Forest transition or just deforestation? Evidence from Brazil.

Overganger i skogdekke eller bare avskoging? Bevis fra Brasil.

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Acknowledgements

This thesis marks the completion of my Master's degree in Development and Resource Economics at the Norwegian University of Life Sciences (UMB). The thesis is a product of my curiosity to dig into new subject areas and a growing interest in global development and environmental issues as well as climate change. The work has been long and challenging, but also very instructive.

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Abstract

Climate change is emerging as one of the greatest global challenges in the twenty first century, and is the result of increasing levels of carbon dioxide and other greenhouse gases in the atmosphere. Deforestation is the third greatest contributor to greenhouse gas emissions, and there is a growing consensus that Reduced Emissions from Deforestation and forest Degradation (REDD) should be included in a post-Kyoto agreement.

This thesis examines forest cover change in the Brazilian Amazon in light of the forest transition theory, where the central idea is that deforested areas eventually will reforest. The relationship between deforestation and forest cover, as well as socioeconomic and biophysical conditions is examined to determine whether patterns and trends in the Brazilian Amazon are consistent with theory.

Public data from various Brazilian sources (e.g. IBGE, INPE, IPEA) at municipality level is used to explain land cover change between 2000 and 2009. Deforestation data have been collected for 783 municipalities, but to ensure reliable results, 41 observations from 2001 have been excluded. The dataset is pooled, and OLS estimation is performed for different specifications.

Evidence of a forest transition relationship is found for forest cover. Municipalities with high forest cover will experience greater rates of deforestation. This effect is found to be stronger at state level when results are tested for sensitivity to geographic aggregation. Results also indicate that poor municipalities have higher deforestation rates. Poor municipalities are often dependent on the forest to make a living, and thus do not have resources to avoid deforestation. A number of other factors have been controlled for in the analysis, and explanatory variables such as distance to capital, population- and road density is found to have a clear impact on deforestation rates.

Sammendrag

Klimaendringer fremstår som en av de største globale utfordringene i det tjueførste århundret, og er resultatet av økende utslipp av karbondioksid og andre drivhusgasser i atmosfæren. Avskoging er den tredje største bidragsyteren til utslipp av klimagasser, og det er en voksende enighet om at reduserte utslipp fra avskoging og skog degradering (REDD) bør inkluderes i en post-Kyoto-avtale.

Denne oppgaven undersøker endring i skogdekke i den Brasilianske Amazonas i lys av teorien om overgangsfaser i skogdekke 'forest transition', der avskogede områder etter et visst tidspunkt i tid vil gjenplantes. Forholdet mellom avskoging og skogdekke, samt sosioøkonomiske og biofysiske forhold er undersøkt for å avgjøre om mønstre og trender i den Brasilianske Amazonas er i samsvar med teori.

Offentlige data fra ulike Brasilianske kilder (f.eks IBGE, INPE, IPEA) på kommunenivå blir brukt til å forklare endringer i arealdekke mellom 2000 og 2009. Avskoging data har blitt samlet for 783 kommuner, men for å sikre pålitelige resultater er 41 observasjoner fra 2001 har blitt utelukket. Samlet OLS estimering er utført for ulike spesifikasjoner.

Bevis for et skogovergang-forhold er funnet mellom avskogingsrate og skogdekke rate. Kommuner med mye skog avskoger mer enn andre. Denne effekten er sterkere på fylkes nivå sammenlignet med resultater fra kommune nivå, når resultatene ble testet for sensitivitet ved geografisk aggregering. Resultatene tyder også på at fattige kommuner har høyere avskoging. Fattige kommuner er avhengige av skogen for å tjene til livets opphold, og har dermed ikke ressurser til å unngå avskoging. En rekke andre faktorer har vært kontrollert for i analysen, og forklarings variabler som avstand til hovedstaden, befolkning og veier er funnet å ha en klar innvirkning på avskogingsraten.

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Abbreviations

BRL - Brazilian Real

COP - Conference of Parties

CO_2 - Carbon Dioxide

EKC - Environmental Kuznets Curve

FAO - Food and Agricultural Organization of the United Nations

FC - Forest Cover

FE - Fixed Effects estimation

FRA - Forest Resource Assessment

FT - Forest Transition

FTC - Forest Transition Curve

GDP - Gross Domestic Product

GHG - Greenhouse gas

IBGE - Brazilian Institute of Geography and Statistics

INCRA - Brazilian Colonization Agency

INPE - National Space Research Institute

IPEA - Institute of Applied Economic Research

IPPC - Intergovernmental Panel on Climate Change

LHS - Left Hand Side variable

MRV - Measurement Reporting and Verification

OLS - Ordinary Least Squares

PIN - National Integration Program

POLS - Pooled Ordinary Least Squares estimation

RE - Random Effects estimation

REDD - Reducing Emissions from Deforestation and forest Degradation

RHS - Right Hand Side variable

UN - United Nations

UNEP - United Nations Environmental Program

UNFCCC - United Nations Framework Convention on Climate Change

WMO - World Meteorological Organization

1 Introduction

"Climate change is emerging as perhaps the greatest environmental challenge of the twenty-first century".

FAO (2010a).

Climate change is a result of increasing levels of carbon dioxide and other greenhouse gases in the atmosphere, in part resulting from tropical deforestation. Therefore, economists as well as policymakers, scientists and the public are concerned by the changes that have occurred in global tropical rainforests. IPCC (2007) has estimated deforestation to be the third largest contributor to greenhouse gasses in the atmosphere, placing it after energy supply and industry but ahead of the transport sector.

The response to this climate threat has been numerous international climate conferences and related agreements. The first conference of parties (COP) was held in 1995, and in 1997 the Kyoto-agreement was agreed upon. The agreement came into force in 2005, legally binding developed countries to reduce greenhouse gas emissions to a level that is 5.2 percent below their 1990 levels in the 2008-2012 period. According to the Stern review (2006), the costs of strong actions are less than the costs of the damage avoided by that action. The economic benefits of climate policy decrease by delay, and Stern argues that the inclusion of deforestation in a new global climate agreement would be the most cost efficient way to reduce greenhouse gas emissions. As the Kyoto treaty expires in 2012, efforts are being made to agree on a new treaty. A financial incentive is required in developing countries, and at the 13^{th} COP in Bali in 2007 policymakers agreed that rainforest nations are to be paid for reducing emissions from deforestation and forest degradation (REDD). Governments have agreed on the potential importance of REDD, and further work on methodological issues will continue throughout 2011 towards the Rio+20 summit in 2012.

A general concept related to changes in forest stocks, the forest transition theory, was first introduced by Aleksander Mather (1990). The theory states that forested areas that initially experience deforestation reach a turnaround point and begin to reforest. This movement may be portrayed by a U-shaped curve of forest cover and time, and is in this thesis referred to as the forest transition curve.

"Occurrence of the forest transition in many parts of the world has raised hopes that macro-scale forces of economic development will bring about a spontaneous solution to the deforestation problem now affecting the tropics".

Chomitz (2006).

There is now widespread evidence of forest transitions in industrialized countries (Mather, 1992), and the question is whether such transitions occurs in the tropical rain forests. Signs of diminishing rates of deforestation and emerging reforestation can now be observed in a number of tropical countries (Rudel et al., 2005), where the full transition may occur over relative short term.[1]

"The threat of climate change cannot be understated, but a more immediate concern is the deforestation of Amazonia".

INPE (2011).

This thesis sets out to investigate if such a transition can be found in the Brazilian Amazon. This is justified by the fact that Brazil hosts the largest remaining area of tropical rain forest, and it participates in many projects and initiatives (such as REDD) to reduce deforestation. The Norwegian government has also committed to contribute in funding projects which intend to alleviate environmental degradation through reduced deforestation.

1.1 Research question

This thesis describe land cover dynamics through investigating how deforestation is affected by forest cover rates, as well as socioeconomic and biophysical conditions. Panel data have been collected for 783 municipalities over a period from 2000 through to 2009. Through investigating annual deforestation, we can determine whether there is a forest transition at regional level, and find out where municipalities are situated on the forest transition curve.

To clarify the objectives of this thesis, the research questions analyzed are:

[1] Decades rather than centuries

1. Are the recent deforestation patterns and trends in the Brazilian Amazon consistent with the forest transition theory?
2. How are socio-economic conditions in Brazil conditioning a possible forest transition?

The intention of these research questions is to provide guidance as to how the forest transition curve theory can be employed to describe and analyze the progression of forest cover change in the Brazilian Amazon. The thesis will also give an overview of some methodological issues concerned with estimating forest resource trends along with socio-economic conditions in Brazil.

1.2 Outline of the thesis

The thesis is divided into seven chapters. First, an introduction to the field of forest and climate change as well as the historical reasons for deforestation in the Brazilian Amazon is presented (chapter 2). Next, I introduce theories of the forest transition, where the factors that affect such a transition are explained and hypotheses are stated (chapter 3). Then the data set is described (chapter 4), followed by a presentation of estimation method, specification of models employed and possible pre-estimation issues (chapter 5). The stated hypotheses are tested by empirical analyses (chapter 6), before the conclusion summarizes the findings (chapter 7).

2 Background

The objective of this chapter is to provide an introduction to the field of forestry in the Brazilian Amazon. First, the relationship between forests and climate change is reviewed before I give an introductory overview of the evolvement of international climate agreements. The situation of tropical forests in Brazil is discussed, and then an overview of the historical paths of deforestation in Brazil is given.

2.1 Climate and forest

The year 2011 has been designated ‘the international year of forests’ by the United Nations General Assembly (FAO, 2011). The attention is on forests as an important source for timber, food, water for drinking and irrigation, fuel wood, stocks of genetic resources and other forest products (Perman et al, 2003).

Governments undertake management and conservation of forests to achieve a balance among multiple uses and values. Figure 2.1 shows that globally around 24 percent of all forests are divided among multiple uses. This can be through any combination of the production of goods, protection of soil and water, conservation of biodiversity and provision of social services, or where none of these alone is considered as the principal function (FAO, 2010b).

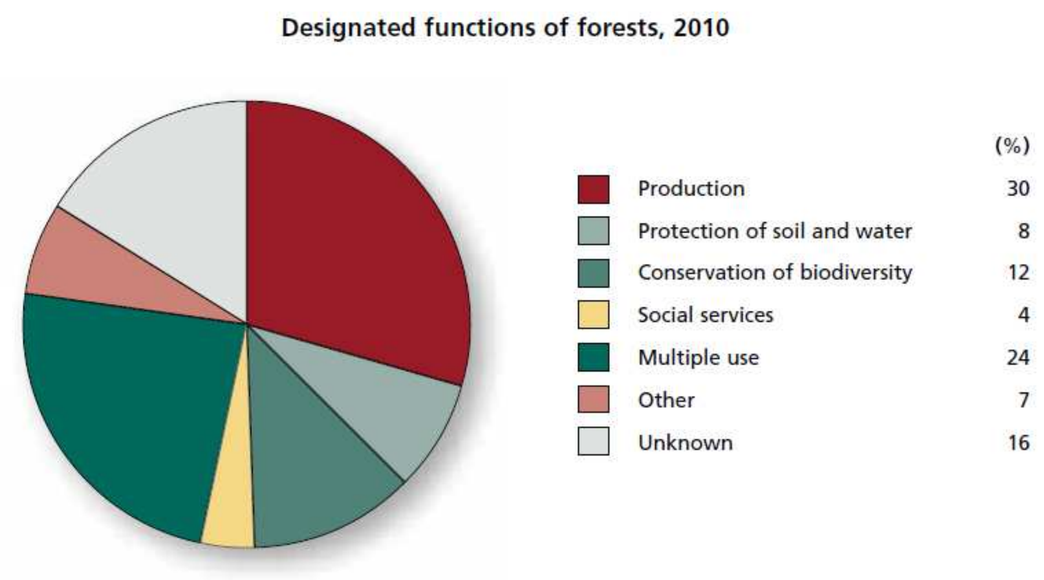

Figure 2.1. Designated functions of forests in 2010 (FAO, 2010b).

In relation to climate change, forests have four major roles according to FAO (2010a). First, forests can be seen as both carbon sinks and sources in the global carbon cycle, they currently contribute to about one-sixth of global carbon emissions when cleared, overused or degraded. Second, it is important to acknowledge that forests react sensitively to changing climate. Third, when forests are managed sustainably, they produce wood fuels as an advantageous alternative to fossil fuels which benefits the environment as a whole. Lastly, forests may absorb approximately one-tenth of global carbon emissions projected until 2050 into their biomass, soils and products. Here it can be conserved in perpetuity if forests are protected from clearing, overuse and degradation.

2.1.1 Global carbon cycle

The earth's most important energy source is the sun, and it powers the climate through short wavelength radiation. Approximately one-third of the energy that reaches the atmosphere is instantly reflected back to space. Most of the remaining two-thirds are absorbed by the surface although some is left in the atmosphere. The earth radiates the same amount of energy back to space at longer wavelengths (due to low temperatures compared to the sun) in order to balance the absorbed energy. The atmosphere absorbs a lot of this radiation (eg.in clouds) and reradiates it back to the earth's surface. This process is called the greenhouse effect and warms the earth's surface. The natural greenhouse effect has been severely intensified through human activities such as the use of fossil fuels and deforestation, causing what is called human induced global warming (IPCC, 2007).[2]

[2] Climate change in IPCC (2007) usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity

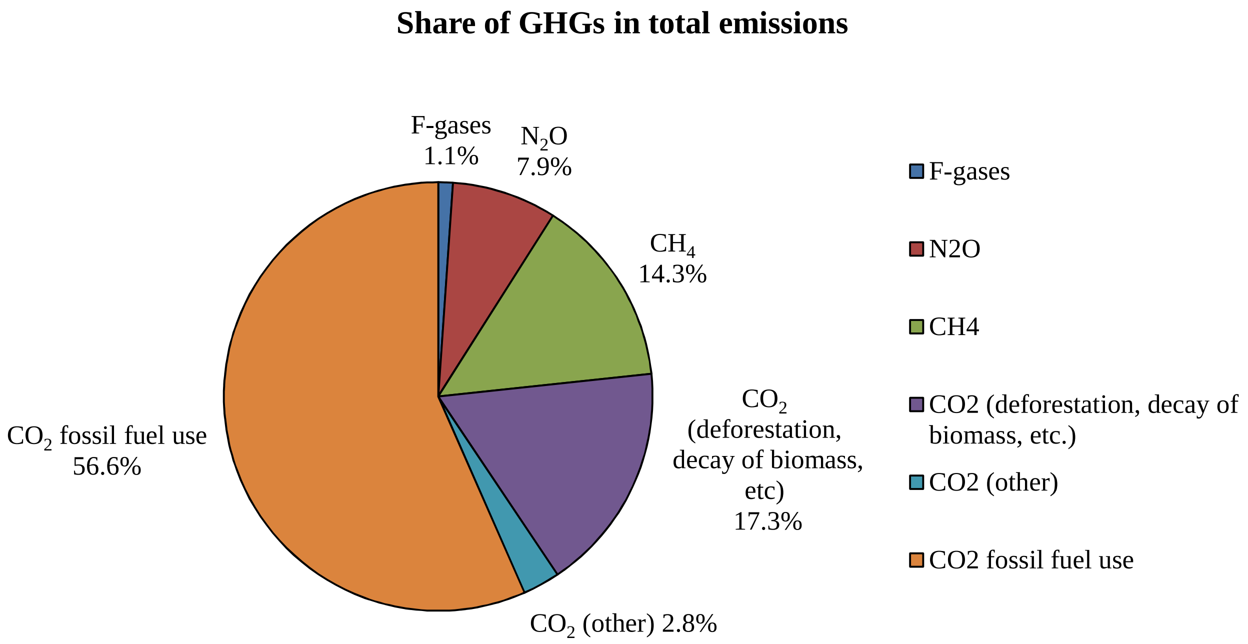

Figure 2.2. Share of GHGs in total emissions in 2004 in terms of CO_2-eq. (IPPC, 2007).

Forests are important components of the climate system as they store large amounts of carbon through the photosynthesis and as such affect the concentrations of GHGs in the atmosphere. CO_2 is extracted from the atmosphere and converted into carbohydrates through this process, but when forests are cleared, burnt or degraded CO_2 is released back to the atmosphere, leading to accelerating climate change. Deforestation is one of the main contributors to higher levels of carbon dioxide in the atmosphere, and is according to IPCC (2007) calculated as the third largest cause of emissions after energy production and industry, placing it ahead of the transport sector.

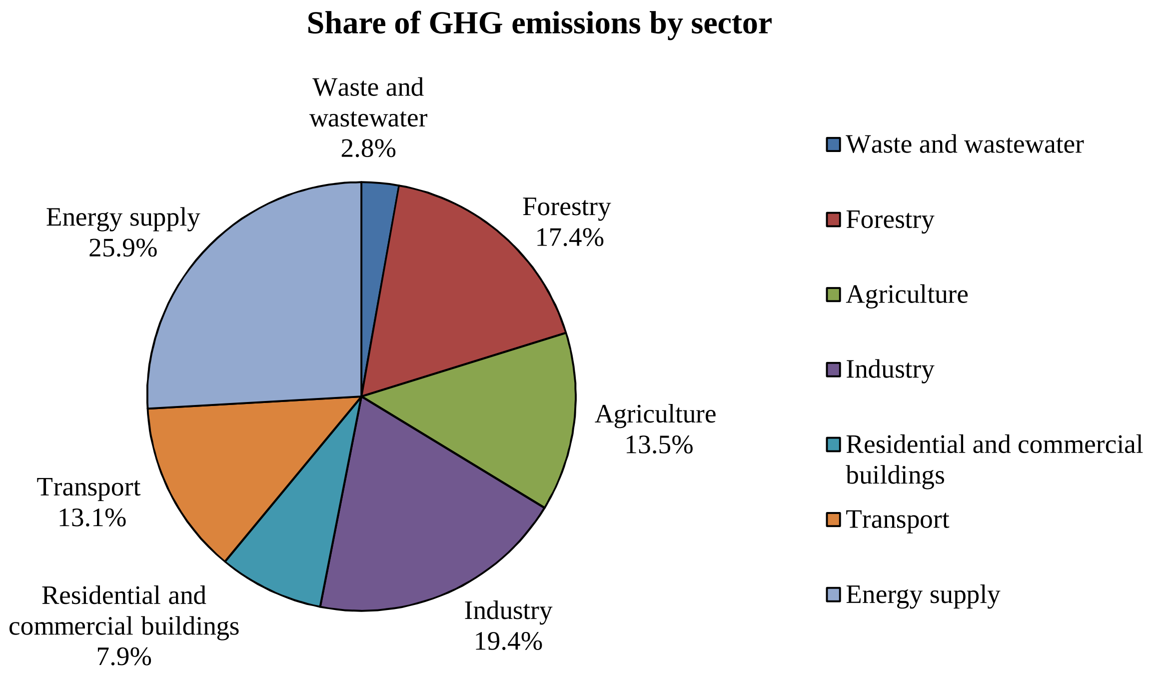

Figure 2.3. Share of GHG emissions by sector in 2004 in terms of CO_2-eq. (IPCC, 2007).

As tropical forests grow rapidly relative to other types of natural forests, they have greater potential for carbon storage. The reduction of carbon emissions through deforestation and forest degradation as well as increasing carbon uptake through afforestation and sustainable forest management contribute to the mitigating of climate change. Forests, as such, play an important role in supporting life on earth (FAO, 2010b).

2.1.2 Biodiversity

Forests are more than just carbon, and the FAO recognized this by celebrating 'the international year of biodiversity' in 2010. Tropical forests play an important role for the earth's biodiversity, as they are some of the most diverse ecosystems (FAO, 2010b). Ecosystems contribute to the mitigation of climate change through the removal of air pollution and regulation of atmospheric quality. They also contribute to nutrient cycling, soil creation, watershed maintenance, and provide habitats for humans and wildlife as well as recreational facilities (Perman et al, 2003).

"If the tropical rainforests are all cut down, we will never know what we have lost… Species will go extinct before they are discovered".

Forsyth and Miyata (1983).

In addition to contributing to and accelerating climate change, deforestation leads to biodiversity loss. There is a great concern that large numbers of animals and plants are subject to extinction. Biological diversity is affected by tropical deforestation in three consecutive ways, namely through the destruction of habitat, dividing former contiguous forests into smaller fragments, and edge and buffer effects within a borderland between forest and deforested areas result in unfavorable physical and biological outcomes (Prance 1982, Pimm et al. 1995).

As this thesis is concerned with the tropical forests in Brazil, it is worth noting that deforestation would have great effect on the diversity of species also here (Houghton et al, 1985). The region is exposed and vulnerable to forest clearing as the Amazon basin is host to roughly half of the world's species, experience intense and complex plant-animal interactions (Mori et al., 1987) and produce rapid nutrient cycling in soil (Dias et al, 1985).

2.2 Climate agreements

The atmosphere is a common resource which will be overexploited by carbon emissions if it is not regulated (Tietenberg, 2006a). Emission of CO_2 is a public bad and creates global reciprocal spillover problems as "the geographical location of the pollution impacts is independent of the location of the emissions source" (Perman et al. 2003). Forest resources therefore have been and still are important in international climate agreements for the protection and sustainable development of this common resource.

The world's first climate conference was held in 1979 in Geneva, and it was sponsored by the WMO and a number of other international bodies. Through working groups of scientists within different disciplines, they tried to figure out how climate change might impact human activities such as agriculture, fishing, forestry, hydrology and urban planning. They all agreed that climate is a vital natural resource, where governments were encouraged "to foresee and prevent potential man-made changes in climate". The leading cause of global warming was identified to be increased carbon dioxide levels from fossil fuels, deforestation and changes in land use. “Humanity’s survival requires us to live in harmony with nature” (UNFCCC, 2010).

A number of intergovernmental conferences focusing on climate change were held in the late 1980s and early 1990s. IPCC was created by the UNEP and WMO in 1988 to analyze and report on scientific findings, and released its first assessment report in 1990. The report confirmed scientific evidence for human induced climate change, and had a huge impact on policy-makers in future climate change conventions (UNFCCC, 2010).

The first international climate treaty, UNFCCC, was in 1992 signed by 154 nations at the Rio de Janeiro “Earth Summit” in Brazil. Through this treaty, countries agreed to prevent global warming from carbon dioxide emissions and set voluntary targets for reducing emissions by industrialized countries (Annex I countries). The UNFCCC came into force in 1994 (Barrett, 2002), and has today 193 parties which are more than any other international environmental agreement.

In 1995, the conference of parties (COP) held its first sessions. This was to become an annual event, where delegates from different countries and observers (such as NGOs) meet to discuss future challenges and agreements in the field of climate change (UNFCCC, 2010). The Kyoto treaty was agreed upon in 1997 and came into force in 2005. The 178 nations who signed this treaty agreed to legally binding emissions cuts within a certain timeframe for industrialized nations (Barret and Stavins, 2003). In this treaty, the principle of differentiated responsibilities between industrialized and developing countries is maintained. The developed countries have agreed to reduce greenhouse gas emissions to a level that is 5.2 percent below their 1990 levels in the 2008- 2012 period.

Tropical deforestation has not had a central role in the negotiation of the Kyoto agreement, as it is mostly concerned with developed countries emission reduction. The idea was that developed countries should reduce their emissions first, so tropical deforestation was not properly included on the agenda before the COP11 meeting Montreal in 2005. Another reason was the lack of measurement and monitoring schemes for forest emissions in developing countries (Point Carbon, 2007).

As the Kyoto treaty expires in 2012, efforts are being made to agree on a new treaty. There are many challenges related to avoiding forested areas in developing countries, such as Amazonia, from ecologically declining. A financial incentive is one of the major challenges, as it is required to compensate for the economic costs of avoiding deforestation.

At the 13th COP in Bali in 2007, progress was made as a “Bali Roadmap” for extension of the Kyoto Protocol beyond 2012 was agreed upon. This states that rainforest nations are to be paid for reducing emissions from deforestation and forest degradation (REDD), either through international carbon markets or a voluntary funds (Santilli et al, 2005, Gullison et al, 2007. Moutinho et al, 2005). This should create incentives for carbon emission reduction from forests and investments in sustainable development. The REDD+ program is an extended version and includes conservation, sustainable management of forests and the intensification of carbon stocks (UN-REDDa, 2011). The World Bank launched a USD 200 million fund and the Norwegian government announced that it would spend USD 500 million annually over a five year period for reducing deforestation in developing countries.

Governments have agreed on the potential importance of REDD (and REDD+), and provide large financial resources to initiate pilot projects. At the 16th COP meeting in Cancún, Mexico in 2010, the UNFCCC highlighted and adopted a decision on REDD+. A roadmap was provided for credible measurement, reporting and verification (MRV) of carbon at country level. Efforts were made to generate cost-effective, robust and compatible monitoring through remote sensing and ground based data. For example, the UN-REDD program cooperates with The Brazilian National Space Institute (INPE), the Group on Earth Observation (GEO) and Google as they are leading actors within this field. REDD may produce multiple benefits in addition to carbon reduction (such as maintaining forest ecosystems), and safeguards have been introduced to ensure the protection, avoid harm and maximize these benefits through monitoring (UN-REDDb, 2011). Further work on methodological issues, including MRV, will continue throughout 2011 toward the Rio+20 summit in June 2012.

2.3 The Brazilian Amazon

Brazil is the fifth largest country in the world in terms of both population and surface area, and includes approximately half of the South American continent's surface area as well as its population (Store Norske Leksikon, 2011). The Legal Amazon[3] is a vast area, most of which has been and still is covered by forest today. The area borders a number of countries in the northwest corner of Brazil, and holds five million of Brazil's total area of 8.5 million square kilometers. Rivers pervade the region, including the Amazon River, which crosses the region from west to east (Pfaff, 1999).

"The threat of climate change cannot be understated, but a more immediate concern is the deforestation of Amazonia".

INPE (2011).

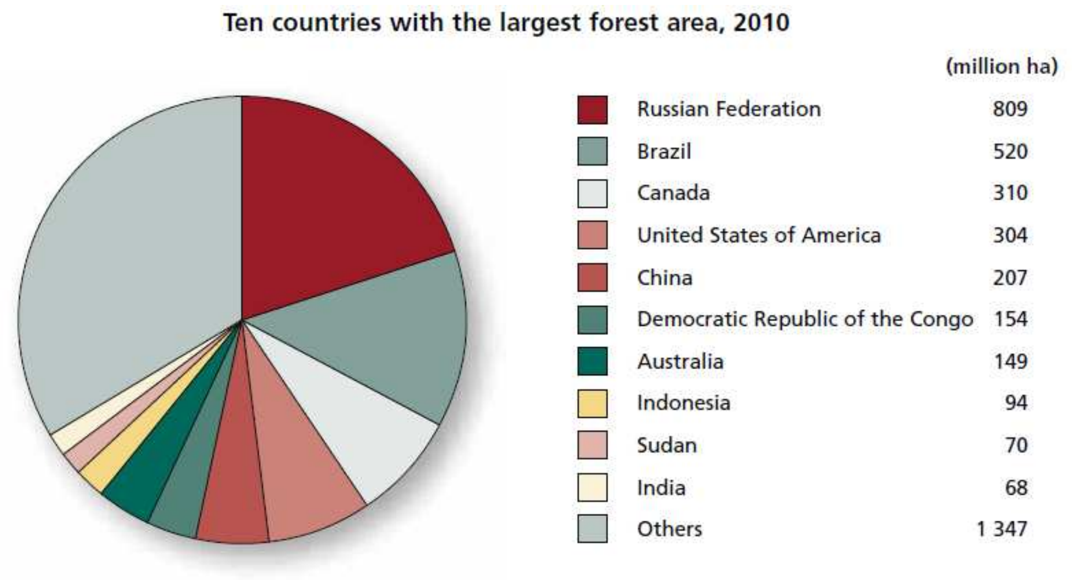

Figure 2.4. The top ten countries with the largest forest area in 2010 (FAO, 2010b).

The Brazilian Amazon contains about 40 % of the world's remaining tropical rainforest, and has according to FAO (2010b) the second largest forest area. For this reason it plays an important role regionally, nationally and internationally. The core purpose for protecting the

[3] Brazil's Legal Amazon is an administrative designation and includes the whole Amazon forest in Brazil, plus some areas of savannah in the states of Mato Grosso and Tocantins (Greenpeace, 2009).

Brazilian Amazon rain forest is to maintaining biodiversity, hydrology and climate regulation, and carbon storage (Salati et al., 1984, Phillips et al., 1998, Fearnside, 1999).

Since 1988, the Brazilian Space Agency has used satellite images to measure yearly fluctuations in the rate of deforestation. As Brazil contains two thirds of the Amazon forest, the changes for Brazil can provide an approximate measure of current, basin-wide trends in deforestation.

Aggregate land cover dynamics in Amazonia have the last 6-7 years shown a change in deforestation rates, as the high rates have come down to less than 40 percent of their historic levels. This is probably due to new drive in Brazil's enforcement actions and to global recession (Nepstad et al. 2009).

A forest code was passed in 1965 for legal protection of forest resources in Brazil. It required landowners to hold 80% of forest area as legal forest reserves, meaning that deforestation could not exceed 20%. Mostly gallery (the width determined by the width of the river) and steep slope forests was intended to be preserved and permanently protected (Tabarelli et al. 2005). There has been great controversy around this code as the measure never has formally been adopted into law. No legal enforcement, prosecution or consequences have been put forward when whole lots have been cleared (Fearnside et al. 1985). Recently, the parliament passed a batch of reforms easing the forest code (BBC, 2011).

A new public forest management law (Law 11,284/2006) was introduced in 2006, intending to decentralize decisions concerning the sustainable use of forest resources. Access to the Amazonian forests became regulated directly by state government entities (Silva, 2006).

2.3.1 The history of deforestation in the Brazilian amazon

Throughout the past 40-50 years, deforestation has received increasing attention. Many authors have engaged in the search for causes and conditions concerning deforestation in the Brazilian Amazon. The following analysis relies heavily on Rudel (2005) and his overview of the development from year 1960 to 2000.

(i) Passive protection (1960-2000).

The Amazons rain forests' flora and fauna have been passively protected by the inaccessibility of the region, thus leaving the forest to mainly persist in its original condition (Barham et al., 1996). The Brazilian populations have until the twentieth century been directly or indirectly dependent on income from exporting agricultural goods, typically sugarcane or coffee, which primarily pushed the country's economic activities towards the Southern coast. As industries and corresponding markets were situated in the South, forests continued to be passively protected from excessive exploitation from the seventeenth to the twentieth century.

During the period 1960 through to 2000, efforts were applied to improve infrastructure in order to make the regions resources more available, but the lack of capital made access advance slowly. Despite this, infrastructure has improved and enhanced the accessibility to the Amazon since 1965. This has increased the Amazon rain forests' linkage to the markets situated on the Southern coast, although some passive protection still seems to exist.

From year 1991 through to 1996, 82 percent of all deforestation occurred in three provinces of the Brazilian Amazon. Rondônia, Mato Grosso and Pará are all situated at the Southern and Eastern boarders of the Amazon, making them more vulnerable for commercial exploitation (Alves, 2002). The areas North and West for the Amazon basin experienced less deforestation, as they are situated too far away from the markets in Southern Brazil to sustain commercial agriculture (Vosti et al., 2001).

In addition to location, the northwestern rainforest is protected by climatic conditions as it doesn't experience any dry seasons. This reduces soil fertility, as heavy rainfall washes nutrients from the soil and allows pests to multiply and infect crops. It is therefore more challenging for farmers to exercise modern agriculture in these areas. The humid conditions and the low fertility of the soils limit the concentration of livestock operations. Many farmers shift their activities elsewhere, and allow their fields to transform back to forest again (Schneider et al., 2000: p. 58). The nature in these areas continues to be passively protected through these climatic conditions together with long distances to markets.

(ii) Large projects break down passive protections (1960-1980).

Even though inaccessibility provided some passive protection of the Amazon basin, government and commercial projects pursuing Amazonian development began to limit the remoteness of the rainforest area during the beginning of the 1960's. The arguments behind these projects leading to destruction of the forest were mainly geopolitical, as they tried to link cities in the Amazon to other parts of the country.

The first national project, the *National Integration Program* (PIN), was a response to problems, such as underemployment and landlessness, with focus on widespread road building to make new areas available and settlement schemes along the newly constructed Transamazon highway. As the oil crisis began in the 1970's and state-led settlement projects failed, the PIN project was substituted for a new project, *PoloAmazonia*, by the Brazilian military and development strategies changed. This project distributed state funds into infrastructure and growth projects, concentrating on exploring and preparing raw materials such as mining, timber and cattle for export markets. World Bank funds were used in the mid 1980's to finance road building and subsidize farm activities in the areas South and West of the forest. Efforts were also made in dam and highway construction north of the Amazon River, as military attendance increased throughout the late 1980's (Hecht and Cockburn, 1989: 95-128). In the late 1990's the Brazilian government introduced *Avança Brazil*, which promised to bring producers in more distant areas close to markets inside and outside of Brazil through an ambitious program of road paving and construction (Laurance et al., 2001a). *Avança Brazil* received great support from alliances of local growth coalitions, and this shaped the decisions about infrastructure, transportation and land use in the Amazon.

The accelerating deforestation trend in the border regions was also affected by other institutional and political factors. The repeated inability to verify land rights created an informal system where "he who works on the land, owns it" (Rudel, 2005). The rush to claim land when constructing new roads led to clearing of large forest areas. The eagerness to claim land eventually abated when all land had claimants that occupied the land physically (Rudel, 1995). These land conflicts where large forest areas are cleared will continue with new rounds until there is a formal order for land rights. A system called *Colono* characterized the agricultural path in Latin America throughout the twentieth century, as smallholders clear large amounts of land to sell it out to better-financed landowners.

(iii) Downscaling of state interventions (1980-2000).

Large projects and weak property rights increased deforestation in the Amazon basin between the year 1960 and 1980, but some of these processes experienced substantial alterations during the 1980's and 1990's. Governmental settlement and colonization schemes were scaled down, and the public sector no longer played a leading role in the deforestation processes. Expansion of settlement in already cleared areas was supported by INCRA, and no new settlement schemes were launched in remote and uninhabited parts of the Amazon (Mahar and Ducrot, 1998).

As colonization schemes was scaled down, the role of road paving projects became apparent as they provided constant access to distanced markets and enabled high-volume operations that produce a continuous flow of products. Loggers, ranchers and soybean producers have supported paving of roads in Brazil as it improves access to resources and markets (Nepstad et al., 2002). Road pavements accelerate deforestation, and there is a causal effect between road paving and the increased clearing of forest (Nepstad et al., 2001).

The drawback of state interests in the development of rural areas has had some unintended effects. As the state decided to cut back on subsidies for large-scale land clearing in the 1980's, it only led to increased logging in the Brazilian Amazon. This growth in logging increased the forests vulnerability to fire, as loggers left behind fuel in the form of slash (deadwood) and because they dried out the remaining forest by cutting down the sunshade cover. When a forest has been burned once, it becomes more disposed to further burning. As a result, the occurrence of wildfires increased. Deforestation magnifies in scale through the development of new enterprises, and this leads to a vicious circle of fires which terminates additional areas of forest (Rudel, 2005).

3 Theory and literature review

The objective of this chapter is to analyze the theoretical foundations behind tropical deforestation and reforestation, particularly in relation to causes and mechanisms leading to changes in the Brazilian Amazon forest resources. When performing the analysis to explore if Brazil experiences a forest transition, the choice of data and methods will depend on the theory discussed in this chapter. Theories concerning land rent and economic growth intend to provide understanding as to how, and not least why, a forest transition may occur. Some evidence of the forest transition theory is presented before limitations of the theory are addressed. The chapter concludes with a presentation of hypotheses tested in this thesis.

3.1 Mechanisms behind deforestation

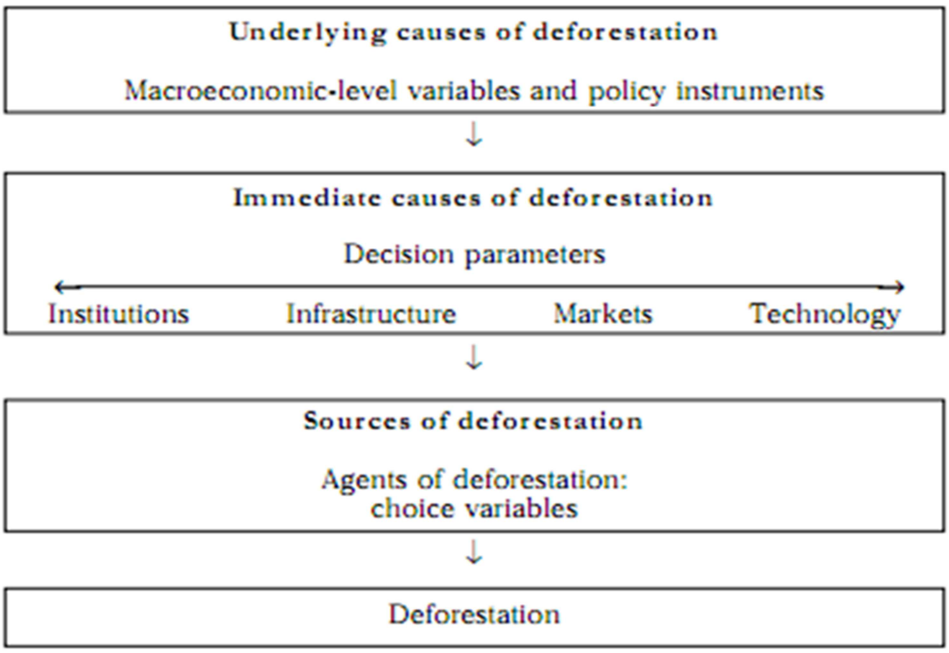

Figure 3.1. Variables affecting deforestation (Angelsen & Kaimowitz, 1999).

Forests have several designated functions (as discussed in the background chapter), and is often characterized by open access. It provides environmental services valuable for the public such as conservation of biodiversity, protection of soil and water and social services. There is no well-functioning market for public goods, as the problem of free-riders often prevails, and thus these services are not managed in an optimal manner. The allocation of land between environmental services and more profitable land uses such as agriculture, infrastructure and logging is a great challenge which has been contemplated by great economists throughout time.

Figure 3.1 illustrate the relations among the main types of variables affecting deforestation. The immediate and underlying causes of deforestation will now be discussed in relation to previously proposed environmental theories.

3.1.1 Immediate causes of deforestation: The issue of land rent

The issue of land rent has been put forward as an immediate cause of deforestation in the von Thünen model. According to this theory, forest cover change is explained as a result of changes in land rent of forest vs. non-forest uses. Land is assumed to be allocated to the use which yields the highest land rent (surplus or profit), and the determination of land rent is dependent on its location to the urban center (Angelsen, 2007). Land rent and distance to the urban center is negatively correlated, meaning that land rent is higher the closer it is to the urban center (the less remote the land is).

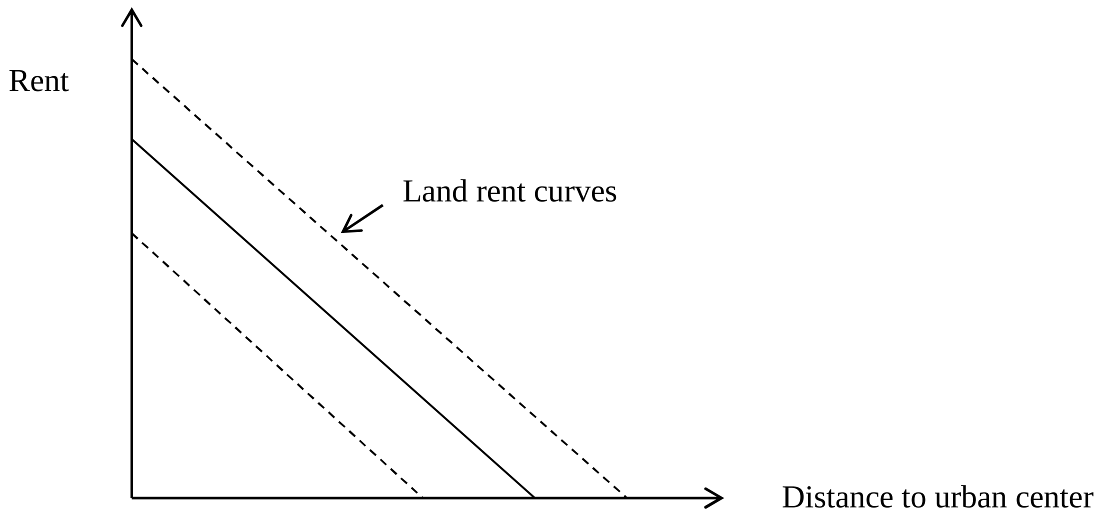

Figure 3.2. Land rent curves in the von Thünen model.

Johann von Thünen’s key to determining land rents in *The Isolated State* (1826) was through assessing the lands location in relation to cities and markets, and the height and slope of the land rent curves is dependent on this measure of remoteness. The theory does not directly state why we experience changes in land rent, thus theories of user behavior and markets (commodities, labor, capital and land) have to be incorporated.

The von Thünen approach focuses on agriculture rather than forestry, as the conversion to agriculture (crops and pasture) is the main source of deforestation. Decisions in the agricultural sector are made by farmers, companies or other land users, and the resolution to deforest depends on which land use is more profitable. The land use which yields the highest land rent also produce the highest profit for the decision-makers, and thus these forest areas are converted to non-forest land uses.

Angelsen (2007) propose a shift in the land rent curve due to new technology in agriculture, and this should make this land more profitable and lead to more forest clearing. An initial shift in the rent of one particular land use generates feedbacks which affect the rent of all land uses. General equilibrium effects through changes in prices and wages may modify or even reverse the initial effect of improved technology. These factors (prices and input costs) may depend directly on the location of the land which affect and shape the land uses (Von Thünen, 1966).

Underlying and immediate causes of deforestation which shift land rent curves are discussed more throughout in appendix I. First, basic model of two land uses (forest and agriculture) is represented before an extended model with five land uses (two agricultural sectors and three forest uses) is elaborated. The analysis is mainly based on Angelsen (2007), and defines deforestation in the von Thünen approach as a result of either an increase in agricultural land rent or decrease in forest land use rent.

The land use yielding the highest land rent and profit for the decision-maker would be chosen, and the von Thünen theory is today used to study the locational aspects of land uses as determined by land rent (Angelsen, 2007).

3.1.2 Underlying causes of deforestation: Macroeconomic forces

Macroeconomic forces and governance factors such as population growth, poverty reduction (through increased income) and economic growth as well as foreign debt and trade liberalization are argued to be the underlying causes of deforestation.

(i) Classical economists and population growth theories

Throughout the 18th and early 19th century, classical economists became greatly concerned with the substance of natural resources and other environmental issues. Natural resources were important factors in determining standard of living and economic growth within a country. Land with its characteristic diminishing returns was viewed as necessary for production but limited in availability, and thus economic progress was temporary. An eventual stationary point would imply adverse standards of living for the majority of the population (Perman et al, 2003).

Thomas R. Malthus (1766-1834) advocated strongly for the limited feasibility of continuing long-run economic growth in his *Essay on the Principle of Population* (1798). An assumed tendency for reproduction caused population growth to exceed the fixed lands potential in production, and output per capita would decrease due to diminishing returns. In the long run, standards of living for the majority of the population would be at subsistence level. The environmental constraint would lead to starvation and death, but Malthus did not believe that this would lead to neither self-constraint nor innovation. The economy would eventually be in a steady state with constant population size and subsistence level standards of living (Perman et al, 2003; Tietenberg, 2006b).

Historical examples such as The Mayan Civilization or the Easter Island support the Malthusian vision. Increased population generates a massive demand for wood to build houses and canoes, leading to the complete destruction of forests which are crucial for attaining sustainable standards of living (Tietenberg, 2006b).

David Ricardo (1772-1823) extended the Malthusian vision of a steady state in his *Principles of Political Economy and Taxation* (1817). The assumption of fixed land was replaced with the assumption that land can be defined within three degrees of quality (Perman et al, 2003).

The increase in population will create higher demand for food, making it necessary to cultivate land of second lowest quality. Low quality land will generate greater costs of production, either through labor or transportation, and will result in increased prices. The first quality land will generate smaller costs of production than the second quality land in relation to the price paid for each unit of production, and thus yield a higher profit. This, says Ricardo, is rent. If population tend to increase further and lead to production on land of third quality, rent on land for both the first and second quality will increase. The costs of production will increase as more labor is required to produce additional quantities, and this will determine the new price of natural products. The laws of supply and demand and the cost of production on the least favorable land determine the price of agricultural goods. There is no presence of rent when land of nearly equal quality guarantees that all human needs are sufficiently met. When an increase in population causes land of inferior quality to be cultivated, rent is paid (Ricardo; Works, 1951-1973).

In the event of increased population, Malthus postulated an absolute limit to resources while Ricardo advocated decreasing quality of available resources. In both theories the returns to land were diminishing. Economic development advance such that the ‘economic surplus’ is measured as the return to land, rent, and proceed towards a Malthusian steady state.

(ii) The environmental Kuznets curve and economic growth

The Kuznets curve was introduced by Kuznets (1955) in his well-known paper on income level and income inequality, which portrayed a bell-shaped relationship between the two. Over the last two decades, the Environmental Kuznets Curve (EKC) has been used to describe the same pattern between income level and environmental degradation (in this case deforestation). It is portrayed as an inverse u-shaped curve, where environmental degradation first intensifies before alleviating as income per capita increases (Panayotou, 1993).

The theory is more of an empirical regularity and the dynamics behind the curve has been given several explanations. Economic growth may increase deforestation rates through increased production of agricultural commodities, thus decreasing forest cover (Kanninen et al. 2007). This effect can be offset as agriculture becomes intensive and off-farm employment opportunities increase. On the other hand, economic growth may increase demand for forest products. The relationship is characterized by increased deforestation rates until a given level of income where they start decreasing (Arrow et al. 1995). The original interpretation behind the EKC was that individual countries eventually would increase environmental protection as the economy grew (Tietenberg, 2006b). Increased environmental awareness at higher income levels thus explains the rise in abatement rates and the greater demand for environmental quality.

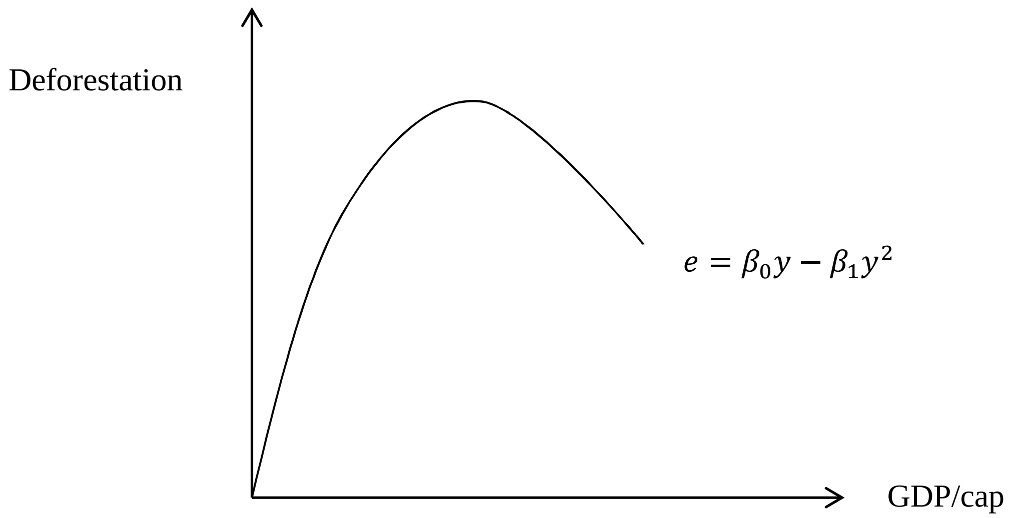

Figure 3.3. Environmental Kuznets Curve (Perman et al. 2003).

The relationship between deforestation and level of income can be explained both graphically and analytically (Perman et al. 2003). Consider that deforestation (e) is a function of income (y):

$$e = \propto y \quad (3.1)$$

$$\propto = \beta_0 - \beta_1 y \quad (3.2)$$

$$e = \beta_0 y - \beta_1 y^2 \quad (3.3)$$

Equation (3.1) portrays that environmental degradation increase linearly with income, but the coefficient α may be a linear function of income as shown in equation (3.2). By substituting α in equation (3.1), we find the inverted U relationship. It has been found that the immediate drivers of EKC are input use, structure of the economy, trade, technology, functioning of markets and regulation (Dinda, 2004: 434-440). If the EKC hypothesis holds in general, economic growth will be a means to environmental improvement. The movement from low income to high income would eventually make environmental degradation fall (Perman et al, 2003).

3.2 The forest transition curve

The theory and general concept of forest transition was developed and initially introduced by Aleksander Mather (1990). In the field of forestry, the notion of forest transition is used to describe long-term changes in forest cover. Mather explains and describes the change from contraction to expansion of national forest areas in terms of increasing agricultural adjustment to land quality. The fundamental factor here is the progressive adjustment of agriculture to land capability, and the consequences of this adjustment in relation to forests. The theory implies that agriculture is located on better quality land, production increase for a given amount of means, and thus other land areas are released and made available for reforestation. Mather et al. (1997:123) do not deny that other factors may influence the forest transition, as the theory only ‘functions in a passive way, permitting reforestation rather than causing it’.

The spatial adjustment of agriculture to land quality, through a learning process and the operation of basic economic influences, provides a theoretical basis for the forest transition. Later, the theory has been used by economists to describe forest areas that have begun to reforest after years of deforestation. The forest transition need not only be caused by agricultural adjustment to land quality, but also by other socio-economic factors such as crisis, state interventions, population migration, and economic development (Angelsen, 2007).

Over a period of time, we can observe how a forested area experience changes in forest cover. This may be portrayed as a u-shaped curve where we initially go through a period with deforestation, before we reach a turnaround point where the forest cover stabilizes and eventually gives reforestation. This is illustrated in figure 3.4.

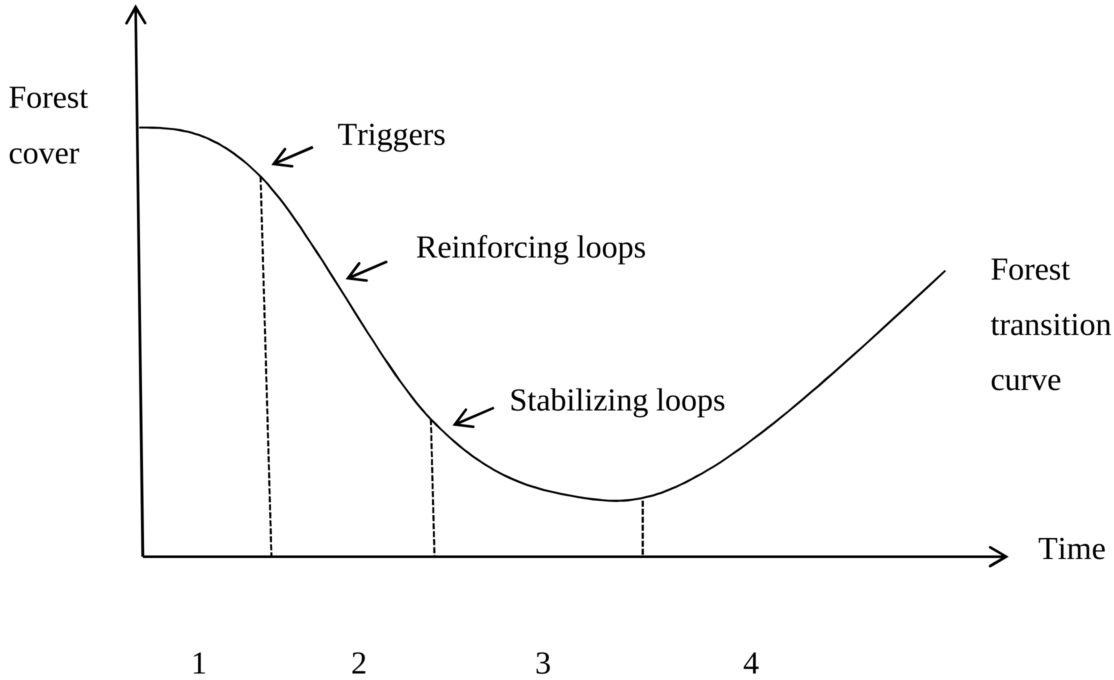

Figure 3.4. Forest transition curve and dynamics (Angelsen, 2007; 32).

3.2.1 The four stages of forest resources

The forest transition hypothesis predicts that there is a universal pattern in the forest cover change, and according to Mather (1990:31), forest resources have four identifiable stages that add up to a forest transition.

The first stage, with relatively undisturbed and extensive forest stocks, is characterized by low deforestation rates. Extraction occurs without concern for future consequences as the forest stock is perceived as almost unlimited. The area may also be inaccessible for commercial production, which provides unintentional and passive protection. Over time, however, factors such as improved infrastructure or economic development may influence the level of accessibility and lead us to the second stage of depletion. Here we experience accelerating and high deforestation rates which may lead to forest scarcity, as forest cover decreases. The trend of clearing the forest continues until the forest cover reaches an absolute minimum, where either the resource is completely exhausted or some reforestation policies are implemented. The turnaround point, with a slowdown of deforestation and forest cover stabilization is the third stage. Here, the society realizes that the resource is finite, and employs reforestation policies as it is economically optimal and socially desirable. As a result, the prices of forest products increase and demand decrease. Angelsen (2007) also points out that a forest transition may occur as a result of agricultural adjustment and concentration to more fertile land, even if no interventions are made in terms of forest policy. In the fourth stage, a period of reforestation occurs as forestry policies such as tree planting are put into action, and together with sustainable forest management it increases the forest cover.

Although the forest transition curve seems fairly simple in its explanations, there are some caveats to keep in mind (Angelsen, 2007). The precise form, slope and turning point of the forest transition curve is hard to predict, as it is individual and depend on the volume of forest cover, deforestation and reforestation rates. The hypothesis is broad enough to include both local and regional differences. Policies also seem to matter when it comes to the shape of the curve, and incorporate historical experience, demographic- and economic forces. The hypothesis is valid for different scales, in this thesis we evaluate the Brazilian Amazon, and includes all types of rainforest in this area. The curve of changing forest extent shown in figure 3.4 resembles those of the forest transition presented by Mather (1992) and Grainger (1995).

3.2.2 Drivers and dynamics of the forest transition

When analyzing the changing forest cover in the Brazilian Amazon, it is important to identify the drivers and dynamics of the forest transition. Several authors have examined the causality links between socio-economic conditions and forest resources, but there is no consensus in previous literature. It seems feasible that factors such as economic development (Mather et al, 1999), demographic conditions (Mather et al, 1998), institutional factors and geographical characteristics (Zhang, 2000) have an impact on forest resources. Walker (1993) propose that economic factors as such as capital availability and labor productivity are drivers of a FT in developed countries, while Mather (1992) argue that changes in forest management explain the transition. Forest declines may be explained by completely different factors than those explaining forest recoveries (Grainger, 1995). Despite the lack of consensus, Angelsen (2007) suggests that there are some triggers, reinforcing- and stabilizing loops that affect the forest cover change.

(i) Triggers

As shown in figure 3.4, the first stage is offset by some initial triggers such as improved infrastructure. The construction of new and better roads make previously inaccessible areas open for migration of both people and capital and increase market participation, which start the deforestation process. This can be related to the von Thünen model, where land rent is determined by distance to commercial center. When distance decrease through improved accessibility, agricultural land rent increase and forest rent decrease resulting in clearing of forest areas. Natural population growth might also be seen as a potential trigger.

(ii) Reinforcing loops

A set of reinforcing loops accelerates the deforestation, where high levels of forest extraction possibly lead to scarcity. Reinforcing loops are generally defined as positive feedbacks which enlarge the initial effect, such as population and economic growth. Both will increase the economic activity, and therefore also the pressure on the already scarce resource. They will also stimulate the development of improved infrastructure and transport facilities.

The history of the Brazilian Amazon provides evidence of the first two stages in the forest transition. As mentioned in chapter 2, deforestation in the 1970s and 1980s was mainly driven by government policies, including road building and subsidies, while in the 1990s independent factors play a more important role (Margulis, 2004; Rudel 2005).

(iii) Stabilizing loops

Socio-economic and political forces will eventually limit the forces that increase the deforestation rates. These will initiate some stabilizing loops, which leads us into stage three and the turnaround point. Some reinforcing loops will change character and turn into stabilizing loops, or new stabilizing mechanisms may kick in. However, the stabilizing loops will dominate the reinforcing loops after some time, and reforestation will result.

Increased population density was one suggested trigger of deforestation and the classical economists, Malthus and Ricardo, proposed it as a driving force already in the 18th century. The demographic pressure would lead to cultivation of more land in order to meet the increased demand for production, thus clearing more forest areas. Malthus theorizes a transition due to insufficient food supply when land is overpopulated. Boserup (1965) does not agree with this conclusion, and suggest that other factors (biological, political or medical) explain the movement from deforestation to forestation after a certain point. Binswanger et al. (1987) describe the Boserup effect as follows; growth in population leads to increased land productivity through intensive cultivation and investment in land. To compensate for necessary labor, old production methods (hand hoe cultivation) will be improved to animal traction and manuring to improve soil fertility. Population growth will also reduce average cost of infrastructure permitting specialization in production and as such economies of scale through trade. Land rights will be specified and the availability of common property resources (e.g. forests) will decrease per capita.

The drivers of a FT depend on which stage and corresponding forest situation an area is in at the time. If the chosen area is in the first stage, development of infrastructure, large-scale projects and settlement would work as deforestation triggers. Government responses and policies differ along with the drivers, and clarification of tenure and forest rights as well as creation of protected areas would slow down the deforestation process. If an area is in the second stage the immediate response should be well-defined property rights, payment for environmental services and reduced subsidized credit to those who clear the land. When an area have reached the third stage, tree planting and improved agricultural technologies is the only way to reverse the trend. The forest transition is, as noted before, an empirical regularity where there are great variations between areas and changing patterns over time. Drivers, capabilities and governmental policies differ as such with a municipality’s stage in the FT.

One distinction in drivers of a FT is between endogenous response (socio-ecological feedbacks) and exogenous change (socioeconomic change) processes (Lambin and Meyfroidt, 2010). These are illustrated by Rudel et al. (2005) who define two major pathways explaining the mechanisms of the FT, namely the forest scarcity path and the economic development path.

Scarcity in forest products or environmental services (decline in ecosystem services) is caused by decreasing forest cover and higher demand due to economic growth. A forest transition may occur if there are established responses to reduce the scarcity in forest products like forest conservation, improved forest management and tree plantation. There is no market for environmental services, making political arenas and policy makers responsible of stabilizing and eventually increasing forest cover. Projects prompting to increased tree planting or ban logging would be effective in that matter (Rudel et al., 2005).

The economic development path evolves as the non-farm sector increase, resulting in higher opportunity cost for labor. This will reduce the supply of rural workers, making farm operations more costly. The creation of non-farm employment pulls farmers out of agriculture, and increased income may decrease demand for forest products as fuel wood is substituted for gas and electricity. Economic growth may result in policy changes issuing protected areas, logging concessions, forest reforms, etc. This will induce the regeneration of forests in old fields (Rudel et al., 2005).

3.3 The link between theories

Efforts have been made to situate the FT in a larger theoretical context, as it shows some resemblance to other theories. Although its resemblance to the EKC has been seen as an unfounded "grand theory" (Perz, 2007), some links between economic development, remoteness and population growth should be investigated and related to the different stages in the transition.

(i) Forest transition and remoteness

While the von Thünen model has a spatial focus the forest transition curve uses time as its organizing principle. Over time, factors such as economic growth and structural changes will have an impact on agricultural and forest rent curves independent of location. Improved infrastructure will also include remote forest areas in the national economy, which will affect the land use decision. As the von Thünen approach, a forest transition can be explained by changes in agricultural and forest rent curves over time.

The three forces, triggers, reinforcing- and stabilizing loops, can be clearly related to shifts in the land rent curves used in the von Thünen approach with only agriculture and forest. The different stages and coherent land rents in forest transition theory are illustrated in figure 3.5.

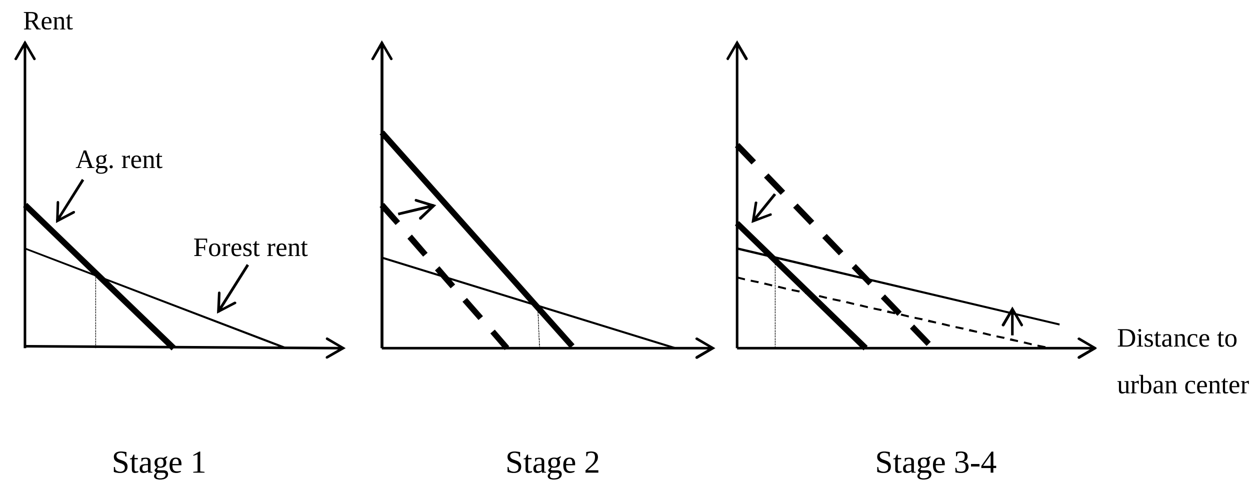

Figure 3.5. Changes in rent curves during the forest transition (Angelsen, 2007; 33).

The first stage is characterized by undisturbed forest with corresponding low agricultural rent, which limits the transition from forest to agricultural land use. During the second stage, both the triggers and reinforcing loops increase the agricultural land rent, leading to a period with high deforestation rates. A dampening of these forces and a set of destabilizing loops will slow down and eventually reverse the deforestation as we enter stage three and four. This is a result of an increase in forest rent (forest scarcity path), a decrease in agricultural land rent (economic development path), or a combination of the two (Angelsen, 2007).

(ii) Forest transition and population growth

Ricardo and Malthus proposed theories related to population growth and land cover dynamics. This underlying cause for deforestation is a trigger and can be related to the second stage in the FTC. In the event of population growth, absolute limit to resources (Malthus) or decreasing quality of available resources (Ricardo) will lead to a transition (in stage 3 and 4) as returns to land and thus agricultural rent were diminishing. The Boserup effect can also condition a transition, but suggest other factors to explain the movement. Increased land productivity, improved production methods and reduced average cost of infrastructure will allow for specialization in production and economics of scale through trade and shift the trend from deforestation to forestation.

(iii) Forest transition and economic development

The environmental Kuznets curve was not developed for deforestation in particular but rather polluting emissions, but can nevertheless be used to predict deforestation and evaluate the forest transition. The EKC is linked to the FTC as it depicts how deforestation is assumed to be correlated with income (reinforcing loops), which is one of the important socio-economic variables in determining whether a forest transition is attainable. Economic growth (GDP per capita) may be used as a proxy for time, and a bell-shaped relationship with deforestation is expected for a forest transition. This may also be related to the EKC, where the relationship between income and deforestation is upward sloping.

The use of the EKC relationship in regards to deforestation has received some criticism in existing literature (Arrows et al., 1995, and Stern et al., 1996). The EKC merely states that an environmental degradation intensifies before it alleviates and thus the Kuznetsian process does not imply that the trend necessarily reverses. As the EKC doesn’t assume reforestation after a certain level of income, the only resemblance is that the forest transition curve may be argued to follow an EKC trend.

3.4 The issue of scale

Walker (2010) is a theoretical paper on forest transition which addresses the scale and spatial domain concerning the theory. Based on a von Thünen approach, the author develops a general equilibrium model for a two good economy. Spatial solutions are considered for land, labor and the production of commodities. The multi-regional model is solved for two regions with corresponding agriculture and industrial sectors.

Whether or not a forest transition is likely to occur in specific places might depend on international trade relations and population flows under globalization (Walker, 1993), as land use change can be observed through movement of population or through trade of agricultural commodities (Robbins and Fraser, 2003). As agricultural populations migrate, long-settled land is released for reforestation and spatial recovery of forest ecosystems (Meyfroidt and Lambin, 2009; Pfaff and Walker, 2010).

Through assessing different scaled regions, a link is made between forest transition and structural changes in the economy. A multi-regional context allows for direct treatment of the scale issue, and provides evidence and explanatory power to the von Thünen approach. It is also important as a means in identifying causal drivers of the forest transition, as spatial relations explain the land cover dynamics within them.

The developed model assesses the possibility of a forest transition in presence of trade and labor movements. A forest transition at global scale is not directly addressed, although the paper draws implications to this outcome by viewing land use change at different spatial scales. Forest transitions are first assessed in individual regions within a country, and then as an aggregate of all regions. Through this aggregation of regional land use systems, a global forest transition may in principle be explicitly considered. The process may be explained by entirely different factors in small regions than those aggregated at a broad-scale. The smaller the region is, the heavier is the effect of external factors.

Whether a forest transition is attainable depends on the forest dynamics in the selected area. Regional forest transition considers newly settled areas whereas an aggregate forest transition relates to long settled areas and frontiers. Walker argues that deforestation in one area may lead to a forest transition in another area through external factors (such as import of agricultural products) which reduce clearing of forests (Pfaff & Walker, 2010. Robbins & Fraser, 2003).

The paper has references to the Brazilian Amazon and the Atlantic forest when addressing the issue of scale. The Atlantic rain forest has experienced forest recovery, and this occurs simultaneously with forest loss in Amazonia, although not at the same rate. Amazonia deforest at a higher rate than the Atlantic rainforest reforest.

The author acknowledges the presence of a regional forest transition as a result of migration flows. Landscape dynamics of a national land use system may reveal an aggregate forest transition, even though it experiences a net loss of wild land. The model reflect the empirical situation in Brazil, although imperfectly, as one regions recovery is slower than the destruction of another. Walker concludes that the choice of scale is critical for identifying a forest transition, and that it may be enabled by external factors.

This paper relates to my thesis through pointing out the importance of scale for identifying a forest transition. The main analysis is done at a municipality level, but will later be aggregated to state level to see if whether it produce a forest transition and assess the magnitude. The paper also have relevance to my research question as Walker (2010) points out that different factors may affect the FT process depending on scale. Different socio-economic factors may condition a possible FT at municipality versus state level.

3.5 Empirical evidence of forest transitions

The theory of forest transitions has over the past decades received much attention in relation to global land cover change, including among resource economists. The empirical evidence of the FT hypothesis (that deforesting areas eventually will start to reforest) is rather strong.

Although there previously was limited long-term global or national time series data, Mather et al. (1999) found that an analysis of several European countries revealed a correlation between historical trends such as economic development and forest stocks in the long-term. Rudel (1998) found evidence for a forest transition in the shorter term. The analysis, carried out for the years between 1922 and 1990 employing FAO data from 5 consecutive surveys of global forest resources, find a relationship between forest transitions, economic development and industrialization. As noted previously (Walker, 2010), slow population growth and a high share of urban population was also in this analysis found to be potential drivers of the forest transition. The data have been criticized for being unreliable and insufficient to draw empirical conclusions (Palo, 2000).

The relationship between population and forest cover has been examined by several authors. Mather et al. (1998) finds that the positive relationship has been reversed throughout the past two centuries. This conclusion is supported by Pfaff (2000); his analysis shows that population cannot be used to explain changes in land cover. Factors such as transportation costs may adjust the initial population effect. Mather et al. (1998) on their side finds that political and cultural environment may adjust the impact of population.

Rudel et al. (2005) analyze data from FAO's FRA2000, and found evidence of a forest transition movement as 38% of the world's countries experience increases in forest cover after periods of deforestation. The conditions of a forest transition may differ across nations, and the authors investigate mainly two trajectories; the economic development path and the forest scarcity path.

Some European and Asian countries reported positive annual forest cover change, giving evidence for a FT. The movement can for the European countries be related to changes in their agricultural economy. The economic development path was a result of increased economic growth and growth in non-farm employment opportunities. Labor is pulled off land, and landowners are encouraged to let the land convert to forests (Bentley, 1989). For the Asian countries, decreased forest cover together with increased prices of forest products raised concerns about the resource’s scarcity (Foster and Rosenzweig, 2003) and forest management policies were employed to ensure forestation. The Asian countries follow the forest scarcity path where immediate policy responses such as tree planting and reservation of communal forests.

The geographical grouping of countries in the two trajectories indicates that a FT in large regions may be affected by its common socio-economic and biophysical conditions (Rudel et al., 2005). Further statistical analyses indicate that some FTs have occurred in developing countries as they respond to the forest scarcity by implementing forestation programs. Countries were sorted, and a FT in the poorer cluster of nations (African-Asian) was expected to be driven by forest scarcity whereas the richer cluster’s (European-American) FT was expected to be driven by economic development. A forest transition in the poor countries is conditioned on the implementation of governmental forestation policies (Rudel et al., 2005).

3.6 Limitations and criticism of the forest transition theory

Although the theory of forest transition is rather robust and only claims that deforesting areas eventually will start to reforest, there are some limitations to the theory that needs to be taken into account. There is no consensus in previous literature as to what drives deforestation, reforestation and the transition. The lack of well specified theory makes the establishment of robust techniques for modeling and estimation difficult, and the predicted effects of the variables are uncertain. Although forest transitions are subjected to common factors, each case of transition has specific characteristics and needs to be treated in relation to level.

The forest transition theory is quite clear on the notion that transition occurs in the long-term, and empirical literature has previously lacked global time series data. Now, local and national time-series data is becoming more available for the analysis of long-term forest cover change. The issue of data is discussed more throughout in section 4.1.

The change in forest cover is usually measured as percent of land area, but this does not provide an accurate measure of actual quantity of forest. Previously used data are therefore unreliable, as the variable should measure forest cover relative to and as a percentage of initial forest cover instead of land area.

Causality and correlation is another issue that needs to be addressed, as it should be treated with caution. Correlation exists in theory if a country experience both economic growth and reforestation of previously deforested areas during a certain period of time (Mather et al. 1999). Correlation between variables does not necessarily imply causality, and one should therefore be careful making conclusions about the relationship between the socio-economic variables and forest transition.

Perz (2007) provides a critical review of the forest transition theory. Evidence exists of a forest transition in advanced industrial countries[4], but the same modeling efforts and applications have yield mixed results in developing countries[5]. Perz argues that many historical context-specific explanations of FT dynamics have been ignored, as the effort in theorizing FT primarily has been based on experiences of advanced industrial countries. Through cross-national studies, developing countries were included in the search for evidence of the FT relationship. Additional doubts about the FT theory were raised, as results revealed different forest dynamics patterns than those expected from FT theory. Thus, biophysical factors (seasonal rainfall and soil fertility), social inequalities, colonization and political conflict become essential when analyzing FT dynamics in less developed areas. The paper calls for identification of broader patterns and unifying concepts behind driving forces of forest transitions, and through critically reviewing previous literature Perz identifies four types of limitations in FT theory.

First, Perz argue that little attention have been devoted to the conditions where a transition might not occur. The author point out that there are important biophysical differences (dependent on regional characteristics such as altitude, humidity and soil) in the definition of

[4] Advanced industrial countries: According to the World Bank classification it is countries in which most people have a high economic standard of living, with high GNP per capita.

[5] Developing countries: According to the World Bank classification it is countries in which most people have low economic standards of living, with low- or middle level GNP per capita.

forests, and that the distinction between primary and secondary forests is often not acknowledged. Definitions of secondary growth and hence of forest area vary, which can affect the forest dynamics observed and our conclusion about forest cover change.

Second, Perz acknowledge the importance of details in the forest transition curve itself. Well-defines variables for rate of deforestation, time until the transition, the amount of primary forest remaining at point of transition, the rate and extent of recovery, and how these factors influence each other are crucial. The issue of spatial scale should also be addressed, as it investigates spatial distribution of forest cover reduction and recovery at a given moment in time over larger land areas. Multiple temporal scales deserve greater attention, as we risk overlooking short- and medium-term forest dynamics. Forest cover change can exhibit important short- and medium-term dynamics that may deviate considerably from the forest transition theory of a smooth, incremental transition curve.

Third, previous literature has not come to consensus about explanatory mechanisms of the transition, and have used numerous of factors in the attempt. Perz find that there is no universal explanatory variable, and that some are included without any specific theoretical foundation. These various explanations have been operating on different scales as important factors behind forest dynamics in developed and developing countries.

Fourth, Perz question how generable these explanatory variables are in obtaining the theoretical perspective of a FT between advanced industrial and developing countries. The mechanisms are not similar between developing and industrialized countries, which means that not only variations in a causal factor but also different causal factors may be important for explaining forest change in different contexts. These specific interactions will help specifying forest cover change patterns.

Perz has some suggestions as to how the FT theory still can be valid. The definitions of primary and secondary forests have to be clarified. Forest transition research may benefit from interaction with research in other related fields, such as forestry and botany, as well as recognize the short- and medium-term dynamics in addition to the focus on long-term transitions. It is important to acknowledge that the driving forces behind the forest transition operate on different scales, from individual actors to global scale processes. Perz concludes that historical-comparative methods and hierarchical frameworks overcome many of these limitations.

3.7 Hypotheses

With regards to theory, I’ve specified some hypotheses that I wish to test. The forest transition curve initially measure forest cover over time (as shown in figure 3.4), but due to lack of good time series data I will investigate the forest transition relationship between deforestation and other explanatory variables. Hypotheses 1 and 2 are of main interest, as they explore the forest transition relationship considering the variables forest cover and GDP per capita. The FTC focuses on forest cover while the EKC focus on GDP per capita. Hypotheses 1 and 2 can then be viewed as a test of which of these two approaches provide best understanding of trends in deforestation. Hypotheses 3 and 4 investigate change in deforestation within the period (2000-2009), and are included as a robustness check of hypothesis 1 and 2. Hypothesis 5 review the different socio-economic variables included in the analysis whilst hypothesis 6 addresses the issue of scale and compares results between municipality and state level.

“Economists prefer, as we all know, bended curves to straight lines, and are keen to produce hypotheses where the first derivatives changes signs.”

Angelsen (1997: 24).

To capture the forest transition process, some methodological specifications of hypotheses is needed. The concept of forest transition can be analyzed mathematically and graphically, and I give a brief review of this for some hypotheses to be able to understand regression results better.

Hypothesis 1. *High forest cover rate leads to high deforestation rate.*

The forest transition theory makes two claims; the first is that large forests will have large deforestation rates, and vice versa, and the second is that forest covers will eventually be partly restored (Angelsen, 2007). In forest transition theory, the flow trend captures the motion from deforestation to reforestation. One way of capturing the forest transition process is by measuring deforestation as a function of forest cover.

Holding all other factors constant, a municipality’s location on the forest transition curve can be found by only looking at its rate of forest cover. From theory it is expected that a municipality having high levels of forest cover is located at the first stage with corresponding low deforestation. As forest cover rates decrease, we expect municipalities to be located further to the right in the graph with increased levels of deforestation (see figure 3.4).

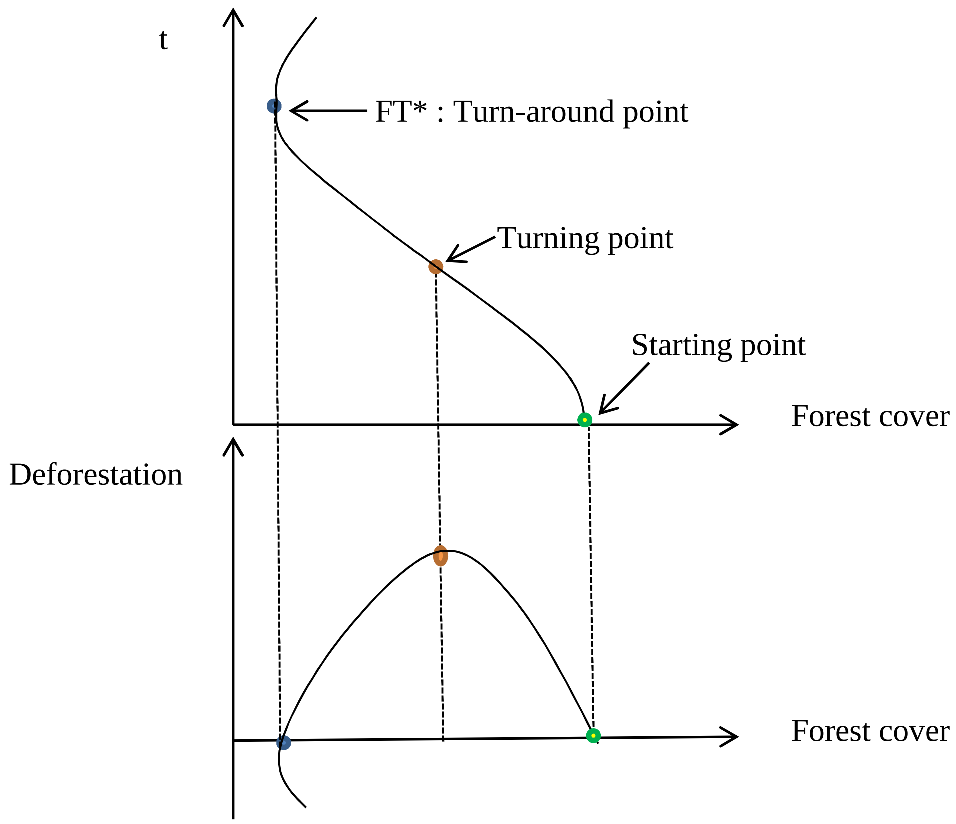

Figure 3.6. Expected relationship between deforestation and forest cover.

The relationship between deforestation and forest cover is represented graphically in figure 3.6. The first graph depicts the forest transition as explained in theory, only the labeling of axes has been swapped. The second graph presents the expected relationship between deforestation and forest cover. Both graphs are read from right to left (as deforestation is defined as a positive number in my thesis), where the starting point (green dot) is defined as the first stage with corresponding high rates of forest cover and low deforestation. To the right of the turning point (orange dot) deforestation increases at an accelerating rate, confirming the hypothesis that a high forest cover rate leads to high deforestation rates. This interval where forest cover is declining represents the second stage in a forest transition. To the left for the turning point deforestation is still increasing but at a decelerating rate until we reach the turn-around point (blue dot) representing the forest transition (FT*). In order to produce a forest transition, this trend is required to cross the x-axis in the second graph with negative deforestation rates and corresponding increased forest cover.

The positive link between deforestation and forest cover can be produced by a linear 1st degree polynomial function of one variable where both the constant and the linear endogenous change coefficient are expected to be positive.

$$Deforestation = a + b_1 FC \qquad a > 0; b_1 > 0$$

To provide evidence for a forest transition curve we apply a quadratic function and assess the signs of the coefficients, although it should be kept in mind that this is a simplified picture. We expect to find an inverted u-shaped curve for forest stock.

$$Deforestation = a + b_1 FC + b_2 FC^2 \qquad a > 0; b_1 > 0; b_2 < 0$$

The linear coefficient is therefore expected to be positive, while the quadratic coefficient is expected to be negative to attain a concave function. To find the turnaround point of the curve, we can use the 2nd degree polynomial function. We find that:

$$\frac{\partial Deforestation}{\partial FC} = 0 \;\rightarrow\; b_1 + 2b_2 FC = 0$$

$$FC = FT *= -\frac{b_1}{2b_2}$$

The first derivative will here express the rate of change, while the second derivative gives the minimum point. This gives the turning point in the forest transition curve, where we have a movement from deforestation to forestation. The change in deforestation therefore depends on the magnitude of change in forest cover.

A municipality's level of forest cover may portray either natural forest or plantation. According to theory, the turnaround point will occur either naturally or through interventions from government or private actors. Forest management and plantation may be implemented to alleviate environmental degradation, or to meet increased demand for forest products. In line with theory, municipalities may therefor report high levels of forest cover. Plantation will produce a positive sign, but if natural forest is cleared for plantation the effect will be lost. From theory, reforestation will make municipalities report high levels of forest cover. They will then be situated to the right in the graph, where the *a priori* sign is ambiguous.

Hypothesis 2. *Low GDP per capita leads to high deforestation rate.*

A municipality's location on the forest transition curve may also be assessed by looking at its level of GDP per capita. The theory of forest transition hypothesizes the municipality's level of forest cover as a function of time. A municipality's level of economic development/income is also measured as a function of time, so in order to assess possible forest transitions we can use GDP per capita (y). It is generally employed as an explanatory variable in forest transition curve analysis, but can also be used as a rough proxy variable for development over time as it gives a pin-pointer of the economic wealth of a municipality.

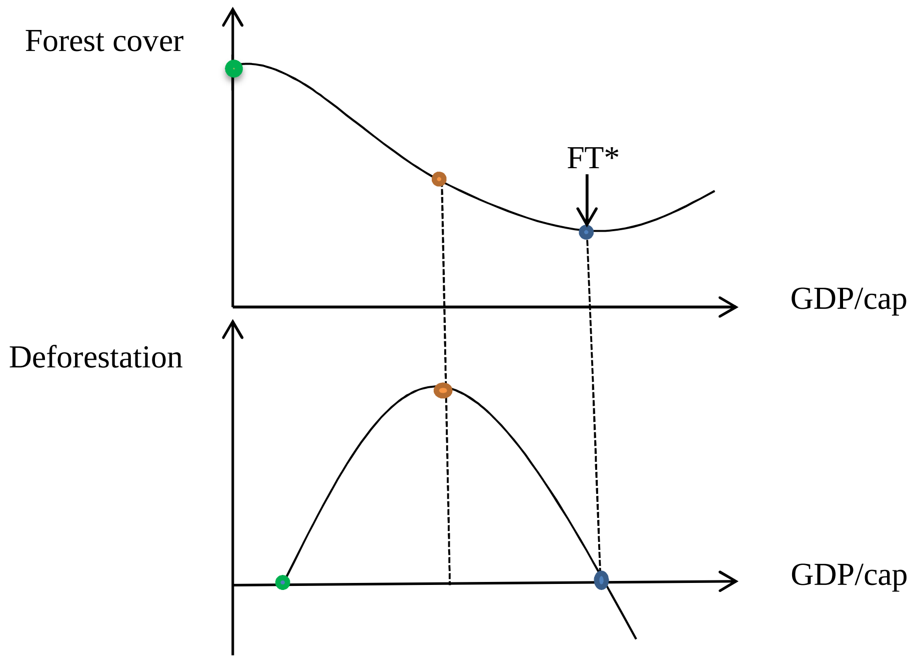

Figure 3.7. Expected relationship between deforestation and GDP/cap.

A graphical analysis may also be given for the relationship between deforestation and income. Figure 3.7 is read from left to right, where the first stage is characterized by low GDP per capita, low deforestation and high forest cover. Municipalities at the early stages of the forest transition curve are the poorest and are therefore expected to cultivate more agriculture leading to high deforestation. Deforestation rates will be accelerating until a certain turning point where it increases at a decelerating rate. A movement from agriculture to manufacturing or governmental legislation concerning resource exploitation may be possible explanations for this trend. Municipalities located to the right of the FT*-point are expected to be wealthier and hence more able to adapt to the threat of forest resources. Deforestation rates will be negative and the municipality will experience forestation.

The forest transition relationship implies that deforestation as a function of income increase before decreasing. The process is generally portrayed as a bell-shaped curve, which can be found by a quadratic function. In order for this function to portray a convex forest transition curve, it is expected that the linear coefficient is positive and the quadratic coefficient is negative:

$$Deforestation = a + b_1 y + b_2 y^2 \qquad a > 0; b_1 > 0; b_2 < 0$$

GDP per capita may be given additional interpretations. Economic development can be reflected through increased demand for agricultural and forestry products leading to higher levels of deforestation, and hence a positive sign is expected. Economic development through investment in infrastructure is expected to have similar effects. To find the turnaround point of the curve, we can use the 2nd degree polynomial function:

$$\frac{\partial Deforestation}{\partial y} = 0 \;\; \rightarrow \;\; b_1 + 2b_2 y = 0$$

$$y = FT* = -\frac{b_1}{2b_2}$$

The forest transition curve has similarities to the Environmental Kuznets curve (EKC) in its relationship between GDP per capita and deforestation. In forest transition theory, GDP per capita and the deforestation rate increases simultaneously until the municipality reaches a certain point where resources are pulled out of agriculture. Deforestation slows down and is eventually reversed (economic development path). The main difference is that the EKC does not assume reforestation after a certain level of income. When computing results, it can be argued that the observed forest transition curve has a kuznetsian deforestation trend.

Hypothesis 3. *High forest cover rate leads to acceleration in the deforestation rate.*

This hypothesis investigates change in deforestation rates, and is included as a robustness check for hypothesis 1. The problem statement is similar, but deforestation is replaced by change in deforestation which is the rate of change in forest cover between two periods. A more comprehensive explanation of the variable is given in section 4.4.

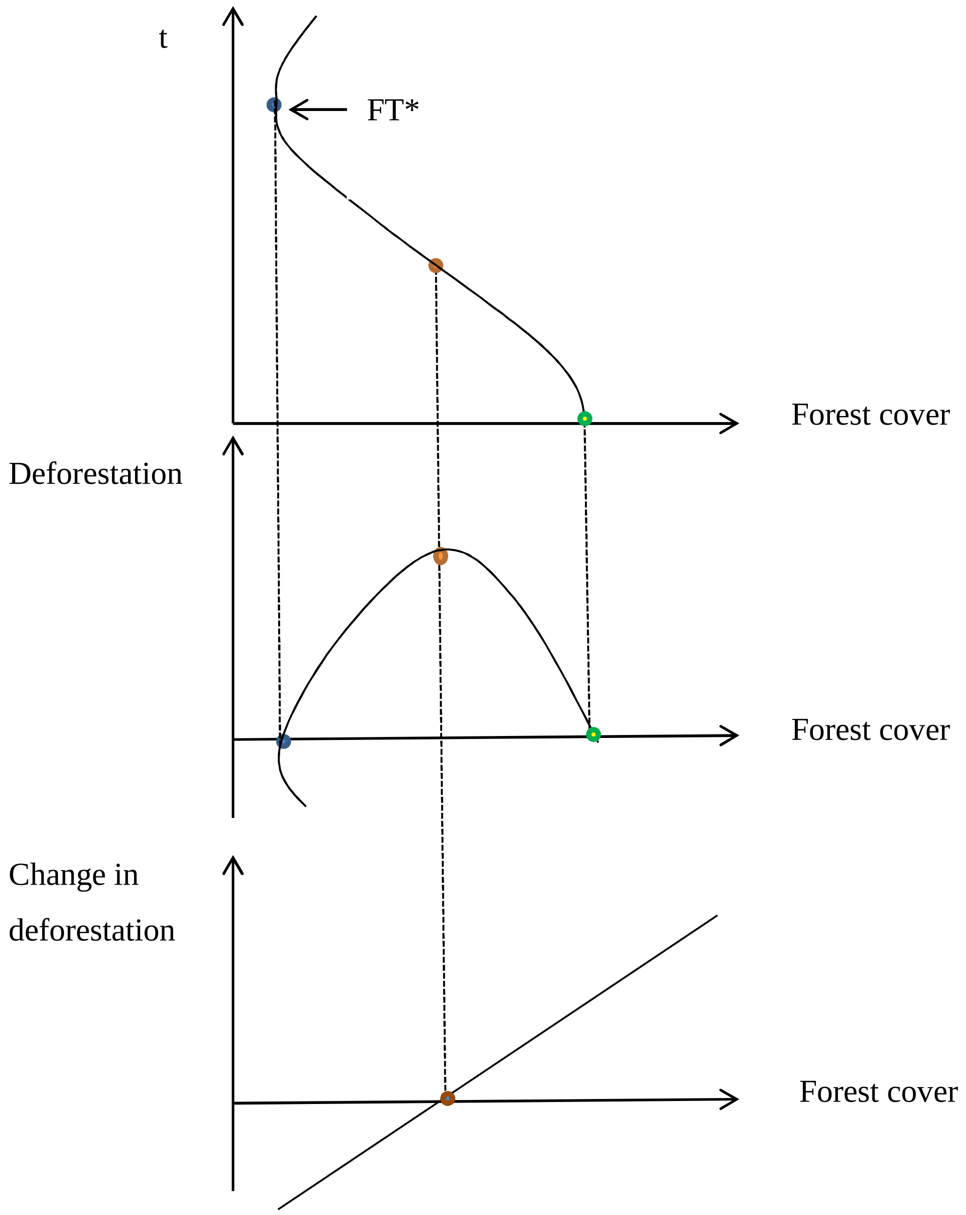

Figure 3.8. Expected relationship between change in deforestation and forest cover.

Figure 3.8 capture the trend in deforestation rates, and the change in forest cover is expected to be accelerating at first before it starts to decelerate. This hypothesis is based on the second derivative, and the relationship is expected to be positive.

Hypothesis 4. *Low GDP per capita leads to acceleration in the deforestation rates.*

This hypothesis is included for the exact same reason as hypothesis 3, namely as a robustness check for hypothesis 2. The only difference is that forest cover is replaced by the proxy-variable GDP per capita. To control the results from hypothesis 2, I intend to compare the rate of change in deforestation between periods. The hypothesis capture the trend in deforestation rates and it is expected that it is accelerating at first before it starts to decelerate.

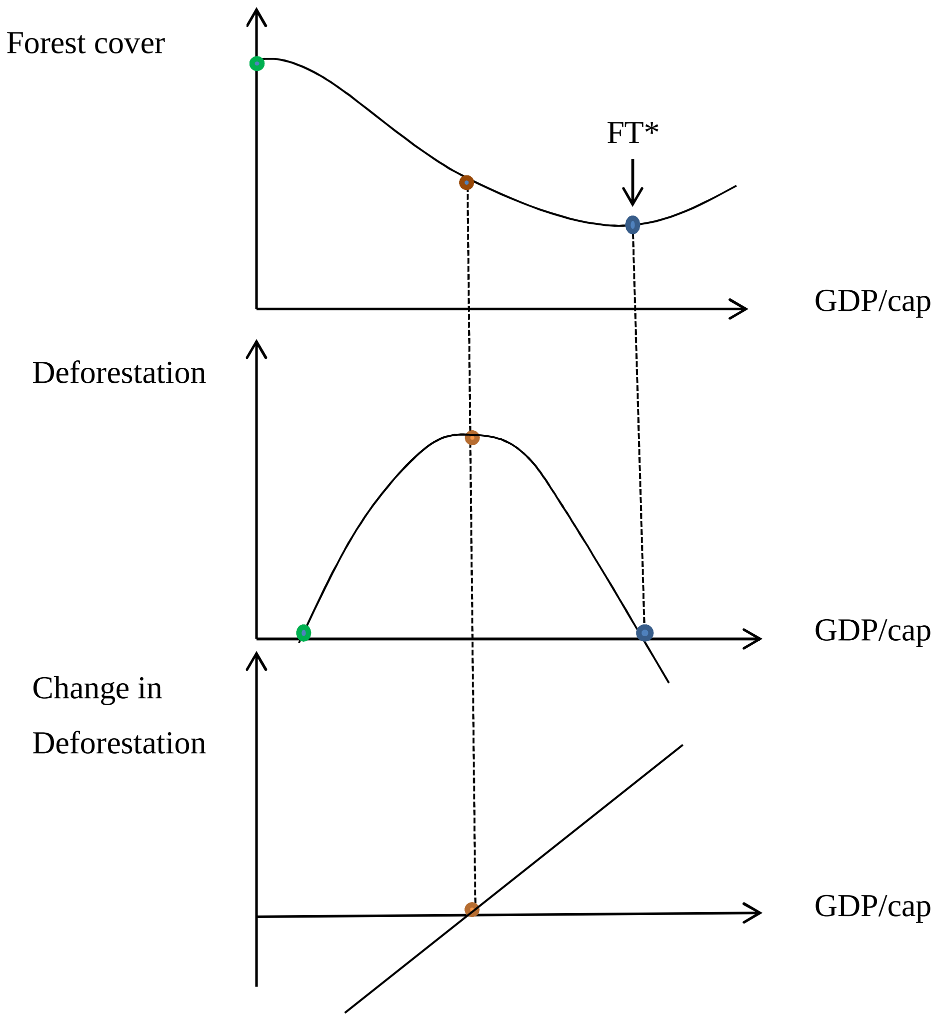

Figure 3.9. Expected relationship between change in deforestation and GDP/cap.

Hypothesis 5. *Socio-economic variables affect the deforestation rates.*

A number of possible drivers of forest cover change are included in my model as explanatory variables. The hypothesis is divided into smaller sub-hypotheses, and these assess the impact of the different socio-economic factors on deforestation rates.

(i) Population density

According to Malthusian theory, higher population density creates a demographic pressure leading to increased deforestation. The pressure on forest resources becomes more intensive as population grows, and this leads to higher rates of land clearing. Migration and new settlement also explain the driving force behind the movement. Increased population density also results in higher production as demand aggravates, and larger forest areas are therefore cleared to cultivate agricultural production.

When the level of population density initially is low, the increase will in line with Malthusian theory lead to increased deforestation. At a certain level the Boserup effect will start to work and deforestation will decelerate and eventually reverse according to the forest scarcity path. Nevertheless, a positive sign is expected for population density.

(ii) Remoteness

The variable labeled remoteness measures distance from a municipality's urban center to the state capital (in kilometers). A measure of distance to the state capital provides a rough measure of how accessible the markets are for a municipality. It is assumed that the further away a municipality is from the state capital, the less deforestation it experiences. Municipalities close to the state capital may be exposed to forest clearing due to road building or expansion of city area. This hypothesis may be related to land rents in the von Thünen model and thus a negative sign is expected as deforestation decreases the more remote a municipality is.

(iii) Road density

The relationship between roads and deforestation relies heavily on logging activities, as it progressed with the construction of roads to gain access to timber. Unfortunately, this thesis does not provide data on logging. The paving of roads is therefore viewed as a way to provide market accessibility, and produce a continuous flow of products. Exhaustion of huge forest areas is a fatal consequence of this action. The intrusion of roads into forests can be devastating as it makes the forest more vulnerable to forest fires as well as pests and other diseases. A chain reaction with increased erosion and waterway sedimentation may occur. Most destructively, it will make a municipality more accessible and may lead to invasions by farmers, ranchers, hunters, miners and land speculators (initial trigger). There is a causal effect between paved roads and the accelerating clearing of forest. A positive sign is expected, as high road density makes the municipality more vulnerable to deforestation activities.

(iv) Latitude

Latitude and longitude are often included in models explaining forest cover change, and it is expected that latitude and longitude will have a spatial effect on deforestation. When it comes to latitude we predict that the greater the distance from the equator is, the higher is deforestation rates. The temperatures are expected to be higher the closer we are to the equator, and high temperatures are expected to affect production utilizing human resources. We expect deforestation to be lower the closer a municipality is to equator. As latitude increases, deforestation is expected to increase.

(v) Rainfall

Climatic conditions affect deforestation, and the level of rainfall is an important factor. Rain is essential to maintain the forest, and it is also an important factor when it comes to agriculture. Brazil experience dry seasons, which makes it hard to produce agricultural goods.

Heavy rainfall over a certain limit washes nutrients from the soil and allows pests to multiply and infect crops. The humid conditions and low soil quality makes it difficult to practice agriculture and therefore limit livestock operations leading to reforestation of old fields. The linear term is expected to be positive, while the quadratic term is expected to be negative.

(vi) Temperature

Deforestation rates may be indirectly affected by temperature through human resources in forestry and agriculture. It is expected that the higher the temperature is, the harder it is for workers to for example clear the land. As no theory or literature relates temperatures to deforestation, temperature is expected to pick up some spatial correlation since most of the deforestation occurs in the Southern Brazil where temperatures are lower. A negative sign is expected as higher temperatures leads to decreased deforestation rates.

Hypothesis 6. *Evidence of a forest transition is stronger at state-level.*

Perz (2007) criticize the effort to theorize forest transition, as it has assumed common mechanisms behind the process. It is important to acknowledge that the driving forces of a FT operate on different scales, from individual actors to global scale processes. By addressing different scales we can investigates spatial distribution of forest cover reduction and recovery at a given moment in time over larger land areas. Walker (2010) assessed different scaled regions in his theoretical paper and point out a link between forest transition and structural changes in the economy. A multi-regional context allows for direct treatment of the scale issue, and the FT process may be explained by entirely different factors in small regions than those aggregated at a broad-scale. Globalization will foster trade in forest products, and those who import may save carbon rich forests. The smaller the region is the heavier is the effect of external factors.

Annual deforestation will in this thesis be predicted on both municipality and state level because I want to test how sensitive the results are to the level of geographic aggregation. My dataset consists of 783 municipalities representing 9 states. This hypothesis expects that evidence of a forest transition from forest cover is stronger on state level compared to municipality level. Local forest change may vary in timing in different parts of the country, and the dynamic may vary spatiotemporally. Deforestation can appear in one area and forestation in another, and observing them on an aggregated scale may enable us to see the overall effect. I assume that the effects are large at state-level due to larger variation in data. Data at greater levels are needed to see that some land is deforested while some is kept as original forest.

4 Data

The purpose of this chapter is to discuss the characteristics and quality of the data used in this thesis. The chapter is divided into three parts. The first part elaborates some general data issues concerning forest resource studies, which includes the level of study, definition of forests and data requirements. The second part elaborates how this thesis addresses some of these issues, and to discuss the reliability of the data utilized in the thesis. Finally, the third part of this chapter provides a review of the dependent and independent variables employed in the analysis of forest transitions.

4.1 General data issues

Many of these empirical studies experience shortcomings due to lack of reliable and comprehensive data (Williams 1989: Mather 1990). The quality and method applied in previous works' collection of data has been questioned and criticized, and many studies fail to address and account for varying definitions and measurements of forest cover, and as such deforestation.

These issues weaken the reliability of the published comparable statistics, and the results derived from these models should be viewed with a portion of skepticism as they rely on weak data (Kummer et al. 1994). Reliable data on trends in forest areas is to a large extent unavailable both for national and global level studies. Even short term analyses are difficult to derive, due to the availability of data (Mather 1992).

Existing empirical work generally rely on FAO data, which has proved to be an uncertain source of data especially for early time periods. The inconsistency in definitions of forests, and the shaky distinction between primary[6] and secondary[7] forest create reason for concern for the reliability of empirical results. The interpretation of estimates calls for great caution (Perz et al. 2003).

[6] Primary forest: Untouched rainforest which exists in its original condition.

[7] Secondary forest: Rainforest that has re-grown after being disturbed in some way, naturally or unnaturally.

The most comprehensive and convenient data source is the FAO *Production Yearbook*, but has been argued to be unreliable due to method of collection. Data on land use and forest areas are reported through national governments' response to annual questionnaires, and is perceived as unreliable due to the national governments' incentive to over -report the actual forest area or from their general lack of satellite or ground based information on the extent of forest cover in the country (Shafik, 1994).

The definition of deforestation can be divided into two categories (Wunder, 2000). The broad definition measures deforestation as forest land use *conversion* and forest *degradation* (reduction in forest quality), whilst the narrow definition only measures change in forest land use (conversion). FAO use the narrow definition, and define deforestation as 'change in and use with depletion of crown cover to less than 10%' (FAO, 1993).

Previous evidence of forest transitions depend on data of doubtful reliability, and literature conclude that all deforestation data sources are questionable (Mather, 1992; Mahapatra et al. 2003). Perz et al. (2003) argues that it is 'widely recognized that airborne and satellite remote sensing is among the best methods for consistently quantifying land areas under different kinds of forests'.

4.2 Data utilized in this thesis

Previous studies suffer from serious problems and lack credibility due to problems in collecting trustworthy time-series and panel data for national forest areas (Mather, 1992). Consequently, there are some methodological issues that need to be addressed adequately.
Brazil has throughout the past decade assembled data on deforestation and socio-economic characteristics at municipality level of good quality. Laurance et al. (2001b) utilize satellite imagery data from INPE in their analysis of deforestation in the Brazilian Amazon.

"Among tropical nations, Brazil probably has the world's best monitoring of deforestation activity".

Laurance et al. (2001b).

My analysis relies mostly on publicly available data from IPEA, INPE and IBGE. The dataset utilized in this thesis contains data for 783 municipalities, with forest stock, deforestation levels and characteristics. Throughout the analysis some observations are eliminated due to missing variables, whilst some are trimmed due to unreliability. The empirical analysis utilizes a total of 2 dependent and 15 independent unique variables over a period of 10 years (2000-2009).

When the variables were collected, the dataset was reshaped from a wide to a long format which changed the variables to observations. This provides this empirical analysis with a dataset with a panel structure.

4.3 Variables

Table 4.1 presents the variables that will be used in the analysis.

The objective of this thesis is to examine changes in forest resources and land areas in Brazil. The deforestation variable is used as a dependent variable (or in derivation of it) when estimating possible forest transitions. It portrays the annual deforestation as a percentage rate of municipality area that has occurred this year.[8] The deforestation data is available for a period of 9 years (2001-2009). The variables utilized in this thesis are relatively stable, which allows for and makes it convenient to use average values. Average annual deforestation will therefore be predicted at state level.

The second dependent variable that is used in this thesis is annual change in deforestation, and it is according to FAO (1995) calculated as:

$$Deforestation\ in\ period\ x = \left[\left(\frac{Forest\ cover_2}{Forest\ cover_1}\right)^{\frac{1}{t_1 - t_2}} - 1\right] * (-1) * 100$$

$$Change\ in\ deforestation = \ Deforestation\ in\ period\ 2 - Deforestation\ in\ period\ 1$$

[8] Deforestation, forest cover and water cover is expressed as rate (a specific kind of ratio) where two measurements are related to each other (in this case of municipality area).

Table 4.1. Overview of variables.

Variable	Type	Unit and description	Source
Deforestation	LHS	% of municipality area (2001-2009)	National Space Research Institute [http://www.inpe.br]
Change in deforestation	LHS	% per year (2000-2009)	National Space Research Institute [http://www.inpe.br]
Trend variable	RHS	Year (2000-2009)	National Space Research Institute [http://www.inpe.br]
Forest cover	RHS	% of municipality area (2000-2009)	National Space Research Institute [http://www.inpe.br]
GDP per capita	RHS	1000 BRL per capita (2000-2009)	Brazilian Institute of Geography and Statistics [sidra.ibge.gov.br]
Population density	RHS	Population per km2 (2000-2009)	Department of Informatics SUS [http://www2.datasus.gov.br]
Municipality area	RHS	Km2 (2000-2009)	National Space Research Institute [http://www.inpe.br]
Remoteness	RHS	Distance to state capital (km2) (2000-2009)	Tim Thomas [www.timthomas.net]
Road density	RHS	Roads per km2 (2000-2009)	Tim Thomas [www.timthomas.net]
Water cover	RHS	% of municipality area (2000-2009)	National Space Research Institute [http://www.inpe.br]
Latitude	RHS	Degrees decimal (2000-2009)	National Space Research Institute [http://www.inpe.br]
Longitude	RHS	Degrees decimal (2000-2009)	National Space Research Institute [http://www.inpe.br]
Rainfall	RHS	Average mm. pr. year (2000-2009)	Institute of Applied Economic Research [ipea.data.br]
Temperature	RHS	Average pr. year (2000-2009)	Institute of Applied Economic Research [ipea.data.br]

Forest cover as a rate of municipality area at two different times, t_1 and $t_{2,}$ is used to calculate annual change in deforestation for period 1 and 2. The first period measures the difference in forest cover between 2009 and 2007, while the second period measures difference between 2003 and 2001. The annual change in deforestation utilized in this thesis is computed as the difference between the two periods. Appendix II reports the complete calculation of periods.

One right hand side variable that needs a brief review is GDP per capita measured at current prices (1000 Brazilian Real). Included in this measure are taxes less subsidies on products at current prices, gross value added at current prices, their respective shares and in general overall economic activity. Data from the latest available year (2009) are subject to revision at next release.

Municipality area is expressed in square kilometer. This area was extracted from the polygon of each municipality, based on the digital map provided by IBGE in the range 1/2.500.000 in year 2001. There may be a minor difference compared to the same area published by the official IBGE.

The temperature and rainfall (mm/year) variables are computed as yearly averages. The variables have been collected from IPEA, but the original source of the temperature variables are from the estimates of CRU CL 2.0 10´ from the Climatic Research Unit of the University of East Anglia (CRU-UEA) published in New et al (2002). The rainfall data is reported as an average over the years 1961 to 1990.

4.4 Limitations in data when estimating the forest transition curve

It is important to acknowledge the limitations of the data analyzed in this thesis. We need to take into account that there only are nine years of deforestation data available, and that these data measure deforestation as Brazil does not measure reforestation. This reduces the potential of creating a fully specified model of forest-cover change associated with a forest transition, and my results will explain the downward trend in the forest transition curve.

There is no data available on reforestation or regeneration. The red dotted line in figure 4.1 represents the data available for Brazil. I have used the data in a descriptive way, in search for apparent relationships between variables related to forest-cover change over time.

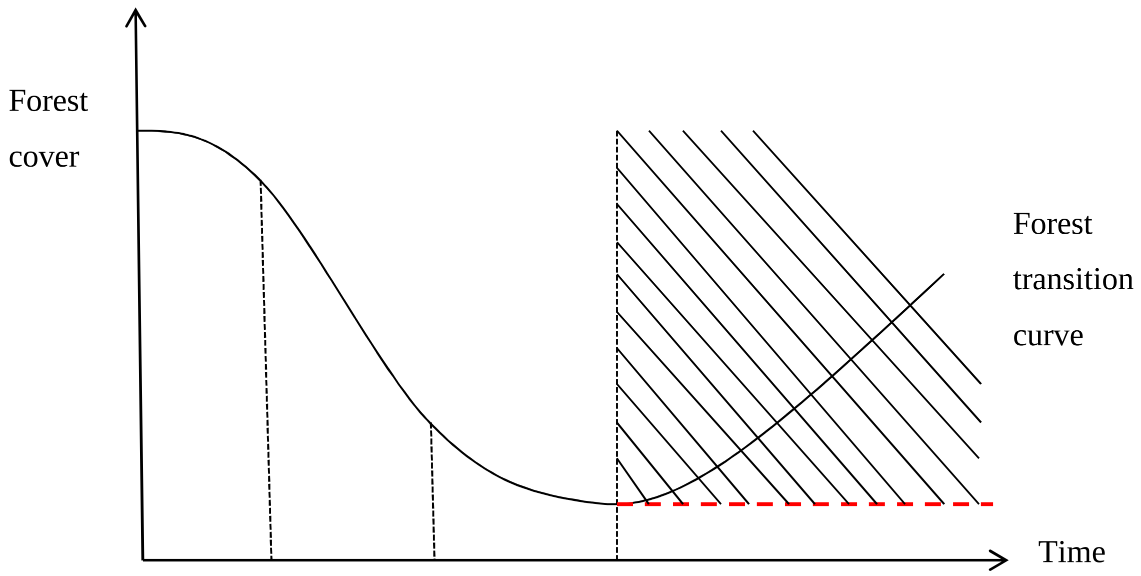

Figure 4.1. Forest transition curve and data limitations.

5 Methodology

This chapter intends to create a link between theory and empirical work, as well as clarify the methodological issues concerning the estimation of the forest transition curve. The chapter commences with specification of the applied econometric technique and methodological specifications for hypothesis testing. A review of the estimated models in this thesis is given, before the chapter concludes with a discussion of some pre-estimation issues that needs to be taken into consideration in the analysis.

5.1 Choice of estimation method

Due to the panel structure of my data set, the primary choice of estimation method for this analysis was between pooled ordinary least squares (POLS), Random Effect (RE) or Fixed Effect (FE).

Several tests were implemented in my data set to find the most appropriate method amongst the three in question. We know that main reason for collecting panel data is to allow for the unobserved effect to be correlated with the explanatory variables (Wooldridge, 2006). By using the pooled OLS method, there is a chance that unobservable variation will result in unequal expectation estimates (biased). The FE method controls for such unobservable variation, but is not appropriate in this analysis given that many of the included variables are time invariant. The pooled OLS method was therefore chosen for the analysis, but RE estimation results will be used for comparison and thus be reported in the appendix VI.

Comparing the two sets of estimates can help determine the nature of the biases caused by leaving the unobserved effect entirely in the error term (POLS) or partially in the error term (RE) (Wooldridge,2006). Even if the unobserved effect is uncorrelated with the explanatory variable in all periods, the pooled OLS standard errors and test statistics are generally invalid. I therefore report standard errors that are robust to arbitrary serial correlation (and heteroskedasticity) and use clustering for municipality.

5.1.1 Pooled Ordinary Least Squares

I will estimate the following model, using pooled OLS:

$$y_{mt} = \beta_0 + \beta_1 X_{1mt} + \beta_2 X_{2mt} + \cdots + \beta_k X_{kmt} + \varepsilon_{mt}$$

The dependent variable that is estimated in this thesis measures deforestation in a municipality *m* at time *t*. The constant term, β_0, is common for all municipalities, and X_{mt} is included explanatory variables. ε_{mt} is an unobservable random error or disturbance term which represents the stochastic context. This term captures unobserved effects that affect the dependent variable, and may include measurement errors in both the dependent and independent variables. The unknown parameters which I wish to estimate by pooled OLS is here represented by $\beta_1, \beta_2, \ldots, \beta_k$.

A number of assumptions for panel regression are needed for validity and consistency of OLS estimators. If these assumptions are met, it will ensure that this method provide efficient results.

(i) The model must be linear in parameters

Violation of this assumption results in specification errors, and means that erroneous explanatory variables are included. This is the case if we use the wrong functional form or have unstable parameters. This assumption is somewhat flexible, seeing that both dependent and explanatory variables can be arbitrary functions of underlying variables, for instance through the use of logarithms or squared variables.

(ii) The error term must have expectations equal to zero

Factors which are not explicitly included in the model should not affect the dependent variable systematically, $E(\varepsilon_{mt}) = 0$. This assumption does not offer any problems in practice, and will therefore not be discussed any further in this thesis.

(iii) Zero conditional mean

It is assumed that all included explanatory variables are exogenous, $E(\varepsilon_{mt} \mid X_{m1},\ldots,X_{mt}) = 0$. The error term is as such uncorrelated with the explanatory variables. If the error term varies with the explanatory variables, there is a systematic component included in the error term that initially should have been included in the model.

Exclusion of variables will result in biased estimates, and give the included variables too much explanatory power. Biased estimates occur when the average value of the error term is correlated with some of the explanatory variables (Wooldridge, 2009). The variables which are rightfully included in the model will report higher variance than it would if the model was correctly specified. The inclusion of variables that does not contribute to explaining the variance in the endogenous variable affects the OLS-estimators as the variance increases, and leaves estimates less efficient (Wooldridge, 2009). A t-test may be employed to the variables individually to check if we have included of too many explanatory variables, and also an F-test to see if the variables have simultaneous explanatory power.

(iv) No multicollinearity

The assumption of no multicollinearity, $Corr\ (X_{m1},X_{mj}) = 0$, means that none of the explanatory variables are constant or perfect linear combinations of other explanatory variables. A violation of this assumption does not affect the predictive power of a model as a whole, but means that multiple variables measure the same, making it challenging to identify each explanatory variables individual effect on the dependent variable. Correlation matrixes reported in Appendix III show that that this does not serve as a problem in my dataset.

The OLS estimators are consistent if the previously mentioned assumptions hold, $E(\hat{\beta}_j) = \beta_j$.

(v) Homoscedastic error terms

Variance of the error term is independent of the explanatory variables. In other words, $Var(\varepsilon_{mt}|X_{m1}, \dots, X_{mt}) = \sigma^2$. This assumption is necessary to make analyses and hypotheses as precise as possible. Heteroskedasticity lead to bias in$Var(\hat{\beta}_j)$, and therefore affect standard errors and test values. The relationship between σ^2 and X_{mt} determines whether the variance is under- or overestimated.

(vi) Normality of error terms

The last assumption that needs to be taken into account states that the error terms must be normally distributed. If this assumption is violated, it can lead to erroneous influence in tests.

5.2 Hypothesis testing

The main objective of this thesis is to assess whether there is a forest transition in Brazil. What this chapter is concerned with are the empirical tests for determining the feasibility of a forest transition, and for identifying and quantifying causality. The primary interest is in testing hypotheses of the form $H_0\colon \beta_j = 0$. As $\beta_j$measures the partial effect of x_j on the expected value of y, after controlling for all other explanatory variables, the null hypothesis states that given the other explanatory variables x_j has no partial effect on the expected value of y (Woolridge, 2006).

The statistical significance of a variable x_j is given by the size of the t-value, $t_{\hat{\beta}_j}$. Both economic and statistical significance of a variable is related to size and sign of $\hat{\beta}_j$. The t-statistic in testing $H_0\colon \beta_j = 0$ is defined by dividing the estimate on the corresponding standard deviation; $t_{\hat{\beta}_j} = \hat{\beta}_j \,/ se(\hat{\beta}_j)$. Thus, the t-value may indicate statistical significance either because the estimated value is high, or because the standard deviation of the estimated parameter is low. It is important to distinguish between these two types of significance in practice, especially when working with a large dataset such as in my case. The larger a sample is the more accurate is the estimated parameters. The standard deviations are often relatively small compared to the estimated coefficient value, and thus statistical significance is more easily obtained although the economic significance can be small (Wooldridge, 2006).

5.3 Specification of models employed

The model utilized in this thesis is purely explanatory, and is used to predict deforestation in the Brazilian Amazon at municipality level. By identifying the drivers of deforestation we can assess a municipality's or the whole country's stage on the forest transition curve. This section introduces the models which will be estimated in this thesis. I have estimated a set of five models, with an increasing number of variables that can be used to determine if we have evidence of a forest transition curve. These models are applied to one dataset with municipalities as units for period 2000-2009.

All of these five models are estimates in 3 separate ways. First we estimate the models with annual deforestation as the dependent variable. Then, the same models are estimated with change in deforestation between two periods. Finally, annual deforestation will be estimated at averaged level with state as unit.

1. Regression w/annual deforestation

$$Deforestation_{municipality} = f(Trend, Forestcover, \dots, Temperature)$$

2. Regression w/change in deforestation

$$Change\ in\ deforestation_{municipality} = f(Trend, Forestcover, \dots, Temperature)$$

3. Regression w/annual deforestation averaged by state

$$Deforestation_{state} = f(Trend, Forestcover, \dots, Temperature)$$

The approach with five models is justified by the fact that we are searching for apparent relationships between socio-economic and forest variables. First, simple correlation is investigated before more sophisticated models with control variables are employed. This is mainly to control the robustness of the simple correlation, and to see whether it also reveal causality. The FT relationship is also investigated at state level to check if there are common drivers on both scales, and whether the magnitude of evidence is stronger in either one. Three considerable steps will be examined. First, the gradients in the underlying environmental variables are analyzed, and then the response of GDP per capita. Finally, population density among other independent variables is included.

Table 5.1. Overview of models for predicting deforestation.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	***A priori* sign**
Trend variable	x	x	x	x	x	-
Forest cover	x		x	x	x	+
Forest cover squared	x		x	x	x	-
GDP per capita		x	x	x	x	+
GDP per capita squared		x	x	x	x	-
Population density				x	x	+
Municipality area (km2)				x	x	+/-
Remoteness				x	x	-
Road density				x	x	+
Water cover				x	x	+/-
Latitude					x	+
Longitude					x	+/-
Rainfall					x	+
Rainfall squared					x	-
Temperature					x	-

Model (1). The first model is fairly simple, and it is based on the forest transition logic. Here, only forest cover and a trend factor is included. It is expected that at early stages of forest transition deforestation will be high before the situation reverses at later stages. This can be explained by the quadratic relationship in forest cover, with a positive linear term and a negative quadratic term. The trend variable captures the tendency in deforestation over time, and is included in all models. This model is used for testing hypothesis 1 when annual deforestation is the left side variable, and hypothesis 3 when using change in deforestation.

Model (2). The second model may also help assessing changes in forest cover. Here, GDP per capita is used as a proxy for measuring stages of the forest transition. A positive sign is expected for the linear term, while the quadratic term is expected to be negative. Municipalities with higher GDP/cap have higher deforestation, all else equal. GDP per capita can also be seen as an adjustment factor which measures the development of a municipality.

The quadratic form is necessary to test if the forest transition theory holds, as it produce the turnaround point in the forest transition curve. A bell-shaped relationship is expected, but this may also be related to the environmental Kuznets curve, where the relationship between income and deforestation is upward sloping. This model is used to test hypothesis 2 and 4 for annual deforestation and change in deforestation respectively.

Model (3). The third model includes both forest cover and GDP per capita as explanatory variables, as well as the yearly trend. Models 1 thought to 3 produce turn around points for the forest transition curve, which tells us how high rate of forest cover or amount of GDP per capita is needed for the deforestation trend to be reversed.

Model (4). The fourth model attempts to include some drivers of deforestation such as population density, size of municipality area (km2), distance to capital, road density and water cover. They are all included in linear form, thus simply explaining an increase or decrease in deforestation.

Municipality area is a good control variable, but as I use forest variables as rates of municipality area, this effect should not be particularly large. *A priori* sign may therefore be ambiguous. A positive relationship may be expected as large municipalities most likely have a larger amount of forest and higher population density, thus making deforestation practices more advantageous. The relationship may also be negative, where large municipalities experience less deforestation. One possible explanation is that forests may be situated in more remote areas and as such be passively protected. Water cover is also included as a control variable, but the expected sign is ambiguous. Either a higher rate of water cover would limit deforestation as these areas have less forest, or a higher rate of water cover would increase deforestation as rivers provide transportation possibilities for forest extraction agents.

Model (5). Finally, the fifth model includes a comprehensive list of socio-economic and geographical variables that are commonly included in deforestation regression models. Latitude and longitude is often included in forest transition analyses, although no clear theory is stated. *A priori* expectation for latitude is positive, as explained in hypothesis 5, but longitude may acquire both signs. As for all the other models, the forest resource trend is assumed to have a uniform shape across municipalities. It is possible that this assumption does not hold, as municipalities may have a unique trend.

5.3.1 Functional form

The functional form of a model chosen for empirical analysis should be specified to satisfy some criteria. First of all it depends on the data available, because it is essential that the model is logically possible. Second, it should be consistent with theory and make good economic sense (Hendry et al. 1983). If the model should fail to satisfy these criteria, it will be subject to functional form misspecification. This problem occurs when a model has omitted functions of the explanatory variables (such as quadratics) or uses wrong functions of the dependent or explanatory variables (Wooldridge, 2006).

To know which functional form is most suitable for the variables, it is essential to get familiar with the data in hand. Histograms (represented in Appendix IV) capture the variation in the variables utilized in this thesis, and show that some are not normally distributed in their original form. A transformation to logarithmic values may be necessary to obtain consistent results in the analysis. We cannot generate logarithmic values of longitude, as it is defined as a negative number, and it is therefore not reported as a histogram. Variables which are expressed as a proportion, percent or rate can appear in either original or logarithmic form, although there is a tendency to use them in level forms. This is because any regression coefficient involving the original variable will have a percentage point change interpretation

(Woolridge, 2006).

The distribution of GDP per capita is skewed and not symmetric, meaning that a majority of the municipalities are situated at the poorer end of the income scale. While the maximum reported income was BRL 50.76 and the minimum was BRL 0.64, the mean for the 5746 reported observations was mere BRL 4.27. The problem may potentially be solved using logarithmic transformations, but when my analysis was performed with a log-log functional form, perfect correlation between quadratic variables appeared. The model dropped all quadratic variables which are essential in the analysis of a forest transition because they allow for movement and curvature of the curve. Although some variables are skewed, the analysis will include variables in their original form with quadratic terms.

The definition of forest variables has, as stated earlier, been criticized for not providing an accurate measure of actual quantity of forest in land cover research. The initial question was whether to use absolute or relative measures of the forest variables. It is possible to use an absolute measure, but it would make it difficult to compare results between municipalities as they differ in relevant characteristics such as land area. It is therefore preferable to use a relative measure, and forest variables measured as percent of land area have commonly been used in previous research. Another approach was also considered in the attempt of meeting the criticisms. All forest variables were generated as rates of original forest cover (accumulated deforestation + forest cover that exact year), in order to create more reliable data. The computed results revealed insignificant coefficients which were did not satisfy *a priori* expectations. Little or no evidence of a forest transition was found. After some trial and error with different definitions, the decision was made to use a relative measure where all forest variables are expressed as rates of municipality land area because it provides the most reliable results.

The goodness-of-fit measure could also be used as an attribute in the selection of functional form. The logarithmic and linear models cannot be directly compared as they don’t have the same dependent variable, but it is evident that the logarithmic model attains a much higher R-squared value. Nevertheless, the R-squared should not be given too much weight as it increases when number of explanatory variables increase. The choice of explanatory variables based on the size of R-squared may lead to nonsensical models and misleading conclusions (Woolridge, 2006).

5.3.2 Scatter diagrams

When we have defined the functional form, we can assess its feasibility by viewing simple scatter plots. We can plot dependent variables against the explanatory variables, and this may assist us in clarifying what types of trends and patterns are expected for theories to hold empirically.

Patterns and trends between variables included in model 3 are illustrated in figure 5.1. The first row shows the relationship between the dependent variable and the explanatory variables. It is clear from these figures that there is more to deforestation rates than just forest cover rates and level of economic development. It is also obvious that we cannot identify any clear outliers.

Through viewing the relationship between deforestation rates and the yearly trend, it is clear that deforestation rates have decreased during the period 2000-2009. There is no clear relationship between deforestation and forest cover rates, rather deforestation rates appear to be quite independent of forest cover rates.

It seems that high deforestation rates are more common in municipalities with low GDP per capita, and that deforestation rates approach zero at high income levels. The trend is as discussed in section 3.7 required to cross the x-axis to produce a forest transition.

The rest of the matrix points out possible correlations between the explanatory variables. A positive correlation is clear, especially between forest cover and GDP per capita. This issue will be investigated further in section 5.5. The brief assessment of the scatter plots neither reject nor accept the possibility of a quadratic relationship between deforestation rates and level of forest cover, and the possibility of a forest transition cannot be rejected. Extensive econometric analysis is required to find apparent evidence of the relationship.

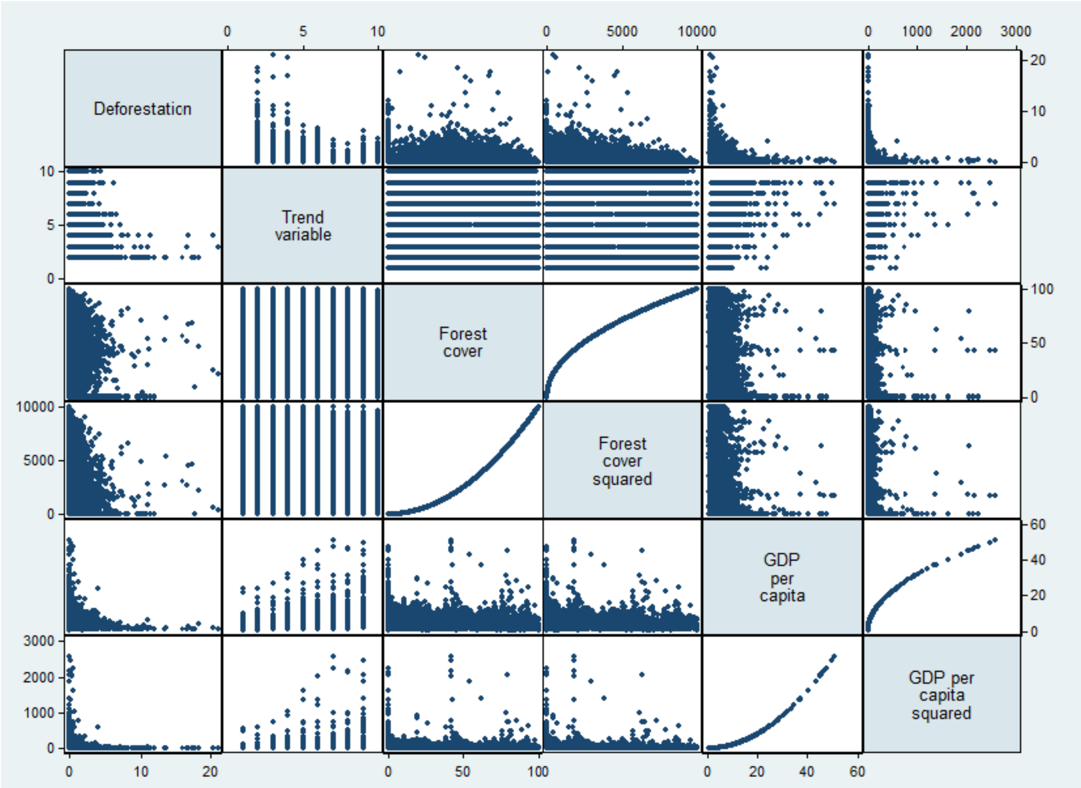

Figure 5.1. Scatter matrix of key variables utilized in the analysis.

5.4 Pre-estimation issues

Before I go through the actual analysis, it is important to review the OLS assumptions and test if they hold. I will now test if we have normality in error terms, heteroskedasticity, multicollinearity and endogeneity in the dataset. Finally, I will look into the possibility of predicting a forest transition in the Brazilian Amazon with only 10 years of data.

5.4.1 Non-normality of error terms

One assumption in the OLS is that the error term is normally distributed. To fully rely on estimation results computed, this assumption must be valid. The distribution of residuals can be revealed through a skewness-kurtosis test. The null hypothesis states that the data are normally distributed, and the alternate hypothesis is that the data are not normally distributed.

The test will report skewness of residuals, the degree to which a distribution is skewed towards one of the tails, which reflects the magnitude of outlier data and the degree of departure from symmetry of a distribution. A positively skewed distribution has a "tail" which is pulled left, while a negatively skewed distribution has a "tail" which is pulled to the right. Level of kurtosis, the thickness of the tails, is also reported. Kurtosis reflects the proportion of observations lying in the tails of the distribution. A high kurtosis report a sharp peak with longer and fatter tails, while low kurtosis has a more flat peak with shorter and thinner tails. A normal distribution has a zero skew and kurtosis equal to 3.

Table 5.2. Results from skewness-kurtosis tests.

Model	Skewness	Kurtosis
Model 1	0.0000	0.0000
Model 2	0.0000	0.0000
Model 3	0.0000	0.0000
Model 4	0.0000	0.0000
Model 5	0.0000	0.0000

From table 5.2 we find that the residuals are different from the theoretical normal distribution. The error terms are reported with zero skew and the kurtosis is low for all models. We find that the data utilized in these models does not provide normally distributed residuals, but the OLS estimates still remain BLUE. One apparent problem when residuals are not normally distributed is that they should not be used in any tests, such as t-tests, F-tests and chi-squared tests, which are derived from the normal distribution.

Residuals may be reported as not normally distributed for several reasons. The dependent variable and one or more explanatory variables may have the wrong functional form, or we may have omitted relevant variables. Correction of systematic errors as these may produce normally distributed residuals.

The observed residual may also be analyzed graphically, and they are presented in appendix V. A histogram may reveal symmetric, bell-shaped and thin-tailed graphs which indicate a normal distribution. Although the reported residuals are skewed and have wide shoulders, the residual skewing the result is fairly flat. For this reason, we can accept the null hypothesis and test-statistics are hence reliable as they do not overestimate the statistical significance of the parameters.

5.4.2 Heteroskedasticity

In the presence of heteroskedasticity the variance in the error term, given the explanatory variables, is not constant. This is a violation of the OLS assumptions, and can be tested for by a Breusch Pagan/Cook Weisberg’s test. If the test reports low p-values, the null hypothesis of homogenous residuals is rejected and the models are subject to heteroskedasticity.

The test revealed that the null-hypothesis of constant variance in the error term could be rejected for all models. The results are given in table 5.3.

Table 5.3. Results from the Breusch Pagan/Cook Weisberg's test.

Model	Chi2 (1)	Prob>Chi2
Model 1	2699.35	0.0000
Model 2	2187.27	0.0000
Model 3	2972.33	0.0000
Model 4	3821.29	0.0000
Model 5	4016.45	0.0000

To correct for the heteroskedasticity problem, clustered panel corrected standard error estimates are reported for all models. When computing the standard errors, it is assumed that the disturbances are, by default, heteroskedastic and simultaneously correlated across panels.

5.4.3 Multicollinearity

To attain valid and consistent estimates, no correlation among the independent variables is assumed for a multiple regression model. A correlation matrix can help me see if this is a problem in my dataset. The matrix (See Appendix III) reveals that multicollinearity does not pose as a particular problem in the data utilized in this thesis.

The variables which are included in both linear and quadratic form report correlation close to one, and should normally be corrected for in order to not affect the results. However, these variables are assumed to be highly correlated as they are generated from the same data, and hence both variables will be included in the model. The variable in normal form will test linear relationships between the dependent and independent variable, while the quadratic variable will allow for movement in the curve.

Municipality area (km2) is included in the different regression models as a right-hand side variable, and I expected it to be correlated with all forest variables as they are rates of land area. Nevertheless, the correlation matrix shows low correlation between the variables. All other variables report low correlation (<0.67) and are therefore not considered significantly high to not bring about any estimation problems.

5.4.4 Endogeneity

Endogeneity appears when there is a correlation between a parameter or variable and the error term. Endogeneity can arise as a result of including irrelevant variables, omitting relevant variables, measurement error, outliers and sample selection errors. Causality between the independent and dependent variables of a model leads to endogeneity (Wooldridge, 2006). To the extent where there are problems with endogeneity in this analysis, there is reason to believe that they are due to omitted variables. Although we can control for a number of variables that are related to the deforestation decision, there are still many variables we do not have access to and do not have opportunity to include in the estimation.

(i) Inclusion of irrelevant variables

When including an irrelevant explanatory variable or as such overspecifying the model, we get an endogeneity problem. The included variable will have no partial effect on the dependent variable, and the regression coefficient will be zero. This will not affect the unbiasedness of the OLS estimators, but it can have undesirable effects on the variances.

The decision of which variables to include is based on theory and previous empirical work. Although these variables have been included in previous literature or is used to theorize a forest transition, it is possible that their effects are particularly small or negligible.

(ii) Omission of relevant variables

If we exclude a relevant variable from the model, it results in an underspecified model. We may omit this variable because we don’t have a measure for it, but it may still affect the other explanatory variables and thus the dependent variable. The effect is captured in the error term, which makes it correlated with the explanatory variable. This case of endogeneity causes the OLS estimators to be biased.

As discussed previously, there may be many underlying factors affecting deforestation and a forest transition which might not be measureable. In addition, Brazil may not monitor or report the underlying causes for different reasons. In the theory chapter, policy and societal factors such as institutions, national economic politics and international politics have been discussed as influencing the deforestation decision. I have no quantifiable information about these variables, but it is evident that they may have an effect on the data utilized in the thesis.

(iii) Error in measurement

When estimating the deforestation model, it is important to take into account that there might be some measurement errors in the variables and that the collected variable does not truly affect economic behavior. Measurement error is defined as the difference between an observed variable and the variable that belongs in a multiple regression equation. It is only considered as an issue if the collected variable deviates from the variable which actually affects decisions by individuals, firms and so on. The noise will be captured both in the explanatory variable as well as the error term, and the OLS estimates will be consistent under some assumptions and inconsistent under others.

As data for this analysis is collected from public records, there is little reason to believe that there are major problems with measurement error in this data set. Alternatively, measurement errors have occurred in preparation of the data set, but the descriptive studies have not shown any signs that this is the case. Measurement errors are also not considered a problem unless it is systematic.

(iv) Detecting potential outliers

Even though this thesis builds on a relatively large dataset, OLS estimates are sensitive to the inclusion of one or a few outliers, as they might change the estimates significantly. The dataset utilized for analysis have been trimmed, as some observations were considered to be unreliable. A scatterplot of the different variables revealed that some municipalities reported very high levels of deforestation. After some data manipulation I found that 41 municipalities reported deforestation levels over 80% in 2001. It is suspected that these municipalities have reported accumulated deforestation until 2001, due to shortcomings in monitoring and reporting, and these observations were therefore eliminated from the analysis as they were seen to be unreliable.

5.4.5 Predictions with only 10 years of data

Forest transition is a long term theory, but new research have found that this relationship can be found in relatively short term, that is decades rather than centuries (Rudel et al., 2005). As Brazil only has deforestation data and no monitoring of reforestation, this analysis is limited to measure the downward trend in the forest transition curve. With only 10 years of data, I expect to find some evidence supporting the theory although I will not be able to predict the evolvement of a full forest transition in the Brazilian Amazon.

I expect to find a decrease in deforestation rates from year 2000 as the state retreated from rural areas, and settlement schemes were scaled down. New highways have not been constructed to open up new areas in the undisturbed Brazilian Amazon. Although the state has reduced impact on deforestation decisions, other illegal activities such as logging might outweigh this effect.

With hypothesis 1 and 2 I use cross-sectional differences to see if the pattern is in line with the forest transition. Through panel analysis I investigate how municipalities change over the course of time. It might be through changes in variables, such as forest cover and GDP per capita, or through differences in variables between municipalities. Hypothesis 3 and 4 examine trends within the period (2000-2009). A variable measuring the change in forest cover between two periods is generated to see whether the estimated results from hypothesis 1 and 2 are robust and reveal similar patterns within the period.

6 Empirical results

This chapter gives the empirical evidence of a forest transition curve in Brazil. The chapter starts with descriptive statistics of variables utilized in the analysis and then moves on to review the different regression models estimated at municipality level. Regression results are also reported at the state level to see if we find evidence of a forest transition on a larger scale. Results from the tested hypotheses are presented before the chapter concludes with a joint discussion of the empirical results for both models and hypotheses.

6.1 Descriptive statistics

This analysis relies on data for 783 municipalities from 2000 through to 2009, and descriptive statistics for the variables are presented in table 6.1 below:

Table 6.1. Descriptive statistics of main variables used in the analysis.

Variable	N	Mean	Std. Dev.	Min	Max
Deforestation rate (% of municipality area)	7006	0.54	1.28	0	20.95
Change in deforestation	6220	-0.06	36.81	-356.47	100
Trend variable	7789	5.5	2.87	1	10
Forest cover rate (% of municipality area)	7789	31.60	33.05	0	100
Forest cover rate squared (% of municipality area)	7789	2090.94	3025.29	0	10000
GDP per capita	5746	4.28	3.92	0.64	50.77
GDP per capita squared	5746	33.67	116.92	0.41	2577.37
Population density	7766	21.76	117.98	0.07	2777.76
Municipality area (km2)	7789	6593.04	13835.24	65	159701
Remoteness	7649	308.15	227.87	0	1476.28
Road density	7449	0.01	0.02	0	0.16
Water cover rate (% of municipality area)	7789	2.33	5.74	0	44.23
Latitude	7789	-6.90	4.75	-17.83	4.60
Longitude	7789	-52.06	7.021	-72.89	-42.11
Rainfall	6262	162.57	35.47	90.6	272.32
Rainfall squared	6262	27685.54	12281.54	8208.36	74157.69
Temperature	6262	26.18	0.86	22.4	27.55

Before looking at econometric results, it might be helpful to know the data better. The graph presented below illustrates yearly deforestation rates as a percentage of municipality area. We can see that the trend has declined throughout the 9 years in the analysis.

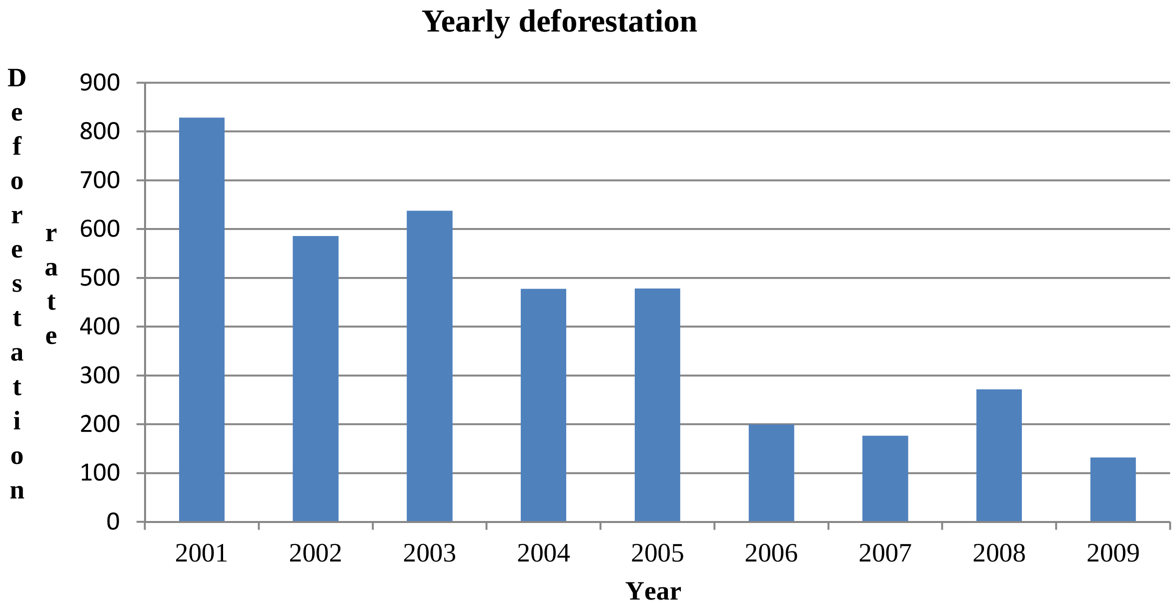

Figure 6.1. Yearly deforestation in the Brazilian Amazon (INPE, 2011).

6.2 Regression results

I have pooled the data from 2000 to 2009 and estimated pooled OLS regressions, with clustered panel corrected standard errors. I have estimated 5 models to illustrate how data on deforestation and forest cover together with socio-economic and bio-physical variables can be used to analyze the forest transition in the Brazilian Amazon. Models using annual deforestation rate as dependent variable are estimated first, before change in deforestation is employed as the dependent variable. Finally, annual deforestation models are estimated at state level.

6.2.1 Annual deforestation

The empirical analysis of annual deforestation reports estimated results in a sequential order as describes earlier in table 5.1. From looking at overall significance of variables and models, we understand that the relationship between annual deforestation and explanatory variables is not straight forward. The models report fairly low goodness-of-fit or explanatory power, although R^2 -values below 20 % are not uncommon in cross-sectional analysis. The Chi^2-values are high, and the models in general exhibit many significant variables.

Table 6.2. Determinants of annual deforestation rates.

	(1)	(2)	(3)	(4)	(5)
Trend variable	-0.12194***	-0.10735***	-0.11042***	-0.11443***	-0.12261***
	(0.00769)	(0.00876)	(0.00835)	(0.00857)	(0.00949)
Forest cover	0.04173***		0.04225***	0.04818***	0.04743***
	(0.00230)		(0.00233)	(0.00256)	(0.00311)
Forest cover squared	-0.00046***		-0.00047***	-0.00051***	-0.00051***
	(0.00002)		(0.00002)	(0.00003)	(0.00003)
GDP per capita		-0.01660**	-0.03191***	-0.03304***	-0.04193***
		(0.00844)	(0.00851)	(0.00919)	(0.01138)
GDP per capita squared		0.00031	0.00062**	0.00075**	0.00118**
		(0.00022)	(0.00025)	(0.00028)	(0.00036)
Population density				0.00067**	0.00043
				(0.00026)	(0.00027)
Municipality area (km2)				-0.00179**	-0.00209**
				(0.00067)	(0.00073)
Remoteness				-0.00014**	0.00001
				(0.00007)	(0.00007)
Road density				7.20121***	9.40473***
				(1.59541)	(2.01949)
Water cover				-0.01928***	-0.02215***
				(0.00401)	(0.00559)
Latitude					-0.02773***
					(0.00697)
Longitude					0.01443***
					(0.00421)
Rainfall					0.01471**
					(0.00598)
Rainfall squared					-0.00002
					(0.00002)
Temperature					-0.03342
					(0.04036)
Constant	0.93159***	1.22727***	0.98813***	0.91666***	0.68284
	(0.04878)	(0.05222)	(0.05252)	(0.06900)	(1.00426)
Turnaround point (FC)	44.8952		44.7945	46.9766	46.1867
Turnaround point (BRL)		26.4505	25.7721	22.0175	17.8374
Wald Chi Square values	719.596	213.557	731.494	711.119	765.567
R-squared	0.121	0.038	0.123	0.149	0.175
Number of observations	5103	5103	5103	4943	3964

****, **, * indicate significance levels at 1%, 5%, 10% respectively. Figures in parentheses are panel corrected standard errors. The number of observations varies due to missing data for some variables. FC=Forest cover. BRL= Brazilian Real.*

Hypotheses 1 and 2 are the main tests of a forest transition in this thesis, where high forest cover and economic development are expected to increase deforestation. If the computed estimates provide the expected signs, the analysis of annual deforestation will provide evidence of a forest transition.

As we can see from the results in table 6.2, the trend variable is negative and significant at a 1% level in all models. This is in accordance with *a priori* hypothesis from looking at Figure 6.1. Forest cover and forest cover squared are also significant at a 1 percent level. There is a quadratic relationship with the forest stock, where a positive linear term and a negative quadratic term is, as discussed in the theory chapter, a sign of a forest transition.

Compared to model (1), model (2) included a trend variable but does not include forest cover. We can see that the R^2-value drops to 3 percent, and both the linear and quadratic coefficients of the GDP variables exhibit opposite signs of what we would expect based on the forest transition or EKC. GDP per capita-squared is also not significant. The negative linear sign indicate that poor municipalities have higher deforestation, all else equal. An increase in GDP per capita will reduce deforestation rates.

All variables in model (3) are statistically significant. The quadratic relationship with forest cover shows evidence of the forest transition, which is also the case for models (4) and (5). GDP per capita (both linear and quadratic coefficients) exhibit opposite sign of what is expected for all models, but is now statistically significant.

Model (4) includes several other potential drivers of deforestation. As well as the covariates included in model (3), demographic and socio-economic factors discussed in literature as important factors of deforestation are accounted for. All new variables are significant at either a 1 or 5 percent level, and have the signs in line with *a priori* expectations. The covariates included in models (1) through to (3) are fairly stable. Road density reports a large covariate, where a higher amount of paved roads leads to higher deforestation rates. Nevertheless, this covariate also has a large standard error.

The last model reports covariates for all data utilized in this thesis. The inclusion of more variables increases the goodness-of-fit, but we can see that population density and the remoteness variable measuring distance to capital are no longer significant. The remoteness variable also changes sign from negative to positive. The quadratic relationship with rainfall presents us with a positive linear term and negative quadratic term in line with *a priori* expectations. Rainfall-squared is not significant, and neither is temperature although they both have expected signs.

We can see that the R^2-value increase with the number of variables, but I still rely on it as a goodness-of-fit measure. The chi^2-values stay high throughout all models, and assuming that the model specifications are correct, the test indicates significance for the individual variables and the whole model based on the chi^2 distribution.

A discussion of turnaround points is needed in order to assess the possibility of a forest transition. Turnaround points for forest cover are reported from 44.7 to 46.9 percent of municipality area for the respective models, which is within the data range. The mean is 31.5 meaning that a forest transition is attainable for forest cover, and thus we get the bended curves that economists like!

The turnaround point is also reported for GDP per capita in BRL. Even though the turnaround points reported (17.8-26.4) are within the data range, there is no evidence of a forest transition when using GDP as the indicator as the coefficients exhibit the wrong sign according to *a priori* expectations based on a forest transition hypothesis.

6.2.2 Change in deforestation

The following estimation results are included as a robustness test to the previously reported results for annual deforestation, and are reported in Table 6.3. Determinants for both annual deforestation and change in deforestation/forest cover between two periods will be compared to see if the results are consistent and reliable.

Hypothesis 3 and 4 indicate that high forest cover and economic growth will accelerate deforestation rates. A positive relationship is expected, and will provide evidence of a forest transition within the period.

The explanatory power of the different models is varying and smaller than previous results. Model (2) has according to the reported R^2-value no explanatory power, and for model (4) the values has decreased from 14 to 5 percent. Also Chi^2-values are lower, especially for model (2). Although it has decreased from a value of 213 to 6.9, it is still significant at a 10 percent level.

Table 6.3. Determinants of change in deforestation rates.

	(1)	(2)	(3)	(4)	(5)
Trend variable	0.27963	-0.08712	0.22466	-0.42584*	-0.07473
	(0.22353)	(0.26645)	(0.25045)	(0.23356)	(0.22055)
Forest cover	-0.15965**		-0.16578**	0.41086***	0.44086***
	(0.08043)		(0.07883)	(0.07649)	(0.07316)
Forest cover squared	0.00511***		0.00517***	-0.00307***	-0.00147**
	(0.00078)		(0.00076)	(0.00070)	(0.00067)
GDP per capita		-0.60547**	-0.03669	1.00079***	0.85950**
		(0.29359)	(0.28194)	(0.28115)	(0.39663)
GDP per capita squared		0.02316**	0.01006	-0.01624*	-0.01650
		(0.00979)	(0.00986)	(0.00980)	(0.01804)
Population density				0.04258***	0.05773***
				(0.01247)	(0.01549)
Municipality area (km2)				-0.00012***	-0.00007***
				(0.00002)	(0.00001)
Remoteness				0.01046***	-0.00033
				(0.00170)	(0.00173)
Road density				-317.6225***	-559.39867***
				(88.95687)	(112.00767)
Water cover				-0.20305**	0.23825**
				(0.07713)	(0.10551)
Latitude					-0.79731***
					(0.19154)
Longitude					0.47403***
					(0.08688)
Rainfall					-1.20031***
					(0.15351)
Rainfall squared					0.00277***
					(0.00044)
Temperature					-3.70600**
					(1.25639)
Constant	-10.32316***	1.79011	-10.13982***	-14.27785***	221.80617***
	(2.05110)	(1.51843)	(2.29258)	(2.62933)	(35.97117)
Turnaround point (FC)	15.6290		16.0303	66.8065	149.581
Turnaround point (BRL)		13.0709	1.82329	30.8097	26.0408
Wald Chi Square values	355.256***	6.960*	360.003***	161.202***	312.878***
R-squared	0.091	0.001	0.092	0.056	0.179
Number of observations	4433	4433	4433	4253	3384

****, **, * indicate significance levels at 1%, 5%, 10% respectively. Figures in parentheses are panel corrected standard errors. The number of observations varies due to missing data for some variables.* ***.*** *FC=Forest cover. BRL= Brazilian Real.*

The models do not have as many significant variables compared to the annual deforestation analysis. We can see that the yearly trend variable switches between positive and negative signs, and that it’s only significant at a 10 percent level with expected sign for model (4).

The quadratic relationship with forest cover show signs of a forest transition for models (4) and (5), and the variables are significant at a 1 and 5 percent level. The linear and quadratic terms report opposite signs relatively to what is expected for models (1) and (3), but are still significant at 1 and 5 percent level. These models predict that a high level of forest cover leads to low deforestation rates.

The same story can be told for GDP per capita. There is inconsistency in reported signs, and in model (3) neither terms are significant. In models (4) and (5) the signs of the linear and quadratic terms satisfy the *a priori* expectations, and both terms are significant in model (4). According to theory, this is evidence of a forest transition.

Remoteness also changes signs in these analyses, where a significant positive value is reported in model (4). This is not in line with theory since greater distance to the state capital is supposed to decrease the level of deforestation. The expected “correct” sign is reported in model (5), but it is not significant.

According to theory, increased road density in a municipality leads to increased clearing of land areas. Road density is in both model (4) and (5) have a negative coefficient significant at the 1 percent level, indicating that the more kilometers of paved road a municipality has the less deforestation it experiences.

The covariate for water cover changes from negative to positive between models (4) and (5). *A priori* expectation was ambiguous, and a negative estimate implies that the greater degree of water cover a municipality contains, the less forest cover and accordingly deforestation it has. A positive coefficient may reflect rivers being used for transportation, making remote areas more available, and thus increase deforestation. Even though the effect is uncertain, both covariates are significant at 5 percent level.

The quadratic relationship with rainfall also report opposite signs for the covariates from what is expected, and they are both significant at 1 percent level. Temperature reports a covariate in line with expectations from literature, and is significant at 5 percent significance level.

Hypotheses 3 and 4 are the main reasons why this robustness check is performed, but since these hypotheses do not address any quadratic relationship between change in deforestation and forest cover or GDP per capita the models could have been performed without a quadratic term. The simple relationship is expected to be positive, but since the quadratic term is included it is important to assess the turnaround points for forest cover and GDP per capita.

There is no clear consistency on the values both forest cover and GDP per capita will have when the turnaround occurs. The range for forest cover expands from 15.6 to 149.5 which is clearly outside the data range. The turnaround point calculated in BRL is relatively more stable, but is for some reason very low in model (3).

There is a substantial difference in both signs and significance levels between the two attempts of predicting drivers of deforestation. Many of the quadratic relationships report changing signs, indicating that the results are unstable. The fact that many variables produce opposite signs from what is expected and from what is found in the analysis of annual deforestation creates some doubt of reliability of the computed results in the analysis of change in deforestation.

6.2.3 Averages by state – Forest transition on a higher scale

The analysis of annual deforestation is now repeated, just at state level, and is reported in table 6.4. I want to investigate whether the results are sensitive to the level of geographic aggregation of the observations. This analysis consider hypothesis 6 which states that evidence of a forest transition is stronger at state level.

The five models are estimated using state level data. We have data for 9 states over a period of 10 years, which should leave us with 90 observations. Deforestation rates in 2001 and GDP per capita in 2009 is missing for all states. One of the 9 states, Mato Grosso, does not provide data on GDP per capita at all. As 26 observations are eliminated, the analysis is performed with 64 observations. However, this to some extent reflects the reduced degrees of freedom as the number of observations have dropped to 64.

With only 64 observations, it is apprehensive to include too many variables. A rule of thumb is that the relationship between the number of observations and the number of explanatory variables should be 14. As the number of variables approaches the number of observations, many coefficients will become significant and the explanatory power will move towards 1 (perfect explanatory power) since the degrees of freedom approach zero. Thus, I should not include more than 4 or 5 explanatory variables in my models.

Table 6.4. Determinant of annual deforestation w/averages by state.

	(1)	(2)	(3)	(4)	(5)
Trend variable	-0.11905***	-0.04928	-0.07797**	-0.16488**	-0.01546
	(0.02355)	(0.06302)	(0.02694)	(0.05501)	(0.05509)
Forest cover	0.04329***		0.05900***	0.03688**	0.00619
	(0.01046)		(0.01206)	(0.01404)	(0.03360)
Forest cover squared	-0.0005***		-0.0006***	-0.00034**	-0.00015
	(0.00011)		(0.00013)	(0.00015)	(0.00029)
GDP per capita		0.17060	-0.09152	0.16860	-0.14496
		(0.12061)	(0.07131)	(0.16451)	(0.15422)
GDP per capita squared		-0.01499*	0.00094	-0.00490	0.00340
		(0.00865)	(0.00491)	(0.00560)	(0.00516)
Population density				0.02087**	-0.06499**
				(0.00707)	(0.03269)
Municipality area (km2)				-0.00001	0.00518***
				(0.00001)	(0.00107)
Remoteness				0.00245***	-0.16540***
				(0.00051)	(0.03797)
Road density				14.58675	2393.08***
				(18.22250)	(412.794)
Water cover				-0.09858**	-9.79164***
				(0.03411)	(1.93973)
Latitude					-7.87903***
					(1.66777)
Longitude					2.27060***
					(0.38868)
Rainfall					0.76872***
					(0.20715)
Rainfall squared					0.00040
					(0.00082)
Temperature					25.3883***
					(6.59909)
Constant	0.85666***	0.61365	0.93263***	-0.64395	-718.609***
	(0.17838)	(0.46272)	(0.21858)	(0.66402)	(169.264)
Turnaround point (FC)	44.7608		44.6732	87.3066	11.4543
Turnaround point (BRL)		6.88169	13.3719	15.3836	4.98713
Wald Chi Square values	41.136***	8.297**	44.657***	166.751***	428.069***
R-squared	0.346	0.080	0.401	0.716	0.846
Number of observations	64	64	64	64	64

****, **, * indicate significance levels at 1%, 5%, 10% respectively. Figures in parentheses are panel corrected standard errors. The number of observations varies due to missing data for some variables. FC=forest cover. BRL= Brazilian Real.*

When looking at the estimation results, the first obvious difference on state level compared to municipality level is the high explanatory power the models has. The R^2-value has increased substantially for all models except for one, model (2). The same accounts for the Chi^2-values, and although it is relatively low for model (2) it is still significant at a 5 percent level. The inclusion of more explanatory variables in models (4) and (5) increases the goodness-of-fit of the model to incredible 86 percent. Even though the models perceivably have good explanatory power, they suffer from changing and unexpected signs and non-significance.

Both have negative constants, which make no sense economically although it's significant at a 1 percent level in model (5). If models (4) and (5) were to be included in the analysis, strong reservations have to be taken into account. As concluded earlier, the high explanatory power is an artifact of the reduced degrees of freedom and less explanatory variables should be included in the analysis. Thus, the estimation results computed for models (4) and (5) are excluded from the analysis.

Models (1) through to (3) are seen as reliable, and model (1) appears to be having good explanatory power as well as all the variables are significant at a 1 percent level and the expected signs. There is evidence of a bell-shaped forest transition relationship between level of forest cover and deforestation. Model (2) appears to be a poor fit in determining annual deforestation, as it mostly consists of insignificant variables in addition to GDP per capita being reported with opposite signs from what is expected from theory. The signs change to the expected in model (3), but they are still insignificant meaning that they have no individual effect on deforestation and other variables therefore have more explanatory power in these models. Although the constant is positive, it is not significant and does not contribute in explaining drivers of annual deforestation at the state level.

Models (1) and (3) report approximately the same turnaround point for forest cover rate. When the rate of forest cover reaches 44.6 or 44.7, the trend will be reversed. Deforestation rates will become negative and forest cover rates will increase, giving rise to the forest. The turnaround points vary a bit more when measured in BRL. For model (2) it's at BRL 6.8 and for model (3) it's at BRL 13.3.

Although the remaining three models suffer from varying signs and some individual variables are insignificant, the state level models in general provide a higher explanatory power compared to estimation results at municipality level. This particular analysis addresses Perz (2007) criticism of the forest transition theory, and hypothesis 6 is directly related to these estimation results.

6.3 Testing of the hypotheses

Hypothesis 1. *High forest cover rate leads to high deforestation rate.*

Model (1) in table 6.2 investigates the forest transition relationship between forest cover and deforestation at municipality level. The positive linear coefficient indicates that there is a positive partial effect between forest cover rates and deforestation rates. At high levels of forest cover municipalities will experience greater rates of deforestation, and this will situate municipalities with high forest cover to the left of the turnaround point in the forest transition curve.

The linear and quadratic term are significant at a 1 percent level throughout all 5 models, meaning that inclusion of more explanatory variables does not alter the evidence of a forest transition. The results fit well with the forest transition theory, and thus the hypothesis cannot be rejected.

Hypothesis 2. *Low GDP per capita leads to high deforestation rate.*

From table 6.2 we can see that the quadratic relationship with GDP per capita is significant in models (3) through to (5). All models report a negative linear term and positive quadratic term, which is the opposite of what is expected from theory. There is a negative partial correlation between income and deforestation, which implies that poorer municipalities deforest more. One possible explanation of this trend is that municipalities at the early stages of the forest transition curve are the poorest and therefore cultivate more agriculture and other livestock operations. This leads to clearing of land areas and contribute to higher deforestation rates.

Although we find a u-shaped relationship and the coefficient signs are not in line with forest transition theory, results still show clear evidence that income affects deforestation rates. Nevertheless, the hypothesis has to be rejected.

Hypothesis 3. *High forest cover rate leads to acceleration in the deforestation rate.*

This hypothesis, as stated earlier, is only included to examine the consistency of annual deforestation estimation results. Models (4) and (5) in table 6.3 provide evidence of a forest transition relationship between forest cover and change in forest cover between two periods. The variables are significant, and therefore have individual explanatory power. The variables in models (1) and (3) are also significant, but provide opposite signs compared to what is expected.

The hypothesis cannot be rejected from models (4) and (5), and they capture an accelerating trend in deforestation rates at first before it starts to decelerate.

Hypothesis 4. *Low GDP per capita leads to acceleration in the deforestation rate.*

The quadratic relationship between GDP per capita and change in deforestation rates in table 6.3 reveal inconsistency compared to table 6.2 which reports estimation results for the quadratic relationship between GDP per capita and annual deforestation. Here, model (4) actually provides significant evidence of a forest transition with a positive linear term and a negative quadratic term. According to theory, this model predicts that richer municipalities deforest more. A possible explanation may be that land cover is exploited due to increased infrastructure and development of commercial activities. Also here, the trend in deforestation rates is accelerating at first before it starts to decelerate.

The hypothesis is rejected for all models except for model (4).

Hypothesis 5. *Effect of socio-economic variables on deforestation rates.*

(i) Population density

Population density is included in models (4) and (5) in both table 6.2 and 6.3. There is a clear positive partial correlation between population densities in model (4) for annual deforestation, as well for both models explaining change in deforestation. Municipalities with higher population density experience a demographic pressure leading to increased deforestation, which is in accordance with Malthusian theory. The pressure on forest resources through increased production demand becomes more intensive as population grows, and this leads to higher rates of land clearing. The hypothesis cannot be rejected.

(ii) Remoteness

In the determination of annual deforestation we see that a municipality's distance to the state capital creates a negative partial correlation. Model (4) in table 6.2 indicates that the further away a municipality is from the state capital, the less deforestation it experiences. In addition, the model forecast that municipalities close to the state capital are exposed to forest clearing for different reasons.

The hypothesis is rejected for the determination of change in deforestation due to unexpected signs and insignificant values.

(iii) Road density

Positive partial correlation is found for road density and annual deforestation in table 6.2. Municipalities with a higher number of kilometers of paved roads relative to its area report higher deforestation rates. Paving of roads consequently leads to exhaustion of huge forest areas, and municipalities may come to experience devastating ripple effects such as forest fires. Increased erosion and waterway sedimentation may worsen the situation.

The hypothesis cannot be rejected in the determination of annual deforestation as there is a positive causal effect between paved roads and the accelerating clearing of forest. High road density makes the municipality more vulnerable to deforestation activities.

The hypothesis is rejected in the determination of change in deforestation as the variable report opposite sign of what is expected, although it is significant in both models.

(iv) Latitude

Latitude is included in model (5), and both tables 6.2 and 6.3 provide a clear negative partial correlation with deforestation and change in deforestation. Municipalities at higher latitude (greater distance from equator) experience lower deforestation rates. The closer a municipality is to equator, the higher is deforestation rates. This is the opposite of expected, but latitude is still picking up some of the spatial correlation of the data. Estimation results are unexpected as deforestation mostly is concentrated in the higher latitudes (Southern border of the Amazon), but based on these results the hypothesis is rejected.

(v) Rain

This hypothesis is rejected as neither estimation attempts produce significant estimates with expected signs.

(vi) Temperature

The relationship between temperature and change in deforestation reveal a negative partial correlation in table 6.3. One explanation may be that change in deforestation rates are indirectly affected by temperature through human resources in forestry and agriculture, and thus increased temperature makes it more difficult for workers to clear land areas. There is no literature supporting this hypothesis, and as the change in temperature between municipalities is not much (1-2 degrees per year average) this variable is probably picking up spatial correlation. Nevertheless, the estimates predicted that higher temperatures lead to decreased deforestation rates, and the hypothesis cannot be rejected.

Hypothesis 6. *Evidence of a forest transition from forest cover is stronger at state-level.*

The quadratic relationship with forest cover provides evidence of a forest transition trend in models (1), (3) and (4) in table 6.4. As discussed earlier, model (4) is excluded from the analysis due to limited degrees of freedom. The remaining models, (1) and (3), are reliable and predict a bell-shaped curve for deforestation and forest cover at state level. All variables are significant at a 5 percent level or better.

It is more reasonable to expect a forest transition at the higher scales as there is greater variation in the data at state level compared to municipality level. This will allow us to assess larger areas, making comparison of land cover changes easier. Forest transition analyses at higher levels might reveal that some municipalities deforest completely, while others conserve most of their forest. As this thesis does not have data on reforestation or regeneration, these estimation results only show whether deforestation rates have changed between municipalities in the same state. Analysis at state-level therefore makes it easier to give evidence of a forest transition from measuring rates of forest cover in larger areas.

With high explanatory power, 34 to 40 percent, deforestation is at state level clearly affected by the level of forest cover. Comparing the goodness-of-fit measure such as R^2- and Chi^2-values at state level with those computes at municipality level, it is clear that the results are sensitive to geographic aggregation and that the effect is stronger at the state level.

6.4 Discussion

Several interesting observations can be made from the computed estimation results. The yearly trend captures a decrease in deforestation over time, indicating that Brazil may be heading towards a forest transition in the future in the sense that forest cover will stabilize. In both theory and previous research, there is no clear consensus about the driving forces behind deforestation. The forest transition relationship is an empirical regularity, and the variables in this analysis have proven its relevance in assessing a possible FT. Most explanatory variables are significant and truly believed to affect forest cover change.

For most models, we find a bell-shaped relationship (positive linear term and negative quadratic term) between deforestation and forest cover rates, which is in line with what one would expect from forest transition theory. The empirical evidence of a forest transition between the two variables, where deforested areas eventually will begin to reforest, is rather strong in this analysis. The notion of forest transition has received critique by Perz (2007), who emphasize the importance of addressing different scales. Perz argues that theory must provide more guidance in relation to determination of unit of observation, as it is an especially important decision that may alter results. I have addressed this critique by estimating annual deforestation at both municipality and state level, but cannot address the authors other critique about how there may be different drivers of deforestation on different scales. This is due to lack of observations. My results support the criticism concerning scale, as the evidence of a forest transition from forest cover is stronger at a higher level.

The most reliable estimation results indicate that higher deforestation is associated with lower incomes in Brazil, meaning that poor municipalities clear more land. The estimates revealed a u-shaped relationship, which is not in line with expectations derived from neither theory nor previous research. Mather et al. (1999) found economic development to be correlated with deforestation levels in several European countries in the long-term and Rudel (1998) found evidence of a forest transition in the shorter term as economic development leads to forest transitions. Simple correlation analysis shows a negative relationship between GDP per capita and deforestation.

The determination of drivers of a forest transition in Brazil may be related to the economic development- and forest scarcity path. Economic development in a country creates new and better paid jobs in non-farm sectors which makes farmers leave the land. The reduced agricultural activity leads to less deforestation. This is not consistent with the estimation results computed in this thesis, which indicate that economic development decrease deforestation before reversing the trend. This is unexpected as history states that deforestation in the Brazilian amazon is not primarily driven by poverty, but by the fact that the major agents of deforestation in the Amazon are capital intensive activities such as livestock and soy bean production.

Brazil may on the other hand follow the forest scarcity path, as we find evidence of a forest transition with forest cover. The scarcity of forests creates awareness among the population and policymakers as deforestation rates increase. Governmental regulation can directly reduce deforestation, either through the creation of protected areas or through adopting the controversial forest code into law. As it currently has no legal enforcement, there is no reason to believe that it affects my results. Even though we don’t know when the transition will occur, we know that Brazil eventually will follow the forest scarcity path with tree planting and forest recovery. I cannot provide evidence for why the transition occurs, but either participation in the REDD program, the forest code or other governmental policies have reduced deforestation in Brazil.

A forest transition in Brazil is probably not just affected by individual effects, but also the variables interaction with eachother. Simple correlation analysis can provide understanding to land cover dynamics and as such deforestation rates in Brazil. According to theory, the more remote a municiality is from the commercial centre (here the capital Brazilia) the less exploitation and consequently deforestation the municipality will experience. It is interesting to investigate the relationship between road density and remoteness as it from logical reasoning is expected that municipalities closer to the state capital have more paved roads and consequently higher deforestation rates. From appendix III we can see that the correlation matrix report a significant negative relationship (-0.1483***) between the two, meaning that the further away a municipality is from the capital the less roads are paved. The lower the amount of roads that are paved, the less is deforestation in that area.

We can investigate the role of road paving even further, especially the relationship between road density and population density. It would be reasonable to assume that municipalities with more paved roads would attract more people, and the increased population density would lead to increased deforestation. The correlation matrix report a significant positive relationship (0.0213*) between the two, although this effect is not as strong as the one between road density and remoteness.

Mather et al (1998) found that the positive relationship between population and forest cover has been reversed throughout the past two centuries and the conclusion is supported by Pfaff (2000) who found that population cannot be used to explain changes in land cover. Population density is strongly affecting deforestation rates in this analysis. An interesting relationship in terms of deforestation worth examining is that between population density and distance to capital. From the background chapter we know that the commercial center is situated around the state capitals. From this line of reasoning, it is assumed that the population density is higher the closer a municipality is situated to the state capital as it provides both access to goods and labor markets. The correlation matrix reveal a negative relationship between the two (-0.1473***), confirming that municipalities closer to the state capital experience higher population density. Nevertheless, we see that both the population density and remoteness variable change signs in for example model (3) in table 6.2. A possible explanation for this may be that some of the effect from this relationship is captured in the longitude and latitude variables.

It is important to acknowledge that even though variables are correlated, it does not necessarily imply causality. Results computed in this thesis both confirm findings in previous research and differ from it. Results may differ as this thesis utilizes different data, and evaluate forest transition at national level rather than international level. The theory has also been criticized as different factors should be utilized between analyzing forest transitions in developing and industrialized countries. Causation should therefore be treated with caution.

The forest transition theory may reveal short and medium term dynamics, but it's the long term transition we are interested in. The results computed in this thesis are consistent with a forest transition on both municipality and state level, but forest transition is a long term phenomenon and this thesis investigates a relatively short period. The length of time until transition is uncertain, but the trend is continuous throughout the period and we expect it to be continuing.

During the analysis period (2000-2009), a forest transition did not take place in this forest rich tropical country and the analysis provides no reason to believe that it will happen in the near future. Old growth forests cannot be viewed as an endless source of potential wealth, and further implementation of forest conserving policies is needed. Although it is appealing to push the results to derive sophisticated conclusions, it is essential to acknowledge that the models employed are very restricted. The assumption that the marginal effects are equal for all municipalities and states are debatable, and thus the results in this analysis should be analyzed with caution.

The forest transition theory can be evaluated using either forest cover or GDP as the variable that drives deforestation. The strongest finding in this thesis is the evidence of a forest transition in relation to forest cover rate, both on municipality and state level. My results indicate that GDP per capita is not a good fit as a key explanatory variable when evaluating the forest transition theory, whilst forest cover provides a clearer picture in its relationship with deforestation. My analyses confirm that economic growth can be used to test for a kuznetsian relationship, but that it is less suited in describing a forest transition.

This thesis also demonstrates that socio-economic variables should be taken into consideration when estimating a possible forest transition. Brazil should experience a forest transition in the future as forests become scarce, and implementation of governmental forestation programs will foster such transitions.

7 Conclusion

The starting point of this thesis is the forest transition theory proposed by Mather in 1990, which explains the path from contraction to expansion of forest areas. In this thesis I have identified the many causes for deforestation and the possible drivers of a forest transition in Brazil. My research question is highly relevant as deforestation and its drivers are an important factor in the development of a new climate agreement. As Brazil contains the second largest forest and 40% of the remaining tropical rainforest in the world, deforestation in Amazonia plays an important role regionally, nationally and internationally.

"Are the recent deforestation patterns and trends in the Brazilian Amazon consistent with the forest transition theory?"

The forest transition theory can be evaluated using either forest cover or GDP as the variable that drives deforestation. Through assessing Brazilian deforestation data, strong evidence of a forest transition is found for forest cover both at municipality and state level. The theory has been criticized for ignoring the importance of scale (Perz, 2007), and this thesis proves that addressing different scales in deforestation analysis has substantial effects on the estimated results. It is easier to identify a forest transition at a higher scale, as some municipalities deforest completely, while others will conserve most of their forest. Although the analysis performed at state level provides stronger evidence of a forest transition when using forest cover as the key explanatory variable, the more complex models (4 and 5) contain too few observations (due to a high number of explanatory variables) and degrees of freedom which make it difficult to prove more complex relationships.

GDP per capita has a negative partial correlation with deforestation, meaning that poor municipalities have higher deforestation rates, and this is not in line with the forest transition theory. From Brazil's historical background we know that deforestation is not primarily driven by poverty, but by capital intensive activities such as livestock and soy bean production.

Economic growth has been a popular variable in land cover analysis, and it is the only explanatory factor in the environmental Kuznets curve theory. My results indicate that GDP per capita is not a good fit as a key explanatory variable when evaluating the forest transition theory, whilst forest cover provides a clearer picture in its relationship with deforestation. The forest transition hypothesis is confirmed in regards to forest cover, but not to GDP per capita. My analyses confirm that economic growth can be used to test for a kuznetsian relationship, but that it is less suited in describing a forest transition.

"How are socio-economic conditions in Brazil conditioning a possible forest transition?"

There is no consensus in previous literature on which variables condition a forest transition. The forest transition relationship is an empirical regularity, and the variables in these analyses have proven their relevance in assessing a possible forest transition. Estimation results indicate that population density, remoteness and road density are good indicators in determining deforestation rates, and are thus important factors in the forest transition.

Forest cover and the socio-economic conditions which affect the forest transition will indirectly have an impact on the environmental services that forests provide. A forest transition shows that impact on deforestation is a factor of forest stock and other drivers. As such, in the downward slope of deforestation impact on climate change worsens as time goes by. A possible recovery after some time would partially mitigate this negative effect but most probably not to the point of restoring forest cover to the initial conditions.

As the forest transition helps explain deforestation, one of some of the global environmental problems, this can drive policymaker's decisions. As deforestation is the main source of GHG emissions in Brazil it should therefore be included as a key point in future climate agreements, and the forest transition should be consulted in guiding principles to predict future deforestation. For example, by establishing economic incentives to keep forests standing through programs like REDD the remaining forest stock may be larger than previously expected.

The determination of baselines for future payments in international agreements (such as REDD) should be addressed. Current agreements consider deforestation rates as linear over time, but the forest transition disproves that. The agreement between Norway and Brazil can be used as a prime example, as a baseline calculated from average deforestation between 1985 and 2005 is used. Brazil gets paid when they are below this baseline, and as Brazil is now experiencing low deforestation rates and these rates eventually will flatten out (as described in figure 4.1), they are basically being paid without reducing deforestation levels further. Countries situated in the first stage with low deforestation during the period the baseline is calculated will not receive any payments, while those situated in stage 2 or 3 with very high deforestation get paid for doing nothing. The forest transition theory should be used in predicting future deforestation and in calculating baselines as deforestation rates are proven not to be linear. REDD payments should especially consider a country's situation on the forest transition curve, and be adjusted regularly.

The strongest finding in this thesis is the evidence of a forest transition in relation to forest cover rate, both on municipality and state level. This thesis also demonstrates that socio-economic variables should be taken into consideration when estimating a possible forest transition. Brazil should experience a forest transition in the future as forests become scarce, and implementation of governmental forestation programs will foster such transitions.

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Appendix I – The von Thünen model

The following presentation relies on the work of Angelsen (2007). The models are based on a number of assumptions for simplification and some are modified in the extended version. These will not be elaborated further in this analysis, and can be found in the original source.

(i) The basic model of two land uses

It can be considered that land only has two uses, namely agriculture and forest. Land rent or profit is represented by equation (A.1):

$$r(d) = py - wl - qk - c - vd \qquad \text{(A.1)}$$

r - Rent
p - Central market price
y - Agricultural production per hectare
w - Wage
l - Labor
q - Annual cost of capital
k - Capital
c - Cost of enforcing property rights
v - Transportation costs per kilometer
d - Distance from city center or market

Land rent is determined as agricultural production income (*py*) subtracted expenses such as labor (*wl*) and capital (*qk*) as well as the cost of enforcing property rights (*c*) and transportation (*vd*). If we assume that forests has zero value, the agricultural frontier (*f*) is defined as the distance at which agricultural cultivation is no longer profitable (i.e. *r (d)* =0).

$$d^f = \frac{py - wl - qk - c}{v} \qquad \text{(A.2)}$$

The immediate causes of deforestation are affected by the decision parameters in equation (A.2) (Kaimowitz et al., 1998) and may be a result of increased price or improved technology. This will enhance production and make agricultural expansion more profitable. Reduced costs for capital (better access to credit or lower interest rates) and transportation yield the same effect. Increased wages and high costs of enforcing property rights will pull in the opposite direction.

The underlying causes of deforestation are more complex, as land rent are determined by societal and policy factors such as institutions, national economic politics and international markets.

(ii) Extended model with five land uses

The von Thünen model has been extended to include five different and mutual exclusive land uses (i= *I*, *E*, *M*, *O*, *G*), whereas two are agricultural sectors and three are forest uses. Land rent will then be given as:

$$r^i(d) = p^i y^i - wl^i - qk^i - c^i - v^i d \qquad \text{(A.3)}$$

I - Intensive agriculture

E - Extensive agriculture

M - Managed forests

O - Open access forests ($c^0 = 0$)

G- Old growth forest

In figure A.1 various land uses are drawn with corresponding rent curves. The border between intensive and extensive agriculture is defined as the intensive margin, while the border between extensive agriculture and managed forests is defined as the extensive margin and describes the transition between the non-forest and forest land use. The magnitude and interface between the borders are individual for each location, and the intensive margin indirectly affects the extensive one. The cost of enforcing property rights is the main difference between managed forestry and open access forests. After a certain point the rent is too low to defend these costs, and open access forests develop. In the tropical Amazon, intensive cropping, extensive pasture and managed forests for timber production are often found (Angelsen, 2007).

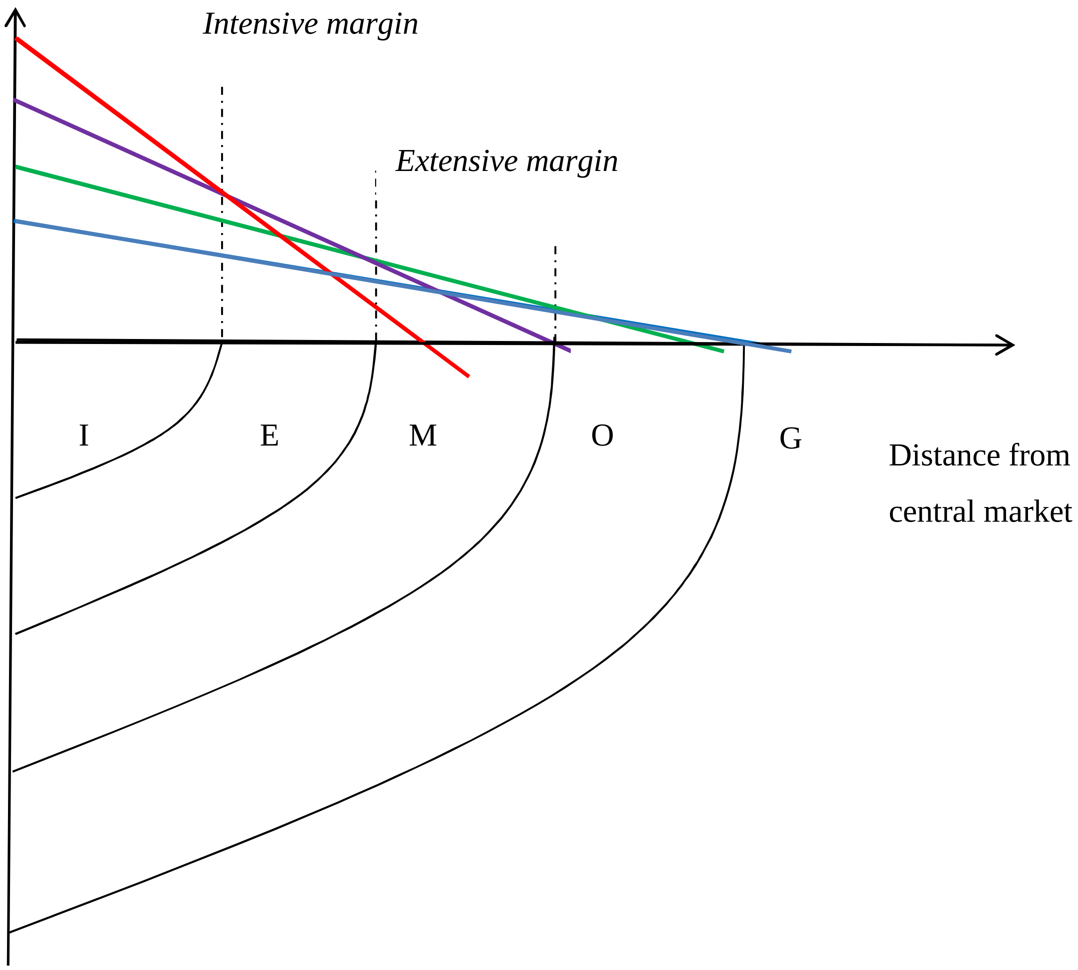

Figure A.1. The von Thünen model with five alternative land uses.

Note: The four rent curves are designated by different lines; red = intensive agriculture, blue= open access forestry, green= managed forestry, purple = extensive agriculture.

Appendix II – Calculation of change variable

$$Period\ x = \left[\left(\frac{Forest\ cover_2}{Forest\ cover_1}\right)^{\frac{1}{t_1 - t_2}} - 1\right] * (-1) * 100$$

$$Period\ 1 = \left[\left(\frac{Forest\ cover_{2002}}{Forest\ cover_{2000}}\right)^{\frac{1}{2}} - 1\right] * (-1) * 100$$

$$Period\ 2 = \left[\left(\frac{Forest\ cover_{2009}}{Forest\ cover_{2007}}\right)^{\frac{1}{2}} - 1\right] * (-1) * 100$$

$$Change\ in\ deforestation = Period\ 2 - Period\ 1$$

Appendix III – Correlation matrix

Table A.1. Correlation matrix[9].

	Def	Change	Trend	FC	FC^2	GDP/cap	GDP/cap^2
Def	1.0000						
Change	-0.0793	1.0000					
Trend	-0.2269	-0.0118	1.0000				
FC	0.0736	0.2128	-0.0837	1.0000			
FC^2	-0.0081	0.2396	-0.0968	0.9625	1.0000		
GDP/cap	-0.0796	-0.0067	0.3411	-0.0575	-0.0759	1.0000	
GDP/cap^2	-0.0424	0.0129	0.1697	-0.0264	-0.0361	0.8575	1.0000
Pop	0.0597	-0.032	0.0121	-0.0677	-0.064	0.005	0.0005
Area (km2)	-0.0574	0.0012	-0.0026	0.4622	0.4819	0.0458	0.014
Remoteness	0.0118	0.0238	-0.0058	0.3015	0.2868	-0.0214	-0.0126
Road	0.0825	-0.1223	0.0034	-0.2489	-0.2342	-0.0955	-0.0572
WC	0.0004	-0.0819	0.0053	0.087	0.0303	-0.0612	0.0145
Latitude	0.0547	-0.0565	0.0058	0.2608	0.2586	-0.2795	-0.1104
Longitude	0.0015	0.0774	0.0063	-0.4874	-0.4532	-0.1817	-0.0448
Rainfall	0.1312	-0.1962	-0.0001	0.4203	0.3883	-0.0544	-0.005
$Rainfall^2$	0.1226	-0.1867	-0.0005	0.3895	0.3644	-0.0634	-0.0057
Temperature	0.0568	-0.0737	0.0056	0.0827	0.064	-0.269	-0.1153

	Pop	Area (km2)	Remoteness	Road	WC	Latitude	Longitude
Pop	1.0000						
Area (km2)	-0.07	1.0000					
Remoteness	-0.1473	0.3189	1.0000				
Road	0.183	-0.1869	-0.241	1.0000			
WC	0.0953	-0.0166	-0.1291	-0.026	1.0000		
Latitude	0.1236	0.1031	-0.1232	0.0794	0.3361	1.0000	
Longitude	0.1045	-0.3579	-0.3337	0.2547	0.0511	0.286	1.0000
Rainfall	0.1248	0.2683	0.0782	-0.0844	0.2654	0.5675	-0.2971
$Rainfall^2$	0.1385	0.2623	0.0663	-0.0743	0.2515	0.577	-0.2689
Temperature	0.122	-0.0829	-0.2719	0.1148	0.3605	0.6724	0.3249

	Rainfall	$Rainfall^2$	Temperature
Rainfall	1.0000		
$Rainfall^2$	0.993	1.0000	
Temperature	0.1648	0.1715	1.0000

[9] Def= Deforestation, Change= Change in deforestation, FC= Forest cover, Pop= Population density, Area= Municipality area, Road= Road density, WC= Water cover.

Appendix IV – Choice of functional form

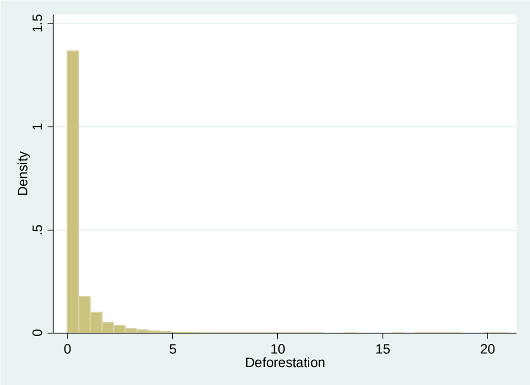

Figure A.2. Variation in Deforestation.

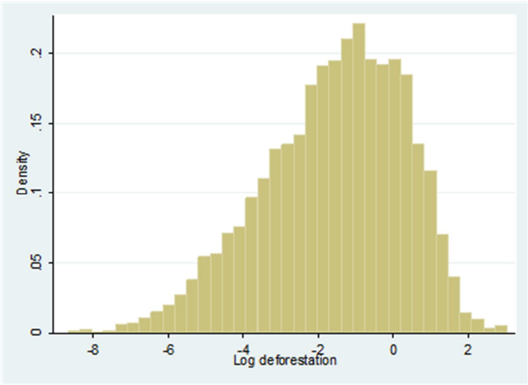

Figure A.3. Variation in Log Deforestation.

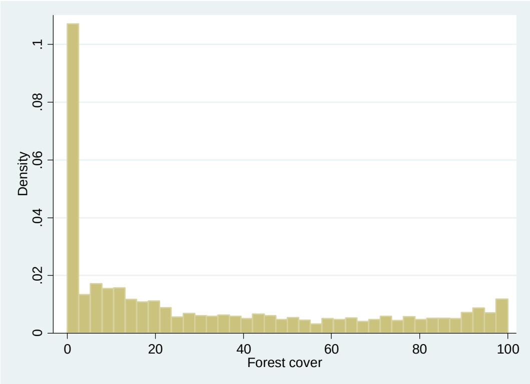

Figure A.4. Variation in Forest Cover.

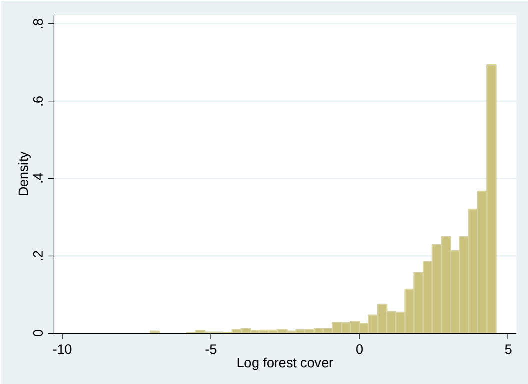

Figure A.5. Variation in Log Forest Cover.

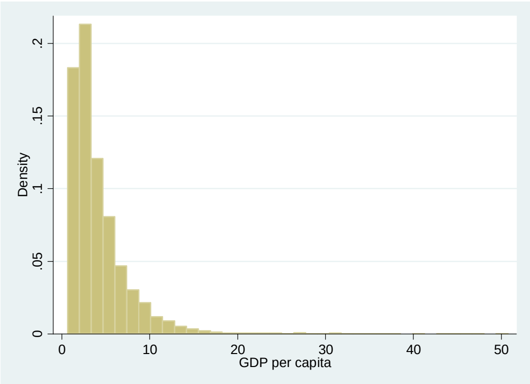

Figure A.6. Variation in GDP per capita.

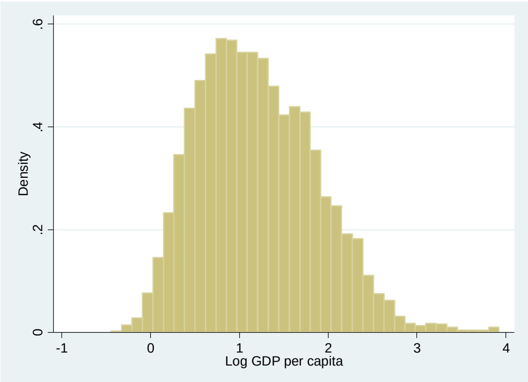

Figure A.7. Variation in Log GDP per capita.

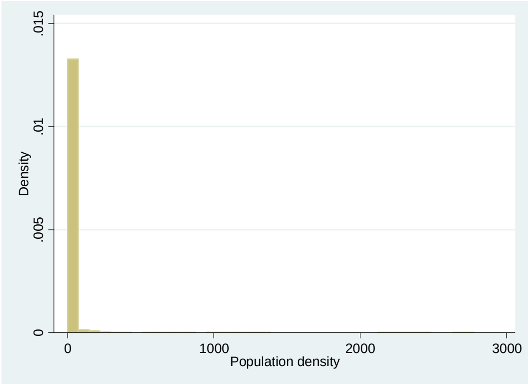

Figure A.8. Variation in Population density.

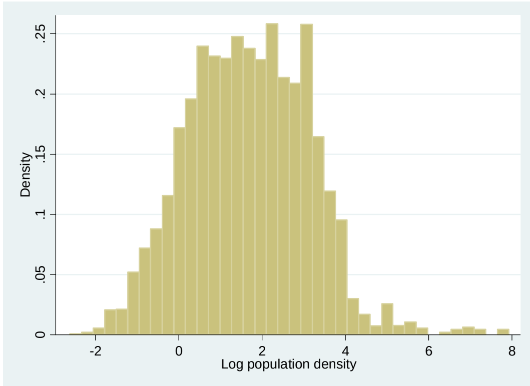

Figure A.9. Variation in Log Population Density.

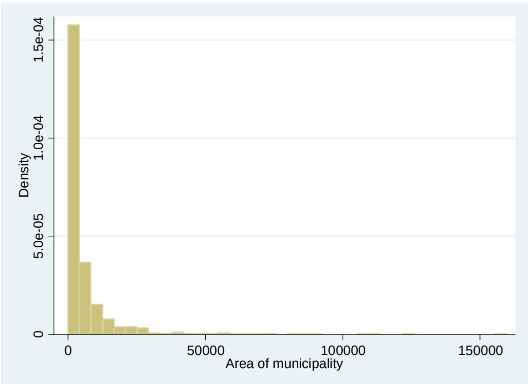

Figure A.10. Variation in Municipality Area.

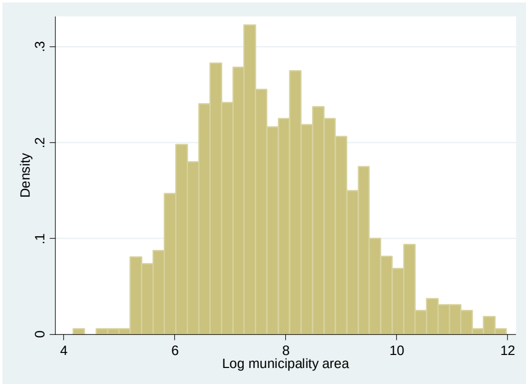

Figure A.11. Variation in Log Municipality Area.

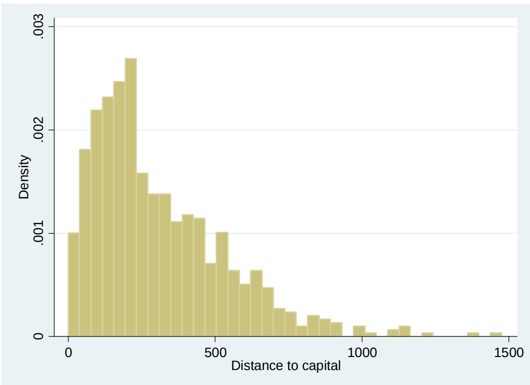

Figure A.12. Variation in Distance to capital.

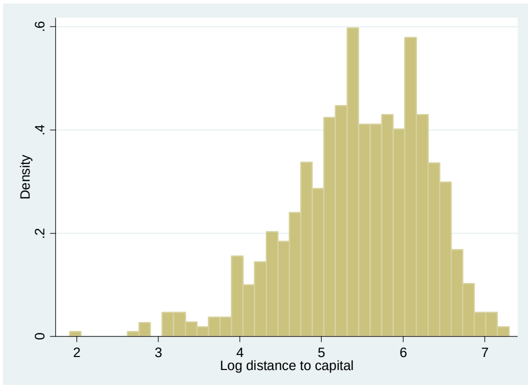

Figure A.13. Variation in Log Distance to Capital.

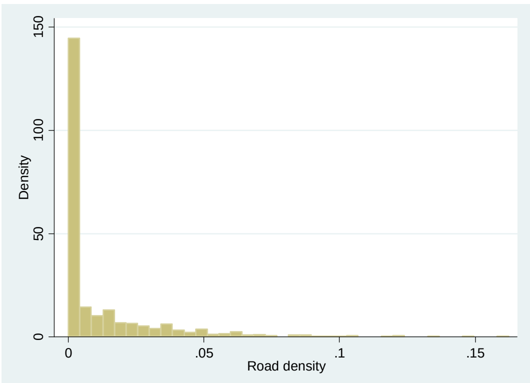

Figure A.14. Variation in Road density.

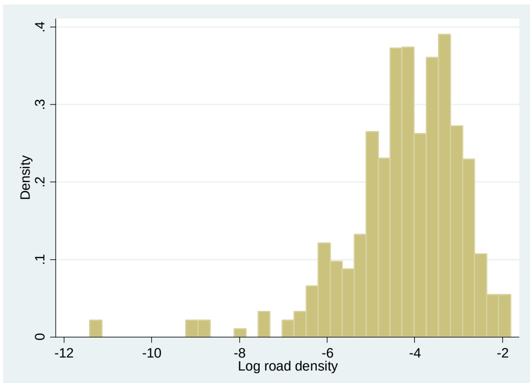

Figure A.15. Variation in Log Road Density.

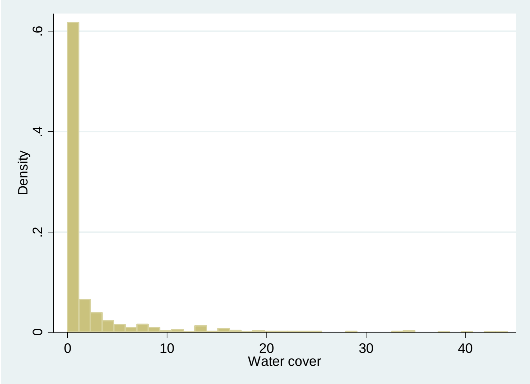

Figure A.16. Variation in Water Cover.

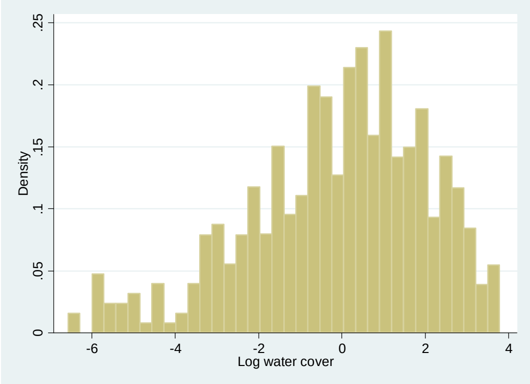

Figure A.17. Log Water Cover.

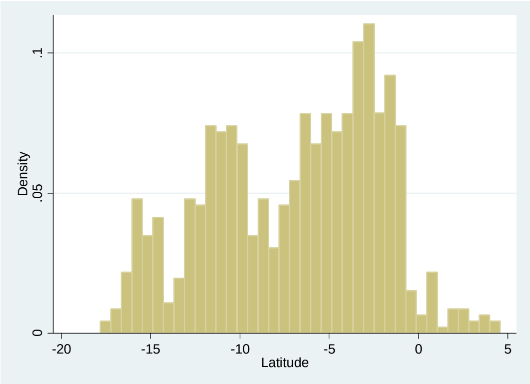

Figure A.18. Variation in Latitude.

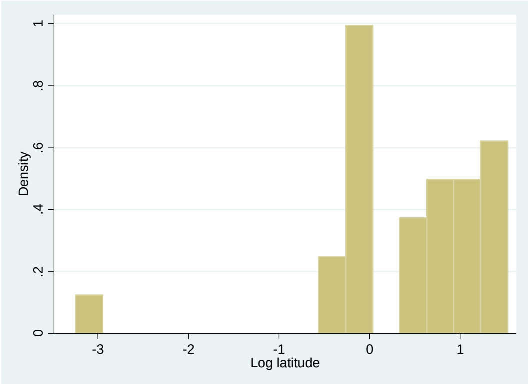

Figure A.19. Variation in Log Latitude.

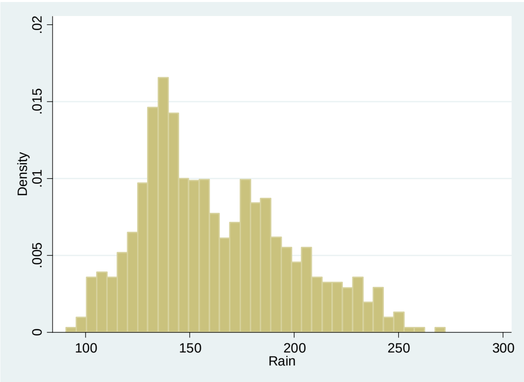

Figure A.20. Variation in Rain.

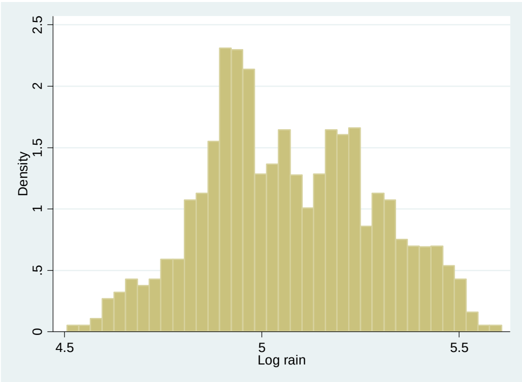

Figure A.21. Variation in Log Rain.

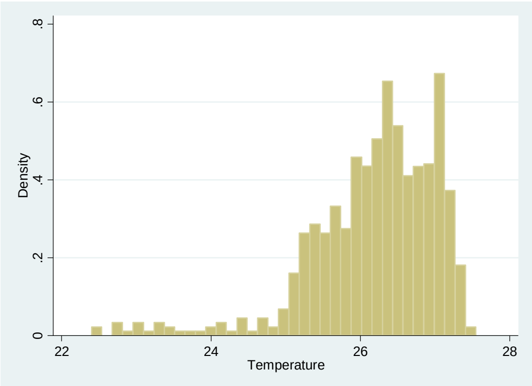

Figure A.22. Variation in Temperature.

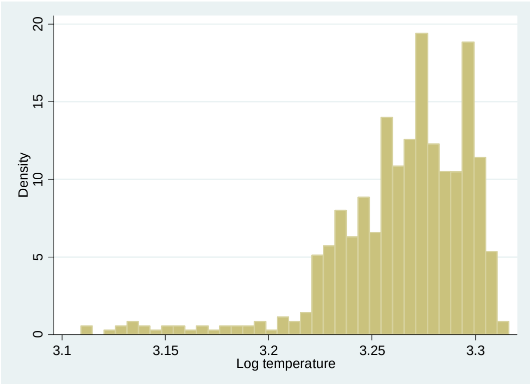

Figure A.23. Variation in Log Temperature.

Appendix V – Testing normality of the error term

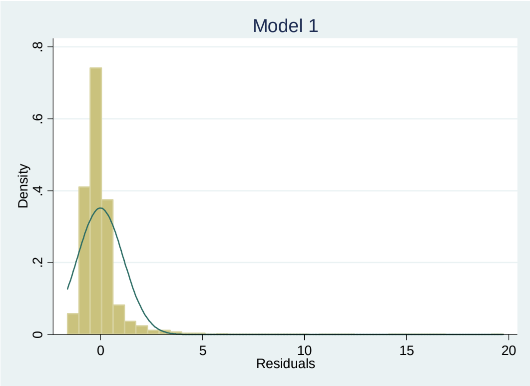

Figure A.24. Observed residuals: Model 1.

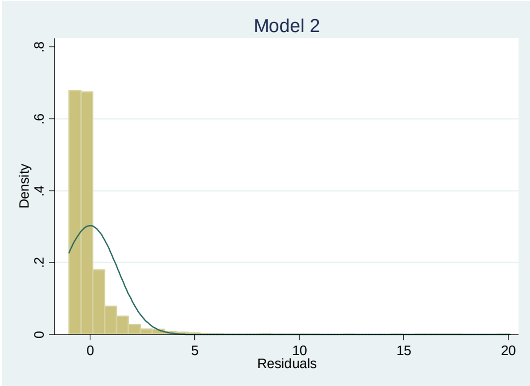

Figure A.25. Observed residuals: Model 2.

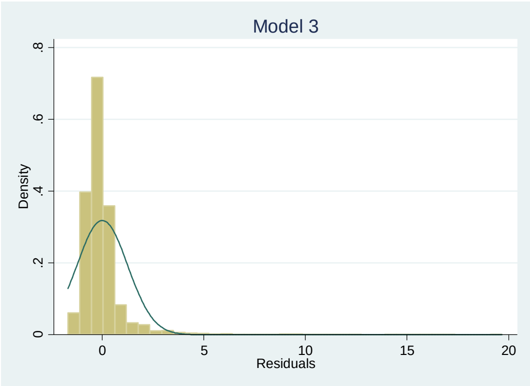

Figure A.26. Observed residuals: Model 3.

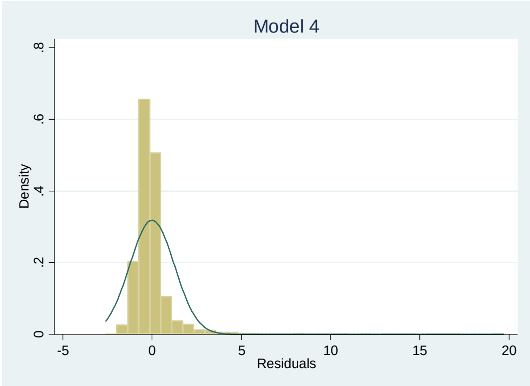

Figure A.27. Observed residuals: Model 4.

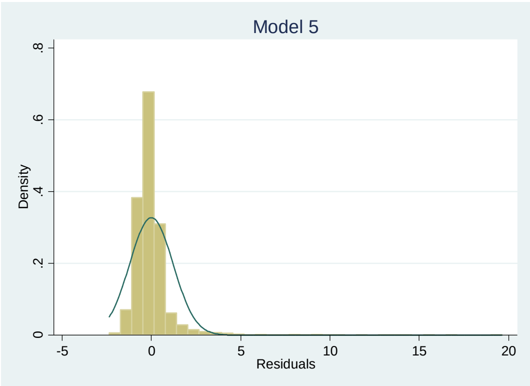

Figure A.28. Observed residuals: Model 5.