-western part of Ethiopia, sharing boundaries with Kenya in the south, Sudan in the west and south-west and the Oromia region of Ethiopia in the north-west, north and east. Astronomically it lies between 4º.43 and 8º.53 North latitude, and 34º.88 and 39º.14 East longitude. The area covers 110 931.9 km^2, which is 10% of the area of the country (SNNPR, 2010).The following map shows the location and the land uses found in the area.

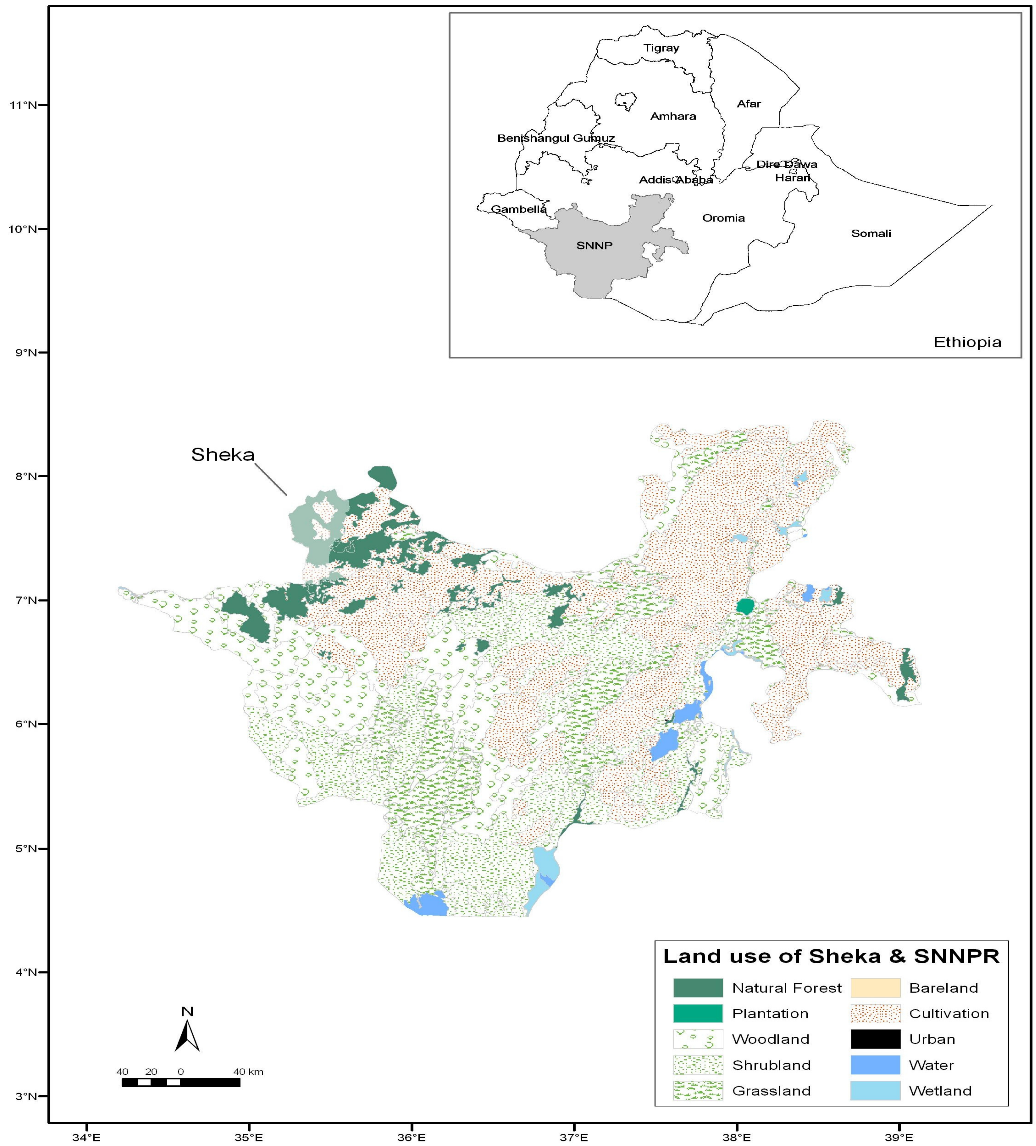

Figure 4.1 Location and land use pattern of the SNNPR

The population size in the area is estimated at 15 042 531; it has a density of 136 persons per square kilometre and is growing at 2.9 % per annum (FDREPCC, 2008). The rural population constitutes close to 90% of the total population in the region (13 496 821). The region has 13 zones, which are sub-divided into 126 woredas (districts); eight special woredas are administrative sub-divisions similar to autonomous areas and are not located in any zone in the region. The woredas are further divided into 3 714 rural and 238 urban sub-woredas.

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The mean annual rainfall of the region has ranged from a minimum of 400 mm in the extreme south of the region to over 2200 mm in the western part of the Sheka and Kaffa zones for the past 30 years. The mean annual maximum temperature ranges from 21.7ºC to 31ºC, whereas the minimum temperatures average between 11ºC and 18.4ºC (SNNPR, 2010). The SNNPR has arable highlands (*dega*), midlands (*woinadega*), lowlands (*kolla*), and pastoral rangelands (*bereha*). The region covers relatively fertile and humid midland where the highly dense rural populations of Ethiopia live (USAID/Ethiopia, 2005).

Enset (*Enseteventricosum*) is a widely produced staple food in the region. Cereals are dominant in relatively high- or low-altitude arable areas, together with pulses and oilseeds. Annual root crops such as 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 and cardamom-like spice (*aframomum).* Livestock production is common in the area both in the pastoral rangelands and agricultural areas. The farmers make butter and fatten animals, mainly for the market (USAID/Ethiopia, 2005).

According to the FAO (2005), 638 427 hectares of Ethiopian forests are found in the SNNPR. These forests are located in the wettest montane moist forest ecosystems of Ethiopia and cover 19% of the total forest area in Ethiopia (WBISPP, 2004). They are located in the south-western plateau, at an altitude of between 800 and 2 500 metres above sea level. These forest ecosystems are diverse in composition, structure and habitat types, with various vegetation types allowing different flora and fauna. The forests contain around half of the high forests that produce quality timber and many forest products such as wild coffee, honey and spices. More than 90% of the people in some of the areas in these forests depend on

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harvesting and production of NTFPs such as wild and semi-wild coffee, honey, wild forest spices and bamboo (Tola & Wirtu, 2004).

The coffee genetic resources in Ethiopia, which are mainly located in these forests, are valued at a net present value of USD 1.45 billion over a 30-year period, at a 10% discount rate (Lightbourne, 2006). The forests also provide major carbon sinks, reducing GHG emissions (FAO, 2001).

The main tributaries to the Blue Nile, the Omo and Baro, which are respectively the second and third largest rivers in terms of flow, and the Didessa River rise in these areas. Fifty percent of the country's irrigable areas are also located in the valleys of these rivers. In addition to national benefits, the Baro and Didessa Rivers have been contributing to irrigation development in the Sudan (Wood, 1993). The local and global importance of national and trans-boundary benefits of these forests is well documented (Aseffa, 2007).

Changes in forest cover, structure and composition are detrimental to the survival of small mammals, birds, ants and butterflies and many rare and habitat-specific species (Tadesse, 2007). Satellite land cover change images of 1973, 1987, 2001, and 2005 show increased deforestation in the south-western area since 1990. It is estimated that the closed high forest of south-west Ethiopia dropped from 40% cover between 1971 and 1975 to only 18% by 1997 (Reusing, 1998 cited in Tadesse & Masresha, 2007:4).). This is due mainly to conversion of forests to agriculture, particularly monoculture plantations of coffee and tea. The country was also recently observed to have the most degraded biodiversity hot spots in the world (Lightbourne, 2006). Table 4.1 gives a breakdown of land use in SNNPR.

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Table 4. 1 Land use in SNNPR

Land use	Area (000 ha)
Forest	638.43 (5.9%)
High wood land	548.48 (5.1%)
Plantation	237.20 (2.2%)
Low woodland and Shrub land	1349.43 (12.6%)
Other land	7780.76 (72.7%)
Water	152.86 (1.4%)
Total	**10707.16**

Source: FAO (2010)

The following maps 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.

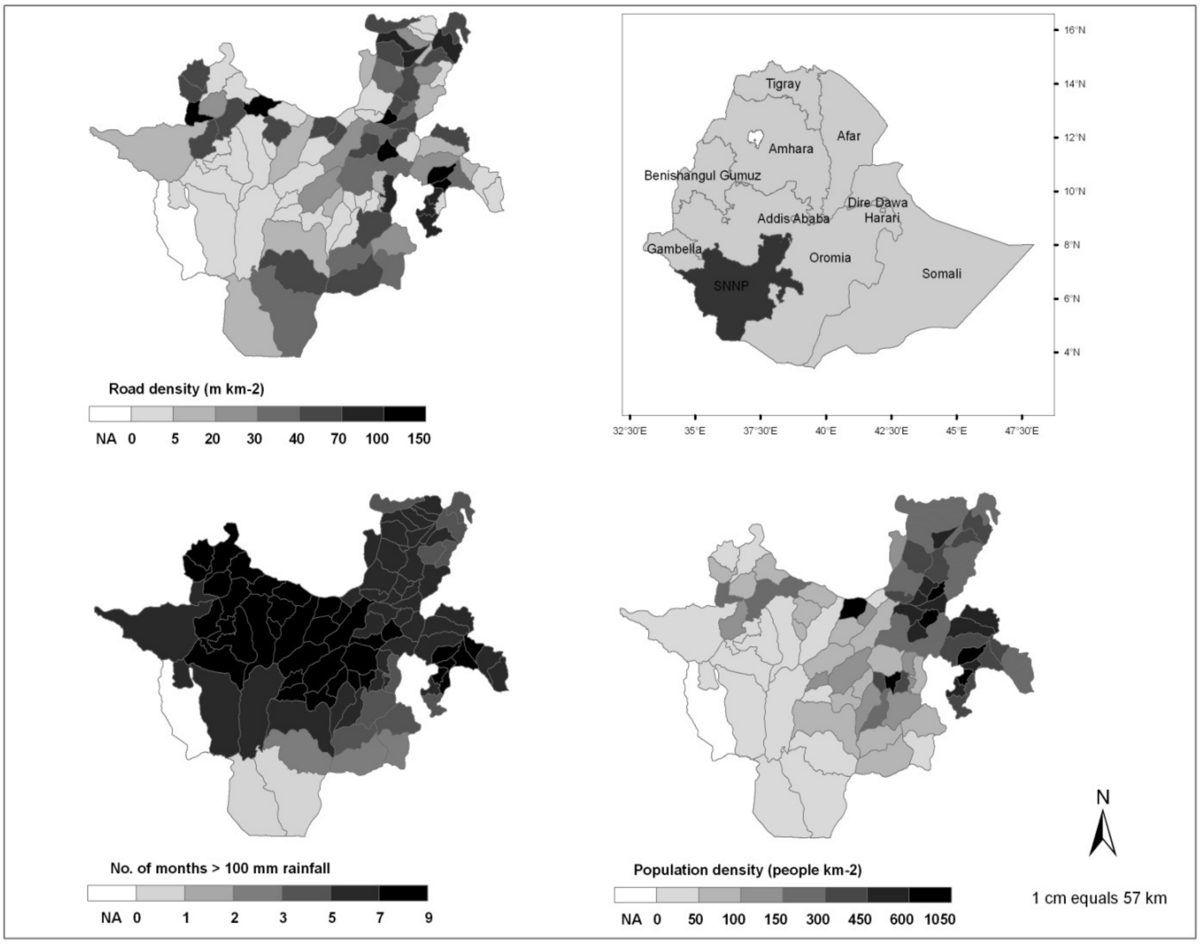

Figure 4.2 Distribution of road density, rainfall and population density

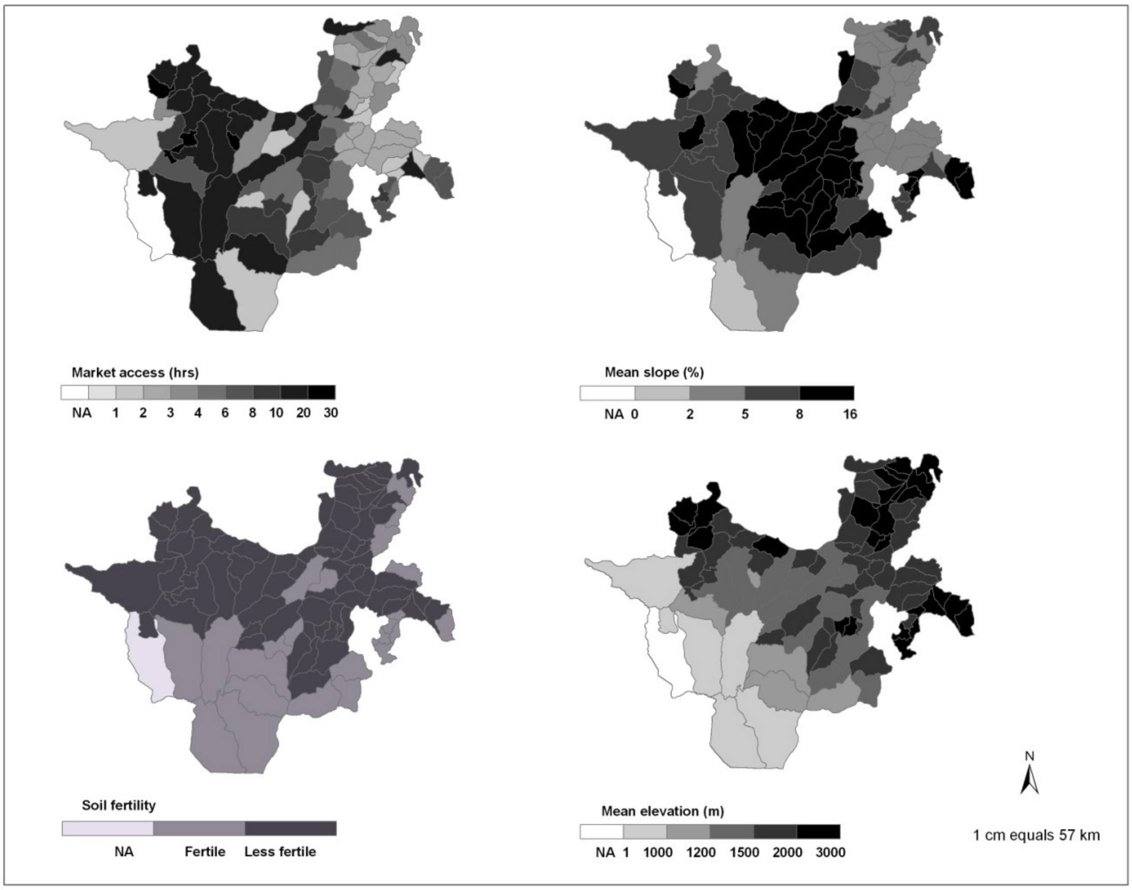

Figure 4.3 Distribution of market access, soil fertility, slope and elevation

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4.3 The analytical framework

The theoretical basis for the econometric model in this study is the rent maximisation concept developed by Ricardo (1817), Barlowe (1978) and von Thunen (1966). This land use theory has evolved to incorporate land quality difference as determinant 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 the characteristics of the land. Recent empirical works (Hardie & Parks, 1997; Parks & Murray, 1994; Plantinga et al., 1999; Wu & Segerson, 1995) have also confirmed the importance of including land quality in explaining current allocations.

In this study the researcher follows a model of aggregate land use data 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 maximum 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 expected profit from land use K (k=1...,K) on land quality h (h,...,H), X is a vector of exogenous covariates such as 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 can be denoted by:

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$$\pi_{hk}(X(t,m_i),a_{hk}(t,m_i),m_i). \tag{4.1}$$

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 amount.

$$\text{Maximise} \sum_k \pi_{hk}(X(t,m_i),a_{hk}(t,m_i),m_i. \tag{4.2}$$

Subject to $\sum_k a_{hk}(t,m_i) = A_h(t,m_i)$.

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

$$a^*_{hk}(x(t,m_i),A_h(t,m_i),m_i) \tag{4.3}$$

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

$$f_k(x(t,m_i),t,m_i) = \frac{1}{A(t,m_i)}\sum_h a^*_{hk}(x(t,m_i),A_h(t,m_i),m_i). \tag{4.4}$$

The land owner faces output and input prices that depend on several 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 as:

$$Y_{ik} = \sum_{m_i}^{M_i} \phi(t,m_i)[(f_k(x(t,m_i),t,m_i)+\varepsilon_k(t,m_i))+\xi_k(t,i)]+\varphi_k(t) = g_k(t,i)+u_k(t,i) \tag{4.5}$$

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 mean zero random variables with finite variance and are uncorrelated across districts and individuals and with the decision variables (Miller & Plantinga, 1999).

4.4 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).

A few attempts to resolve this problem have been made. For the linear model the predicted values from an Ordinary Least Squares 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. 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 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

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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).

The researcher follows Mullahy's (2010) extension of the above univariate case for 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 vector of exogenous covariates and B is the total land use in a district (the upper bound). The data can be characterised by the following:

$$Y_{ik} \in [0, B_i], \Pr(Y_{ik} = 0 / X_i) \succ 0 and \Pr(Y_{ik} = B_i / X_i) \succ 0 \text{, and } \sum_{n=1}^{N} Y_{in} = B_i \quad (4.6)$$

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

$$E[Y_k / X] \in (0, B) \text{, } k = 1, \ldots, N \; and \sum_{n=1}^{N} E[Y_n / X] = B \text{ .} \quad (4.7)$$

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. However, this is limiting in cases where for some values of X, the probability that Y_k taking the values of 0 and B is one. 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:

$$S_k = \frac{Y_k}{\sum_{n=1}^{N} Y_n} = \frac{g(x,\sigma_k)+u_k}{\sum_{n=1}^{N} g(x,\sigma_n)+u_n} = \frac{g(x,\sigma_k)+u_k}{Y} \tag{4.8}$$

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 Appendix 1):

$$E[S_k / x] = \omega_k(x, \sigma). \tag{4.9}$$

The interest in this study is in the estimation of the conditional mean structure $E[S_k / x] = \omega_k(x, \sigma)$. As interpretations of the σ_s are not straightforward owing 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 derivation of the conditional moment with respect to X_i:

$$\frac{\partial E[S_{ik} / X_i]}{\partial X_{i1}} = \sigma_{n1}\omega_n - \omega_n \sum_{n=1}^{N-1} \omega_n \sigma_{ni} \tag{4.10}$$

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

4.5 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 are based on district (woreda) level information. This atlas was developed using data from the 2001/02 Ethiopian Agricultural Sample Enumeration (EASE) and various other secondary data sources such as 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 and the farming practices applied and implements and technologies used. EASE data generated at the Central Statistics Authority of Ethiopia was assembled into a GIS-enabled database by Ethiopian Development Research Institute. The other non-spatial data were also 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 this 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 4.2). Explanatory variables are chosen to explain observed changes in land use at the level of study (i.e. district). LUC is assumed to be a function whose profitability is determined by changes in prices, economic conditions, policies or infrastructure development. Other determining variables used in the analysis include elevation, slope, rainfall, access to markets and roads, population, income, conservation policy and access to credit facilities.

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Table 4. 2 Land use shares and explanatory variables summary statistics

Share/Explanatory Variables	Units	Mean	Standard Deviation	Minimum	Maximum
Agriculture	Share of total land	0.56	0.32	0	1
Forest	Share of total land	0.19	0.26	0	1
Grassland and Shrub lands	Share of total land	0.26	0.27	0	1
Market Access	Hours to nearest market	8.18	6.20	1.50	29.00
Access to Credit	% receiving credit	5.47	7.71	0	52.68
Mean Elevation	Meters (above mean sea level)	1770.67	491.25	429.51	2840.09
Mean Slope	% incline	7.07	3.21	0.70	15.46
Mean Rain Fall	# of months with >100 mm	6.36	1.70	0.45	9.00
Road Density	Meters/KM2	33.05	36.18	0	145.07
Population Density	Total population/KM2	241.59	221.85	4.00	1036.00
Main Income Source	Cash crops (yes, no)			0	1
Protected areas	Presence of a forest protected area (yes, no)			0	1

The following hypotheses have been tested on the relationships between land use shares under agricultural and forestland, shrubland and grassland, and the explanatory variables given in Table 4.2:

(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. Though this may be true of aggregate production at the global level, its application at local level, especially at the forest

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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 the researcher's scale of analysis, i.e. district level.

(ii) Population density. Many farmers in the tropics practise unsustainable farming methods, as continuous cultivation results in 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 is more likely to 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 adoption of more labour-intensive methods of cultivation (Pender 2001). Labour-intensive technologies are expected to have a negative impact 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 forest land, other modern farming methods such as the use of fertilizer may be labour-intensive. Thus, the effect of higher capital input

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use on 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. Population density was consequently 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 tests 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 is thus 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 production of higher-value crops and more intensive use of inputs. However, if the cost of factors rises as a result of constrained supply, a reduction in agricultural area is possible, as productive factors are concentrated on 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 through the ability to finance purchased inputs or investments that increase land productivity or/and through substitution

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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 will be analysed in the study.

4.6 Empirical Result and Discussion

The results of the estimated average partial effects of the explanatory variables on land use shares are given in Table 4.3 below. Only five of the explanatory variables have been found to affect LUC in the region significantly. The significance of the explanatory variables has been tested further by contracting confidence intervals for each of the average partial effects. The Lagrangian multiplier specification test was conducted to test the null of no omitted variables in the conditional mean function versus the alternative of presence of omitted variables. The result shows failure to reject the null of no omitted variables (p=0.9319).

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Table 4. 3Average 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
Mean slope	0.0053234	0.506
Mean Rainfall	0.0024032	0.866
Road density	0.0011797**	0.048
Population density	0.0003203**	0.04
Income	0.0499062	0.231
Protected Areas	-0.0463113	0.309

Significance levels: *=10%; **=5% and ***=1%.
Sample size=93

As expected, distance to the market decreases the share of agricultural land and hence increases land allocated to forests, shrublands and grasslands. Similarly, higher road density had the expected effect of promoting conversion of forestland into agricultural land. One of the objectives of the 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. Though 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 this case study area was found to have a positive impact on the share of agriculture in land use, but with a very small magnitude (0.003%). This result is consistent with findings of previous studies in the area that revealed low adoption rates of fertilizers and improved seeds, and attributed this to the absence of medium- and large-scale loans that would have been used to buy complementary inputs such as irrigation equipment, fertilizer and improved seeds.

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The effect of elevation shows high statistical significance in conversion of forestland 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 1770 m above sea level), which receives more than 1400 mm of rainfall and has relatively deeper soils. These, together with a temperature range 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 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 are problematic for sustainable land management and hence are omitted from any intervention. This, however, remains a big challenge to the country's SLMP, as high population pressure is a major cause of 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 unexpectedly 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 is not statistically significant, it tends to increase the share of agriculture in land use. These results suggest that higher incomes in the study area do not seem to reach the levels of financing intensification sufficiently to realise the productivity gains effect on land saving. The presence of protected areas had the expected effect on conversion to agriculture. The low

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statistical significance can be attributed to the high cost 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 and specifically in the study area show that single-benefit streams from the sale of 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. Because of the absence of clear property rights, benefits from timber extraction have also been blamed for promoting deforestation.

4.7 Summary and Conclusion

This study analysed determinants of LULCC as an economic decision-making process where 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, biophysical and climatic factors on shares of agricultural land, forestland, 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 district level in the SNNPR of Ethiopia.

Higher population density, proximity and dense road infrastructure indicating better access to markets, together with the 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 Ethiopia. Initiatives such as 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 is therefore 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 construction of rural road networks with minimal environmental impact, while contributing to decreasing transport cost to sell output and access inputs. Credit provision should not focus only on the delivery of fertilizers and improved varieties, but must also consider other complementary investments, such as irrigation in water-stressed areas and conservation practices in areas prone to soil erosion.

Investment in such more capital-intensive technologies is currently minimal 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 farming will be necessary to reduce the pressure of population growth on land.

In addition to promoting the 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 intensification of agricultural production in non-forested land are needed. In addition, forest policies that facilitate 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.

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CHAPTER 5

FOREST CONSERVATION VERSUS CONVERSION UNDER UNCERTAIN MARKET AND ENVIRONMENTAL FOREST BENEFITS IN ETHIOPIA: THE CASE OF SHEKA FOREST

5.1 Introduction

Both the convention on biodiversity and framework on climate change signed in 1992 and recent concerns about global warming provide many developing country governments with strong incentives for conserving their forests. The carbon market is one important mechanism through which developing countries will be rewarded financially by the developed nations for sustaining and improving the carbon sink capacity of their forests (Lovera, 2009). Ethiopia has consequently started earning carbon credits through clean development mechanisms from rejuvenation of previously denuded land (WBI, 2010). In addition, the country has the potential to receive support through REDD initiatives, as it has submitted Nationally Appropriate Mitigation Actions (NAMAs) in the forestry sector following the Copenhagen Accord. Among the NAMAs submitted to the United Nations Framework Convention on Climate Change are the sustainable management of natural high forest, deciduous forestland and national parks to reduce GHG emissions from deforestation and forest degradation (UNFCCC, 2011).

Privatisation of natural resources has been advocated as one of the vehicles of growth without considering its environmental impact. This has been implemented in the dense south-western tropical rainforests (including wild coffee genetic diversity hotspots) where large tracts of these forest areas are given to private investors to develop coffee, tea and rubber plantations.

This strategy clearly emphasises the short-term benefits of export revenue to the commercial farming sector (Aseffa, 2007; MCKEE, 2007). Expanding tea production has resulted in complete removal of the forests in the area, as no buffer zones have been reserved for riverine vegetation along the Baro River, which is the main tributary to the Blue Nile and has huge potential for irrigation development (Bedru, 2007; Tadesse & Masresha, 2007). The East African and Bonga Tea Plantation companies, which are the main investors in tea production, had cleared about 6 000 hectares of the south-western forests in Ethiopia by 2001 and this deforestation process is continuing (Tadesse et al., 2002).

Environmentally sound development options are often overlooked in agricultural growth strategies owing among others to lack of knowledge about the natural comparative advantages in the area (Assefa, 2007; McKee, 2007). The conversion of primary forests to agricultural land is considered an irreversible loss, particularly regarding their biodiversity functions. The decision to develop forests should therefore be made cautiously and this becomes even more critical, as the benefits from tropical rain forests are uncertain. Tropical rain forests are one of the environmental assets on which we have only limited information. Delay in developing the forest improves the chances of obtaining better information about the values of forest functions. The above two phenomena render conventional CBA inappropriate to use in the analysis of optimal land use allocation decisions. Hence modelling, which takes account of the combination of uncertainty and irreversibility, given the opportunity to learn more, is important in analysing the costs and benefits of forest conversion (Graham-Tomasi, 1995; Pearce et al., 2006).

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In addition, the identification of stakeholders who benefit from the forest helps to reach agreements (social optima) that leave all stakeholders in a better-off position than they were previously. Hence multiple benefits from forests should be taken into account in land use decision analysis (Pearce et al., 1999).

Concerns about forest conservation in Ethiopia have been approached from the economic values that this resource will give to forest communities. Most of the studies focus on both poverty reduction and tropical forest conservation through sustainably managing the NTFPs (Mohammed & Wiersum, 2011). It was expected that by maximising the benefits from the tangible incomes, the soft values (the indirect and non-use values of forests) would be preserved. However, it was shown that single-benefit streams, especially NTFPs, could not be successful, as forest use could not prevail over agriculture (Belcher and Screckenberg, 2007; Wood, 2007) and experience further suggests that this was the case even in places where there is forest coffee production (Belcher et al.2005; Ros-Tonen & Wiersum 2005). Other land use studies in the study area fail to incorporate the indirect and non-use values of forests in their analysis (Reichhuber & Requate, 2007; Schravesande-Gardei, 2006). In addition, these studies assume a deterministic framework, which ignores uncertainty facing forest products and the irreversible nature of the deforestation process, which undermines the value of the forest further.

This chapter intends to explore the effect of considering price uncertainty of forest products in the face of the irreversible nature of the deforestation process on optimal land use choice between forest and tea production. The chapter also considers the multiple forest values and the possibility of payments for carbon storing benefits of forests. The study is conducted in the Sheka zone of the south-western forests of Ethiopia.

The next section describes the study area. Section 5.3 presents the analytical framework applied in the study. Sources of data and parameter values are discussed in section 5.4, and section 5.5 presents the results. Section 5.6 concludes distilling key findings and recommendations.

5.2 The study area

Sheka is a zone located in the SNNPR region where the wettest montane moist forest ecosystems are found and shares many of the regional characteristics mentioned in chapter 4, section 4.2. Unlike the other zones in the SNNPR, most of the deforestation in the Sheka zone is due to forestland allocation to large-scale commercial agriculture, e.g. tea. A deforestation rate of 36% had been observed in the area between 1987 and 2005 for tea production (Bedru, 2007). There is also evidence that the deforestation activity in the area is getting worse. Close to 40 investment projects were given licenses recently for large-scale commercial agricultural production, without conducting any environmental impact assessment (Tadesse & Masresha, 2007). A study in the Baro-Akobo sub-basin estimated the total net cost of deforestation of the high forests and woodland at USD 53.8 million/year, which is forecast to rise to USD 1 345 million/year in 25 years' time (ENTRO, 2009).

5.3 The analytical framework

Investors in the study area demand land for spice, coffee or tea production. The main driving factor of deforestation in the area in recent years, however, has been expansion in tea farming, which implies critical trade-offs between investment in agriculture and conservation of natural forests, as tea production requires complete removal of the forest cover and investors request fertile areas to minimise the cost of production (Aseffa, 2007). This study has consequently considered tea farming to be the main attractive alternative land use competing with forestry.

The study employs a continuous-time stochastic dynamic framework to analyse the optimal land use choice between forest and tea plantations. This analytical framework considers optimal preservation of a forest resource, the consumption of which is irreversible in uncertain conditions about future prices. The decision to deforest is analysed using a threshold model with incremental forest conversion to agriculture, using dynamic optimisation (Bulte et al., 2002; Dixit & Pindyck, 1994).

It is assumed that the social planner aims to maximise the discounted value of land use under forest and tea plantations. The model accordingly chooses the optimal amount of land to convert from forest to agricultural use (tea production). The irreversibility in the deforestation process arises from loss of key ecosystem functions and services of the rainforest. For instance, once the forest is cut, its supporting biodiversity function and other regulating services are completely lost and this is considered an irreversible impact, since it will take many years to re-establish such ecosystem services through replanting of a new tree cover.

Given stochastic changes in per hectare forest benefits over time, forest benefits may reach a certain critical value below which more land clearing for tea production is initiated. This will then determine optimal clearing of the forest at a rate equal to the difference between the previous and new area under agricultural use.

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The benefit from forest products is assumed to follow a geometric Brownian motion:

$$dB = \alpha Bdt + \sigma Bdz \qquad (5.1)$$

where α is the mean rate of change in forest benefits (the trend) over an interval of time and σ is the variance (deviation from the trend, i.e. the uncertainty parameter) and $dz = \varepsilon\sqrt{dt}$ with ε~N (0, 1). If the total land area is assumed to be Z, F as area under forest and A as area under tea production, the total area is fixed at any point in time and is distributed between the two. The total benefit from forest conservation (which is assumed to be proportional to forest size) will then be defined as:

$$TB\ (B, F) = B(t)\ F(t) = B(t)\ [Z-A(t)]. \qquad (5.2)$$

The opportunity cost of forest conservation is the net benefit foregone from producing tea. The benefit from tea is assumed to increase with the rate of inflation and assumed to be certain. The shadow price of land under tea is calculated as a function of area under tea as:

$$P_A(A) = \psi A^{-\gamma} \qquad (5.3)$$

where ψ refers to net returns per unit area and hence the discounted net benefit from tea production in the study area is measured by:

$$\int_{a=0}^{A} P_A(a)da = \int_{a=0}^{A} \psi a^{-\gamma} da = \frac{\psi}{(1-\gamma)} A^{1-\gamma}. \qquad (5.4)$$

The study area’s annual flow of net benefits is:

$$NB[A(t),\ B(t)] = \frac{\psi}{(1-\gamma)} A(t)^{1-\gamma} + B(t)[Z - A(t)]. \qquad (5.5)$$

Using the Bellman optimality principle, optimal choices of the two land uses can be found (Bulte et al., 2002; Dixit & Pindyck, 1994; Hertzler, 2009). The social planner adjusts the area under tea in response to changes in benefits from conserving the forest and hence the discounted value of land use can be calculated as follows:

$$V(A, B) = \max [(\frac{\psi}{(1-\gamma)} A^{1-\gamma}) + B(Z - A)]dt + \frac{1}{1+rdt}\{E[V(A', B + dB)] - C(A' - A)\} \quad (5.6)$$

where V (A, B) is the discounted value of land use, r is the continuous time discount rate, A' is the new optimal land area, B is the benefit obtained from conserving the forest, A is the area under tea plantations and C is the conversion cost.

Solving equation 5.6 (see appendix 3) gives the critical benefit function that relates optimal forest stock and area under tea:

$$B^C(A) = (\frac{\beta}{\beta-1})(r-\alpha)[\frac{\psi}{r} A^{-\gamma} - c] \quad (5.7)$$

where β is the root of the fundamental quadratic involving r, α, and σ and $\frac{\beta}{\beta-1}$ measures uncertainty with values ranging between 1 and 0.

5.4 Source of data and parameter values

Data used for the study come from several sources. To analyse the discounted net benefit from tea, data are gathered on the productivity of land with different qualities, inflation, prices of tea, the cost of production, loss of net revenue due to climate change and temperature. Tea productivity figures for different land qualities were acquired from an interview with Mr Yemaneberhan, the manager of Agriceft tea-producing company, in March 2010. The benefit and cost of production per hectare of tea were sourced from valuation studies made in the Sheka area (Aseffa, 2007). To project prices and costs of tea production, the researcher used forecast inflation rates for Ethiopia based on World Economic and Financial Surveys (IMF, 2009).

Forecast revenues from tea adjusted to control for climate change damage using estimates of farm net revenue loss due to climate change in Ethiopia amounting to USD 21.61 per ha were obtained from Deressa and Hassan (2009). The forecast temperatures for 50 years are calculated by taking the average of two model outputs from HADCM3 and ECHAM5 experiments for A1B and A2 scenarios from a data source of Lowe (2005) and Wegner (2007). The per hectare forest benefits in the study area were obtained from previous contingent valuation studies carried out in the area (Aseffa, 2007).

Returns to tea production were estimated by discounting the net benefit stream of tea production in the area for the coming 50 years. Net revenues were further adjusted for climate change effects on productivity, as mentioned above. Tea prices and production costs were projected for a period of 50 years, using inflation rates forecast for Ethiopia. The tea benefits function, calculated at 5% discount rate with climate change effects on productivity considered, is $P(A) = 5808.84A^{-0.104}$ and when the effect of climate change is ignored, the function becomes $P(A) = 7423.31A^{-0.0677}$.

Based on work of Aseffa (2007), the economic value of the forest is estimated to be USD 2123.27 per hectare per year, of which USD 1343.09 represents the value of the carbon sequestration service of the forest (Table 5.1). Direct use values of NTFPs considered in the study capture values of forest coffee, honey, spices, bamboo, palm, fuel wood and charcoal, beehives, wild fruit and traditional herbal and plant medicines directly harvested from the forest. Non-use values refer to the option value and bequest and existence values (Aseffa, 2007). Option value was measured as the value that the local people are willing to pay for risk aversion, depending on the level of uncertainty expected in the supply of ecological and environmental services in the future and future preferences. The bequest and existence value were calculated together as permitting the existence of intact-natural forest for the future generation. The reason for measuring in one category was respondents' inability to differentiate between the bequest and existence value of the natural forest (Aseffa, 2007).

Prices of a ton of CO_2 as calculated by global models - IIASA MESSAGE (Riahi & Roehrl, 2001) and Chaldna (2007) - were used. These represent carbon tax or the value of carbon emissions permits created for carbon-trading markets. Because of lack of time series data for other functions of the forest, the trend and uncertainty parameters calculated for the forecast carbon price of 0.03625 and 0.16604, respectively, were applied to the sum of forest benefits.

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Table 5. 1 Economic value of Sheka forest (USD per ha per year) [2]

Direct use values	
• Construction materials and implements	6.57
• Non-timber forest products	600.89
Indirect use values	
• Eco-tourism	0.24
• Water shade protection	54.98
• Carbon sequestration and storage	1443.46
• Biodiversity	15.9
• Socio-cultural value	0.11
Non-use value (Option, Bequest and Existence value)	1.12
Total	**2123.27**

Source: Aseffa (2007)

Data from a woody biomass inventory and strategic planning project have been used to map forest and agricultural activities in the study area employing GIS spatial analysis tools (WBISPP, 2004). The study area covers 227,336 ha, of which 102,236 ha is currently under forest.

5.5 Result and Discussion

5.5.1 The optimal land use allocation between tea and forest

To maximise the gain from land use under both agriculture and forest, the social planner adjusts the control choice variable, which is land under agriculture. Decreasing returns to scale is assumed in agricultural production (which could be due to distance from the market as more land is converted to agriculture). Each hectare of land is considered as a separate

2The Ethiopian Birr (ETB) values are changed into their US dollar equivalents according to the exchange rate equivalent of 1 USD=13.55 ETB which prevailed in 06/06/2010.

investment project where the investment problem is to find threshold benefit for each to decide whether to invest on the next hectare of land or not. As a result one can have more units of the discrete projects with less and less marginal productivity. Maximisation of the value function 5.6 with respect to land for agriculture requires that the expected marginal cost associated with land clearing (acquiring new unit of land) be equated to the marginal benefit (see appendix 3).

Figure 5.1 depicts the estimated critical benefit curve, showing an inverse relationship between benefits from forest and land use for agriculture, implying lower benefits from forests, leading to more deforestation.

Optimal forest stocks change on the choice of the two parameter values (trend and uncertainty), discount rates and whether the effect of climate on tea productivity is considered or not. The optimal forest stocks for the different trend and uncertainty parameter values are calculated below, using a discount rate of 5%.

When forest benefits are certain, the value of σ approaches zero and the term $(\frac{\beta}{\beta-1})$ goes to one, where the benefit function expresses a deterministic relationship, i.e. $B^C(A) = (\frac{\beta}{\beta-1})(r-\alpha)[\frac{\psi}{r}A^{-\gamma}-c]$ becomes $B^C(A) = (r-\alpha)[\frac{\psi}{r}A^{-\gamma}-c]$. Under this assumption the optimal forest stocks are higher compared to when there is uncertainty in the benefits, suggesting further deforestation. In figure 5.1, the upper curve is the forest benefit threshold curve under certainty, whereas the lower one indicates when uncertainty is considered.

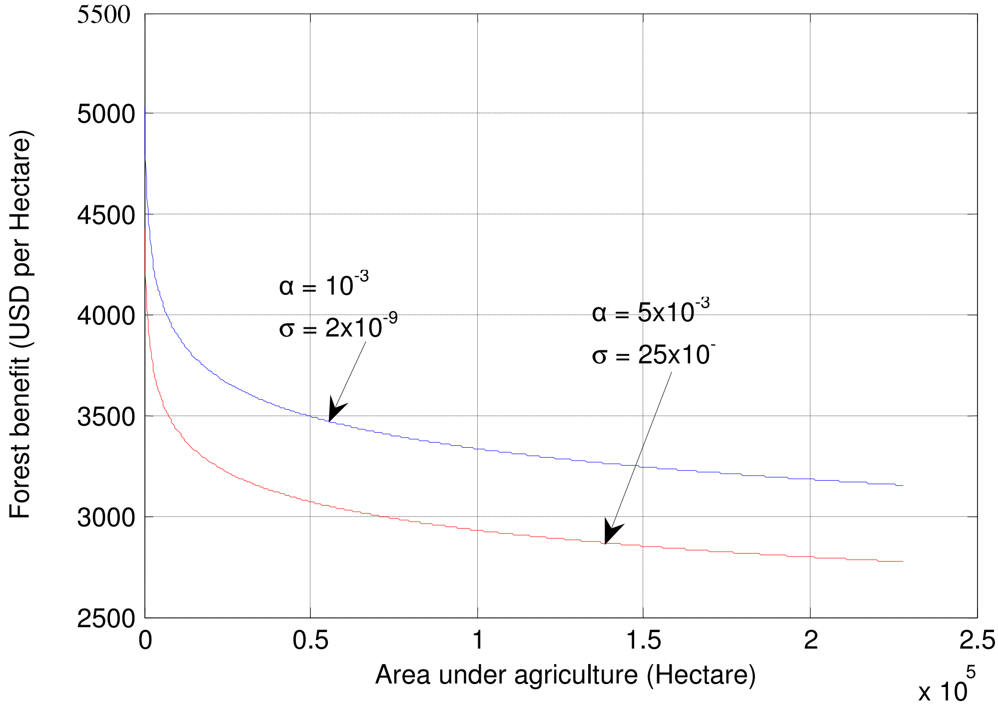

Figure 5.1 Critical forest benefits with- and without consideration of uncertainty

Tables 5.2 and 5.3 show the optimal forest stocks when the effect of climate change on tea production is considered, whereas tables 5.4 and 5.5 show the optimal forest stock without the climate effect. A summary of optimal forest stocks at different discount rates for the current trend and uncertainty parameters of α= 0.03625 and σ =0.16604 is given in appendix 4.

Table 5.2 shows the sensitivity of optimal forest stocks to different trend and uncertainty parameter values of forest benefit. The optimal forest stock at the two parameter values where forest benefit is evolving, i.e. α=0.03625 and σ=0.16604 is 227 920 ha, which is more than the current stock of 102 236 ha. At α=0.025 and σ=0.16604 the optimal forest stock is 217 945 ha, which is again more than the current stock, but when α=0.025 and σ=0.05, further clearing of land, which amounts to 65 965 ha (102 236 ha - 36270.98 ha), or 65% of the existing stock, is optimal. At values of $\alpha \leq 0.005$ and $\sigma \leq 0.025$; and at $\sigma=0.05$, 0.16604 and $\alpha=0.005$, 0.001, complete deforestation is optimal.

Table 5. 2 Optimal forest stocks accounting for climate change effect on tea production but without carbon storage value of forests

		σ=0.000000002	σ=0.025	σ=0.05	σ=0.16604
α	0.001	0	0	0	0
	0.005	0	0	0	0
	0.025	0	0	36,270	217,945
	0.03625	227,007	227,083	227,273	227,920

However, when the carbon storage value of the forest is included (Table 5.3), the optimal decision is to preserve the existing forest and the optimal forest stock is more than the existing 102 236 ha of forest land. While in both cases the effect of climate change on tea production is considered, optimal forest stock calculations in table 5.2 did not consider the carbon storage value of the forests. Optimal forest stocks corresponding to the different trend and uncertainty values in table 5.2 are less than the ones in table 5.3, which accounted for carbon values, indicating that without global transfers compensating for carbon sequestration services of forests, lower stocks are optimal from a local point of view.

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Table 5. 3 Optimal forest stocks accounting for both climate change effect on tea production and carbon storage value of forests

		σ=0.000000002	σ=0.025	σ=0.05	σ=0.16604
α	0.001	215,117	221,409	224,897	227,881
	0.005	222,298	224,259	226,151	227,920
	0.025	227,955	227,957	227,963	227,975
	0.03625	227,975	227,975	227,975	227,975

Table 5.4 shows that complete deforestation is optimal at values of α<0.03625 and σ<0.16604, but at α=0.03625 and σ=0.16604 it would have been optimal to have additional forest land amounting to 107 479 ha (209 715 ha -102 236 ha).

Table 5. 4 Optimal forest stocks ignoring both carbon storage value and climate change effect on tea production

		σ=0.000000002	σ=0.025	σ=0.05	σ=0.16604
α	0.001	0	0	0	0
	0.005	0	0	0	0
	0.025	0	0	0	0
	0.03625	0	0	0	209,715

With carbon storage value of the forest added to the other forest benefits, the optimal stock is beyond the existing forest land (Table 5.5). Hence complete preservation of existing forest is required for all trend and uncertainty values given except for α =0.001 and σ=0.000000002. At these two parameter values clearing of forest equivalent to 9,495 ha (9% of the existing 102,236 ha of forest) is optimal. The results of tables 5.4 and 5.5 confirm the same findings of tables 5.2 and 5.3 in terms of why lower forest stocks are optimal when global benefits are ignored.

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Table 5. 5 Optimal forest stocks accounting for carbon storage value but ignoring climate change effect on tea production

		σ=0.000000002	σ=0.025	σ=0.05	σ=0.16604
α	0.001	92,740	158,876	195,580	226,978
	0.005	168,246	188,832	208,689	227,392
	0.025	227,763	227,787	227,840	227,968
	0.03625	227,975	227,975	227,975	227,975

Both table 5.3 and table 5.5 consider carbon values, but table 5.3 considers the effect of climate change on tea production, while table 5.5 ignores that effect. One plausible explanation why the optimal stocks increase with consideration of climate change could be that the decline in productivity of tea discourages investment in tea, hence lower deforestation.

Climate change decreases the return to agricultural land and with the assumption of mono-crop cultivation and no technological change, production can only increase through increasing land under tea production. The value-matching condition for optimal land use decision suggests, at the threshold the expected contribution of any additional land under agriculture to the capitalised profit flow to equal to its cost of instalment plus the opportunity cost of the land under agriculture i.e. benefit from forest

$$(B^C)^{\beta_2} \frac{\partial \omega_2(A)}{\partial A} + \frac{\psi}{r} A^{-\gamma} - \frac{B^C}{r-c} = c \,.$$

Given all the other factors and lower ψ (return to the best hectare of land in agriculture), ensuring this equality requires that land under agriculture be increased.

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The optimal forest stock also varies according to the choice of the discount rate. Appendix 4 shows the different levels at the existing trend and uncertainty parameter values of α= 0.03625 and σ=0.16604. It can be observed that at a 5% discount rate the existing stock is lower than the optimal stock, whether the effect of climate change on tea productivity and the carbon storage functions of forests are considered or not. When the carbon storage function of forests is not taken into account, complete deforestation is optimal at a 7% discount rate, with or without consideration of climate change on tea production. However, when this benefit is considered, the optimal forest stock is beyond the existing level. At a 10% discount rate, complete deforestation is optimal in any of the cases considered.

Sensitivity analysis was also conducted on the value of forest benefits to accommodate the variations in the value of the forest, as valuation of forest products depends on the demographic structure, economic position, market price, technology and resource endowment of households (Babulo et al., 2008; Yemiru et al., 2010). An increase of 25% in the value shows that the existing forest stock is sub-optimal, both in a deterministic case and when uncertainty in forest benefits is considered. A decrease of 25% in forest value leads to complete deforestation in the deterministic scenario, but to preservation of existing stock in the case where uncertainty in forest benefits is considered.

From the above discussion it is clear that consideration of carbon storage value is important to keep the existing forest intact by closing the gap between local and global optimal forest levels. When both trends and uncertainty increase, the optimal forest stock also increases, suggesting preservation of the existing forest. When a deterministic land use decision is taken, except under higher mean forest income from local forest benefits (as in table 5.2) or inclusion of carbon storage values in the CBA, complete deforestation is the optimal choice.

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Local forest benefits can be achieved through the creation of markets for those products or services that are under-priced, putting in place clear property rights and improving the managerial and technical capacity of forest managers, etc.

Contrary to the above, the stochastic analysis suggests forest preservation at the current pace and uncertainty parameter values that forest benefits are evolving. This is despite the fact that carbon storage values are taken into account in land use decision-making. However, when the two parameters are allowed to be flexible in small intervals, decreasing uncertainty and increasing the trend, complete deforestation becomes the optimal land use strategy in the absence of carbon storage values of forests.

The same conclusion can be reached when one looks at the discount rate the country is using to appraise projects, which is more than 5%. At discount rates higher than 5%, complete deforestation is the optimal decision in the absence of compensation for the carbon storage value of forests.

Measures to prevent deforestation in the past could not address the drivers of the deforestation process and involve protected areas, participatory forest management and traditional forest management and forest conservation measures. The current condition of protected areas shows continuous human encroachment and other forms of severe disturbance.

Participatory forest management is one of the management measures undertaken to promote sustainable forest management by involving communities that live in and around forests, while improving their socio-economic status. The communities are expected to be involved as co-managers and share benefits accruing from the sale of forest products. Though

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successful in a few places, deforestation is still a major problem. This could be due to conflicting policies on the rights of people to manage and own land and forest resources, and sharing of benefits from forest production. A close look at the different laws and proclamations at the federal, regional, zonal and district levels reveals inconsistency regarding land and forest ownership rights of local communities. This also presents a challenge in implementing the current financial incentive based system to protect forests (i.e. REDD+), as it requires strong community participation to be successful.

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. However, 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 others on the state sector specific programmes 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) recognises the ownership of rural lands by governmental organisations and NGO, sassociations and private individuals, as long as they follow regional land administration and utilisation laws (FDRE, 2007). At the sub-national level a number of regional proclamations are in place as well 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.

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

REDD+ policies and projects should be implemented carefully, as these might have a negative influence on biodiversity and a possible negative impact 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.

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5.6 Summary and conclusions

This study developed and applied an empirical stochastic model to analyse optimal land use decisions in the choice between conservation and conversion of forestland for tea production in Ethiopia. Study results suggest that land use allocation decisions are sensitive to the consideration of uncertainties, irreversibility, and externalities associated with the conversion of land resources use and discounting future values. When benefits from forests are treated as stochastic outcomes, optimal forest stocks are higher than when one ignores uncertainties, as the deterministic framework suggests additional land under agriculture, i.e. further deforestation. This indicates that a planner should be cautious before investing in irreversible projects, such as developing forestlands for agricultural use. Sub-optimal decisions may also result if the international community does not consider compensation for the positive global environmental externalities of carbon storage in forests. Similarly, when the negative consequences of climate change on agricultural productivity is considered, the optimal forest stock declines, as more land under agriculture is now required to reach the optimal mix of land.

Results of the empirical analysis show that higher social discount rates encourage deforestation over preservation. At a discount rate of 5% the current forest stock is below the optimal level, which could be attributed to institutional failures in the country, hence the social planner should preserve the existing forest stock. From the local benefit perspective, at higher discount rates deforestation is an optimal choice, but when global benefits are considered it is not.

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Considering the imperfect valuation strategies available for valuing ecosystem services, the occurrence of environmental costs much later than benefits and interdependencies among ecosystem services, it would be advisable to be cautious when choosing appropriate discount rates. In contrast, lowering the discount rate too much also raises issues of intra-generational equity.

At the current level of the discount rate the country adopts, the only way to preserve the existing forest stock is for the international community to pay for the global benefits it is gaining from the forests. The REDD+ programme is one of the initiatives to address this problem.

CHAPTER 6

SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS OF THE STUDY

6.1 Summary and conclusions of the study

Land use change dynamics in Ethiopia involve mostly conversion of forest, grassland, shrubland and woodland to agricultural use. All land use changes are not necessarily bad, but the conversion in Ethiopia is progressing at unsustainable rates. Forests' contribution to GDP is high and they provide employment opportunities to large segments of the population. Hence proper forestland resource management is critical to the country. However, institutional constraints, lack of appropriate land use policies and the focus on non-forest rural development strategies present great challenges to proper management of forest resources in Ethiopia.

Major unplanned and planned land use changes are observed in the country and specifically in the case study region of the SNNPR. Planned changes are driven by agricultural development strategies of the government, which promote conversion of forestland to large-scale commercial farming, such as tea farms. Unplanned changes represent the choices of individual farmers who allocate their land to different uses, depending on the profitability of the products from the land. Both conversion types (large commercial and unplanned farmers' choices) can influence each other. This could be through change in income wedges between regions, leading to in-and-out migration among regions until equilibrium is reached. This might also lead to more conversion of forestland to agricultural uses, more road and other infrastructure construction in response to population growth, urbanisation, etc. This study analysed land allocation decisions by farmers to study determinants of forestland conversion.

In both cases the land allocation process does not follow proper environmental assessment procedures and prudent land use plans, leading to suboptimal allocation of land to different uses. The suboptimal nature of the allocation process is due to the absence of proper cost benefit analysis conducted by government bodies, these analyses only consider financial returns and ignore the economic and social values of key forest services.

To analyse whether current rates of forestland conversion are optimal, it is necessary to consider the multiple ecosystem services of forest and the uncertainty facing the values of some of these services. In addition to market values, non-market values of regulating forest ecosystem services (together with their uncertainties) and the irreversible nature of forestland conversions are important when studying land use decisions. This requires employing a stochastic framework for analysing the costs and benefits associated with forestland conversions. No study in Ethiopia has yet attempted to look at the effects of uncertainty and irreversibility on land use decisions. The present study therefore adapted the land use shares approach and a stochastic dynamic optimisation framework to investigate drivers of LULCC and evaluate the trade-off between forest conservation and conversion to other land uses.

The study was conducted in the SNNPR of Ethiopia, which covers 19% of the total forest area in the country. The forest ecosystems in the study region are diverse in composition, structure and habitat types, with various vegetation types in areas with different flora and fauna. The SNNPR forests contain around half of the high forests that produce quality timber, and many forest products such as wild coffee, honey and spices. More than 90% of the people in some of the areas in these forests depend on harvesting and production of non-timber

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forest products (NTFPs) such as wild and semi-wild coffee, honey, wild forest spices and bamboo. The coffee genetic resources in Ethiopia, which are mainly located in these forests, are valued at USD 1.45 billion over a 30-year period. These forests also provide major carbon sinks, reducing GHG emissions.

6.1.1 Analysis of LULCC drivers in Ethiopia

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

Higher population density, proximity and dense road infrastructure and better access to markets, together with availability of credit services, were found to be important drivers of forestland, grassland and shrubland 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 Ethiopia. Initiatives such as the Sustainable Land Management Programme (SLMP) are being implemented in the country with the objective of increasing the agricultural productivity of small-scale farmers in an environmentally sustainable manner through developing community infrastructure such as feeder roads among others. Though this contributes to improving the livelihoods of farmers

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through generating income from agricultural production, the negative effects that road construction and improved access to markets have on sustainable land use should be taken into account during implementation of the programme. It is therefore 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 construction of rural road networks with minimal environmental impact while contributing to decreasing transport cost to sell output and access inputs.

Credit provision in the study area should focus not only on the delivery of fertilizers and improved varieties, but must also consider other complementary investments, such as irrigation in water-stressed areas and conservation practices in areas prone to soil erosion. Investment in such more capital-intensive technologies is currently minimal to reduce the pressure on land through improved productivity. This is mostly attributed to the absence of medium and large-scale loans, specifically in the SNNPR and in Ethiopia in general.

Higher population density was also found to increase the share of land under agriculture. With minimal investment in capital-intensive technologies, it would be challenging to reduce the pressure on land through improved productivity. Moreover, only moderately populated areas are targeted by the SLMP interventions, as the programme is designed in the belief that areas under high population pressure are fragmented and are problematic for sustainable land management and hence are left out of any intervention. This, however, remains a big challenge for the country's sustainable land management, as high population pressure is a major driver of conversion of forestlands, grasslands and shrublands and hence it needs to be addressed. Options and strategies for creation of income and employment opportunities outside farming are also necessary to reduce the pressure of population growth on land.

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In addition to 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 intensification of agricultural production in non-forested land are needed.

Forest policies that facilitate capturing of forest rents are important for preservation of forests as well. Capturing forest rents, both extractive rents and payments for environmental services, are incentives that encourage land owners to preserve forests. Single-benefit streams from the sale of 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.

6.1.2 Optimal forestland and conservation under uncertainty and irreversibility

Use of deterministic frameworks to study optimal land allocation between forest and agricultural use assumes current and future benefits and costs of forest conservation to be known with certainty. This may lead to policies biased toward more deforestation. In addition, forest development is an irreversible process where some of the functions of forests, such as biodiversity, are lost forever. Ignoring this also leads to bias towards development and conversion of forestland. This study considered uncertainty in forest benefits from non-use values of forests, such as future carbon prices. The analysis looked into different scenarios about the irreversible nature of land conversion from forest to agriculture, especially with regard to biodiversity, the uncertainty involved in forest benefits, the effect of climate change on agricultural productivity, compensation for the carbon storage value of forests and discount rates.

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The stochastic analysis shows the sensitivity of land use allocation decisions to consideration of the above factors. The treatment of forest benefits as stochastic leads to optimal forest stocks higher than when they are ignored, as in the case of deterministic frameworks. If compensations for the positive global environmental externalities of carbon storage in forests by the international community are ignored, conversion of additional land for agriculture is more likely. In addition, ignoring the effect of climate change on agricultural productivity leads to a decline in the optimal forest stock. Furthermore, it is shown that at a 5% discount rate the current forest stock is below optimal. From the local or private point of view deforestation is optimal at higher discount rates, but when global benefits are included it is not.

As uncertainty in returns from forest benefit increases, the threshold value linking the stock of agricultural land and forest benefit decreases warranting additional deforestation. But the consideration of irreversibility in modelling the deforestation process makes the additional deforestation to be more stringent when uncertainty is taken into account. In addition, higher mean growth rate of forest benefits leads to preservation of more forests.

If government ignores the trend or mean growth rates and uncertainties of forest benefits, the perceived optimal forest stock is significantly smaller than the current stock or the optimal stock. Hence complete deforestation may appear as optimal. This is one of the reasons why lots of forestlands are converted to agricultural uses.

Compensations for the positive global environmental externalities of carbon storage in forests by the international community are found to be more important than considerations of climate change and uncertainty in preserving forests. In the presence of these transfers, optimal forest stocks are higher than current forest stocks in almost all scenarios considered in the study.

The study also shows the sensitivity of forest conservation to the choice of discount rates. Higher optimal forest stock is inversely related with the discount rate and at discount rates higher than 5% complete deforestation becomes the optimal land use choice. Hence, to preserve the existing forest stock, discount rates that are less than or equal to 5% should be used when analysing the local costs and benefits of forests and tea production. This shows that there is a need for critically reassessing discount rates currently applied to approve projects in Ethiopia, which are generally higher than 5% and which do not distinguish projects with long-term environmental costs and benefits from others.

It is clear from the above explanations that compensation for externalities from conservation of forests or carbon storage functions of forests should be taken seriously, and laws, institutions, and incentives should be developed or strengthened to benefit from them.

REDD+ is one such mechanism where financial transfers can be used to manage forests in a sustainable manner. A number of policy instruments, such as the creation of protected areas and biospheres, are being implemented in the country and in the SNNPR to protect biodiversity and important ecologically sensitive areas. However, these measures could not prevent deforestation, as these forests do not generate income to the communities living inside and adjacent to the protected areas. Mandatory replanting of trees after harvest is also applied in private lands to ensure rapid reforestation. This excludes the majority of the forests, which are owned by the state and the community.

REDD+ is more appropriate to preserve existing forests in both state and communal forestlands and where multi-stakeholders are involved. It is the current common financial incentives-based strategy to compensate the national government and sub-national actors such as regional governments and communities in return for demonstrable reductions in

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carbon emissions from deforestation and forest degradation and enhancements of terrestrial carbon stocks. Though the strategy is believed to contribute to sustainable land use decisions, there are challenges that need to be considered seriously.

Currently there is no national REDD+ policy in Ethiopia but few pilot projects that have completed the readiness stage of REDD+ and ready-to-sell carbon credits have been conducted. Lessons learnt from these indicate the need for strategies, legal and management frameworks on benefit sharing, carbon rights and responsibilities to manage credits to enable the sale of carbon credits to voluntary markets. More explicitly, implementing REDD+ on the ground requires that the incentives address drivers of deforestation, equitable distribution of benefits and political participation of forest communities, and that the tenure rights of communities are recognised, strengthened and secured (Angelsen, 2008; Giffiths, 2009 ; Springate-Baginiski and Wollenburg, 2010).

Allocation of benefits from demonstrated emission reductions depends, among others, on the state level sector-specific programmes and policies to provide a system of incentives and law enforcement that achieves the emission reduction targets and improves the livelihoods of economically marginalised rural populations. Existing federal and regional land and forest ownership laws and proclamations reveal challenges associated with tenure rights, political participation and equitable benefit-sharing of communities involved in forest management.

The Forest Development, Conservation and Utilization Act (No. 542/2007), the Development, Conservation, and Utilization of Wildlife Proclamation Act (No. 541/2007), and the Federal Rural Land Administration and Land Use Proclamation Act (No. 456/2005) are federal laws that are most relevant for REDD+ implementation in Ethiopia. According to the constitution and federal forest laws, forests belong to the communities and the state. The forest policy of the country also emphasises empowerment and participation of local communities and their organisations at all levels of environmental management activities, with a benefit-sharing scheme for the people from forest development. It encourages the involvement of local communities inside and outside protected areas (FDRE, 1997). However, only a few community-based organisations own forests and the state forests are still open access areas. According to the constitution of Ethiopia, land is a common property of nations, nationalities, and the people of Ethiopia. Though it recognises ownership of land by local communities and puts emphasis on customary rights, exclusive ownership is not given to local communities. This constitution provides for the co-ownership of land by the state and local communities (Article 40(3) of the FDRE constitution1995: Art.40(3)). The SNNPR federal rural land administration and land use proclamation, on the other hand, defines communal holding as "rural land which is given by the government to local residents for common grazing forestry and other social services" (FDRE 2005:Art.2(12)). The lands given by the government are fragmented and are not continuous territorial lands. Article 5(3) of the same proclamation recognises the government as the owner of rural land and allows the conversion of communal lands to private lands as deemed necessary. This is in contradiction to the constitutional rights of the local communities and leads local government officials and local communities to believe that land belongs to the state. This in turn leads to community land allocation for different purposes.

Another contradiction is observed in the SNNPR rural land administration and utilisation law. The preamble of the law emphasises sustainable land use in proclamation no.456/2005 article 12(1), but sub-article 2 contradicts the law. According to this article, unoccupied land that is suitable for farming and land with potential for agriculture in possession of the government can be redistributed to landless individuals, farmers with insufficient lands, investors and

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willing settlers in the region. In this proclamation the term unoccupied land includes forestlands. Hence the SNNPR land administration proclamation does not consider the land ownership right of local communities. However, the Oromia region rural land use and administration proclamation recognises the communal ownership right of local communities and it prohibits clearing forest resources for agricultural purposes. Oromia Forestry Proclamation (No.72/2003) is a favourable pre-condition for implementing REDD+ at landscape level in the Oromia region because it extends the definition of forest ownership from state and private ownership to include community forests.

Lack of clarity on responsibilities among different government bodies also leads to the rights of local communities to participate and decide on their own development needs being taken away. Forests in the SNNPR belong to the regional state and private individuals or groups of individuals. Specifically when one looks at forestland use rights of local communities in the Sheka zone, the regional rural land administration proclamation excludes the possibility of giving land that is in the possession of farmers, land designated as parks, forestland, land demarcated for natural resource development and protection, etc. to investors. Nevertheless, in reality forestlands are being given to investors by the zonal department of trade, industry and urban development, though the Land Administration and Environmental Protection Authority of the Region, that has desks at zonal and district levels is responsible for the execution of the Regional Land Administration Law. The natural resource unit section, which falls under the agricultural and natural development desk of the zone, which also falls under the zonal department of rural development, has no power to allocate land to investors, though its role involves conducting studies on the suitability of land for investment and whether or not the land to be given for investment is part of forestland. Furthermore, the department of public participation affairs of the zone mandated to enhance the participation of local communities in issues related to forest management has not demonstrated any organised and effective participation of the communities in areas by getting consent to make decisions on allocation of land for different purposes (Mellese and Mohammed, 2007).

In addition, the right to sell carbon has not yet been established in the country. There is no specific mention of carbon rights or the role of forests as carbon sinks in existing legal texts. Only the need of forest communities to access and use state forests for household and subsistence use is recognised in the Federal Proclamation, which states that the extraction of NTFPs is permitted as long as this follows an approved management plan (Article 10.3 & 10.4 FDRE, 2007).

In light of the above, the implementation of REDD+ in SNNPR requires the establishment of management systems that guarantee ownership rights to the forest products.

Another issue that needs consideration is related to the development of a market that links emissions reducing private and public sector programmes with GHG-emitting companies to comply with the cap-and-trade regulations. Efficiency in the delivery of finance and scale make the regulated market attractive compared to official development assistance type of funding that depends on political situations and bureaucratic inefficiencies. However, in the absence of clear tenure rights the regulated market for forest carbon can lead to displacement or exclusion of local communities by commodifying carbon. This is particularly important in the SNNPR, as land ownership is unclear and complicated. There are ground-level initiatives such as the Bale Mountains Eco-Region REDD+ project and the Humbo Natural Regeneration project (CDM project) that use the Climate Community and Biodiversity (CCB) standards to inform project implementation. These emphasise the generation of social and environmental co-benefits (FDRE, 2011), but with growing demand for cheaper sources

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of carbon credits, there is expectation in the move towards the use of a verified carbon standard compared to a community carbon and biodiversity standard to qualify for the voluntary carbon market, hence social and ecological co-benefits would receive less attention. In addition, REDD+ being a low-cost option to mitigate climate change, ambitious emission reduction targets established by countries could lead to expansion of the carbon market that could be responsible for "global land grab" in the absence of legal and procedural mechanisms in place to protect local rights, livelihoods and access to resources. Regarding safeguards, Ethiopia is in the early stages of developing a policy for addressing social and environmental safeguards for REDD+, but there is a plan to develop an Environmental and Social Management Framework in line with the World Bank safeguards and standard operating procedures.

Finally, implementing REDD+ activities at different jurisdictions is an approach that countries are considering as options in view of a number of challenges to implement REDD+ at national level. This is believed to be efficient, especially in countries where sub-national governments have authority over land management, as in the case of Ethiopia. These initiatives take into consideration implementation on a scale larger than pilot projects that can provide early experience on how to integrate land use planning at municipal, district or provincial levels into low-carbon development strategies. This study contributes to this by identifying the drivers of land use change at district level in the SNNPR of Ethiopia.

6.2 Key policy recommendations

Policy recommendations that follow from the above results are given below. Forest resources are currently found to be below optimal at contemporary social discount rates, indicating that more conversion of forestland should be halted. In using cost benefit analysis to allocate land optimally among forest and agricultural use, the social planner should incorporate the effect of the irreversibility of the forest conversion process and uncertainty of forest benefits.

The other parameter that should be emphasised is the discount rate. Higher discount rates lead to policies that lead to more deforestation. Considering the imperfect valuation strategies available for valuing ecosystem services, occurrence of environmental costs much later than benefits and interdependencies among ecosystem services, it would be appropriate to be cautious when choosing appropriate discount rates. In contrast, lowering the discount rate too much also raises issues of intra-generational equity.

In the analysis of optimal land allocation, social values of forests should be included. This is because international forest policies through initiatives such as REDD+ focus on forest preservation through paying compensation to nations supplying global benefits. The implementation of the REDD+ policy should be considered with care, as in the absence of ownership rights to forestland and the absence of safeguards, it might have negative effects on biodiversity, ecosystem services and local livelihoods.

Regarding driving forces behind land use change, national policies are the focus of intervention. Given the fact that there should be a balance in the supply of population needs and avoidance of negative effects of land use change, government should improve access variables as long as they do not lead to degradation of other land uses. Rural development strategies should be formulated in such a way that they do not contradict forest conservation and environmental protection policies.

Credit policy should take into account the fact that provision of credit could lead to adverse effects, namely the conversion of more forests and other lands, unless the beneficiaries of the services are selected based on some other criteria. Credit provision should not focus only on the delivery of fertilizers and improved varieties. Provision should take into consideration other investments required to benefit from the full potential of these inputs, such as irrigation in moisture-stressed areas, and conservation structure in areas where erosion is prevalent, etc. In addition, the technologies provided should be analysed based on relative scarcity of inputs in the study area. This helps to intensify agriculture while preventing unwanted land conversion of forests, shrublands and grasslands. Credit subsidising of non-farming activities and sources of employment and income would also enhance environmental conservation.

Markets for forest products are limited, making land use to cater for them uncompetitive, but the relative profitability could be increased through the introduction of payment arrangements such as REDD and PES for the values of forests that are not captured in the private benefits of land owners.

In relation to road developments, roads should be constructed in areas where agricultural production is intensive. This will help to preserve the benefits from agricultural production while preventing undesired land use changes in densely forested areas.

Population policies should adhere to lowering the fertility rate and minimising the number of people that migrate to the area.

6.3 Limitations of the study

Only a single-scale analysis was carried out in studying drivers of land use change. Multiple-scale analysis, however, will require employing integrated assessment models, suggesting potential future extension of this work. The present study could also not account for urban-rural interactions and spatial autocorrelations. Hence future studies should consider a mix of factors and different scales to provide strong empirical evidence and confirm observed influences of LULCC drivers in the study region.

Although this study analysed optimal land use choices under uncertainty, a number of important sources of uncertainty were not considered. Examples include uncertainties associated with future agricultural prices, effects of climate change on forest production, and the effect of forest preservation on agricultural productivity.

The interaction between large-scale and small-scale agriculture in the study region is assumed to be non-existent owing to the small percentage of large-scale agriculture present in the area and absence of temporal data to see the dynamics. Hence further studies should consider examining the interactions and how these affect land use decisions.

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APPENDICES

Appendix 1

Assumptions and specification of the multivariate fractional logit (MFLOGIT) conditional mean of the share equation.

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

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

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:

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

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:

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

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. Though

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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:

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

The extension to multivariate fractional logit (MFLOGIT) according to (Mullahy 2010) is given by:

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

Our interest is in 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).

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

The log quasi-likelihood is:

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

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

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

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 see 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).

Appendix 2

Dependent and explanatory variables of the land use share model
Ratio of land under agriculture
Ratio of land under forest
Ratio of land under grassland and shrub land
Average hours to the nearest market
Soil fertility
Mean Agricultural Household size
Literacy level for Agricultural population aged 15 to 30
Percent of households utilizing credit services
Percent of holders utilizing advisory services
Average district elevation in meter
Average district slope in percent
Average number of months with >100 mm rainfall
All weather road density in meter per square kilometer
Total population per square kilometer

Appendix 3

With the possibility of adjusting agricultural land according to changes in net benefits from forests in future periods, the maximized discounted value of land use is:

V (A, B) = max $[(\frac{\psi}{(1-\gamma)}A^{1-\gamma}) + B(Z-A)]$dt + $\frac{1}{1+rdt}$ {E [V (A', B + dB)]-C (A' – A)}................................ ……………………………………………..Eq.(3.1)

Assuming the optimal policy rule is not deforest, A'=A, and again assuming the flow of benefits and costs, the deviation, the initial and terminal values are not functions of time (Dixit and Pindyck, 1994)

V(A,B)=$[\frac{\psi}{(1-\gamma)}A^{1-\gamma}$+B(Z-A)]dt+$\frac{1}{1+rdt}$ {E[V(A', B+dB)]}…………Eq.(3.2)

Applying Ito's lemma, the expected value of the change in forest benefits is:

E [V (A, B+ dB)]=E[V (A, B)+V_B dB +1/2 V_{BB} $(dB)^2$] ....Eq.(3.3)

= V (A, B)+$\alpha B V_B$ dt +1/2 σ^2 B^2 V_{BB} dt ....Eq.(3.4)

where V_B and V_{BB} are the first and second derivative of V respectively.

Substituting equation 3 into 4 and allowing higher order terms of dt to go to zero gives

$[\frac{\psi}{1-\gamma}A^{1-\gamma}$+B (Z-A)] + $\alpha B V_B$+1/2 σ^2 B^2 V_{BB} –rV =0 ……………………………Eq.(3.5)

Assuming a functional form to solve the homogeneous part of the above equation as $V=\omega B^{\beta}$ gives:

1/2 $\sigma^2\beta^2$-(1/2 σ^2 –α) β-r =0 ……………………………………………………...Eq.(3.6)

with roots $\beta_{1,2} = (1/2-\alpha/\sigma^2 \pm \sqrt{(1/2)-\alpha/\sigma^2) + 2r/\sigma^2}$ and homogenous solution of

V (A, B) = ω_1 (A) Bβ1 + ω_2 (A) Bβ2…………………………………………......Eq.(3.7)

When forest benefit increases the value of the option to develop land decreases resulting in $\omega_1(A)=0$.

Hence the value of the total land area will be:

V(A,B)= $\omega_2(A)B^{\beta_2} + \frac{\psi}{r(1-\gamma)}A^{1-\gamma} + \frac{B(Z-A)}{r-\alpha}$ ……………………………………Eq.(3.8)

By applying the value matching condition (expected marginal benefits of clearing land should equal the marginal clearing costs) we get:

$$(B^C)^{\beta_2}\frac{\partial\omega_2(A)}{\partial A} + \frac{\psi}{r}A^{-\gamma} - \frac{B^C}{r-c} = c$$ ……………………………………………Eq.(3.9)

The smooth pasting conditions (marginal benefits of land clearing and its marginal costs meet tangentially at the threshold), and differentiating equation 8 with respect to B^C gives:

$$\beta_2\frac{\partial\omega_2(A)}{\partial A}(B^C)^{\beta-1} - \frac{1}{r-\alpha} = 0$$ …………………………………………………Eq.(3.10)

By combining equation 8 and 9 we get the following threshold function:

$$B^C(A) = (\frac{\beta}{\beta-1})(r-\alpha)[\frac{\psi}{r}A^{-\gamma} - c]$$ ………………………………………………Eq.(3.11)

Appendix 4

Discount Rate in %		Optimal forest stock with climate change		Optimal forest stock without climate change	
		Without carbon storage function	With carbon storage function	Without carbon storage function	With carbon storage function
	1	beyond existing stock	beyond existing stock	beyond existing stock	beyond existing stock
	2	beyond existing stock	beyond existing stock	beyond existing stock	beyond existing stock
	5	227920.1459	227975.9961	209737.92	227975.9932
	6	210649.824	227975.9223	0	227973.2871
	7	0	227974.8461	0	215437.32
	10	0	0	-	-