Problematizing quantification of indirect land-use change (ILUC)

Connected to expanding ethanol production in Brazil

"All models are wrong, but some are useful"
– Box (1979)

Master's Thesis
Spring 2009

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Abstract

Indirect land-use change is an important factor for the climatic performance of biofuels and has been the reason for a vivid debate, triggered by some attempts for quantification of the former, in 2008. In this study we evaluate the possibilities for quantification of indirect land-use change by using partial equilibrium models and compare this with the alternative approach offered by the emerging field of agent-based modeling.

The investigation was performed in separate modules covering a methodology study on partial equilibrium models; a literature study on agent-based models; a qualitative description of land-use dynamics in Brazil; a description of an agent-based model, constructed as a part of the project; and a discussion on the potential for these types of models for explaining and quantifying indirect land-use effects.

The partial equilibrium models are sensitive to choices made by the modelers and different research teams reach contradictory conclusions using similar methods; it is hard to trust any quantitative results regarding indirect effects based on subjective assumptions. The agent-based models are good tools for studying and understanding micro-level dynamics important for indirect-land use change, but seem too data intensive and complex to be used for quantification of indirect land-use change.

Our conclusions suggest a hybrid model, using a combination of agent-based models for micro-dynamics and a partial equilibrium model for macro-dynamics. This model would be a powerful tool for understanding cause-effect relationships and for improving the qualitative understanding of the system, but would probably still not be able to provide quantitative results. We propose that the question has been posed in the wrong way and that quantification of such complex effects cannot be done unequivocally, however, an understanding of the dynamics is fundamental for decision-makers and research should thus be continued.

Acknowledgements

First we would like to thank our supervisors in Sweden, Göran Berndes and Kristian Lindgren at Chalmers. Your directions and support have been of much value to us. Pivotal for our work was also Gerd Sparovek at ESALQ in Brazil, thank you for making it possible for us to visit Brazil and work in your lab. Edgar Beauclair, thank you for lending us your time and contacts, they were very valuable to us.

Second, we would like to thank for financial support from:

SIDA
Chalmers Vänner
Willinska Stiftelsen & Stiftelsen Göteborgs Arbetsstugor
Emma Berglunds fond

In Brazil, Coplacana showed us how the production of ethanol works, from the fields to the mill. Thank you for letting us get a hands-on experience, now we know what poor sugarcane cutters we are!

Felipe Tonato, thank you for letting us stay in your house and helping us with everything from interpretations to driving our bags half-way across the country.

Finally, we want to thank all our interviewees and other persons that have helped us with our work, directly and indirectly, in both Brazil and Sweden.

Contents

Chapter 1

Introduction

This report is a Master's thesis written by Anders Åhlén and David Bryngelsson at the Department of Energy and Environment at Chalmers University of Technology, Göteborg, Sweden, as final project on the Master's program *Industrial Ecology – for a sustainable society.* The thesis project was conducted partly at Chalmers and partly as a *Minor Field Study** at ESALQ, a university of agriculture in the state of São Paulo, Brazil.

The thesis is built up in modules, covering loosely connected topics regarding land use and land-use changes, as well as their indirect effects, connected to expanded sugarcane ethanol production in Brazil.

The separate modules cover: a methodology study on partial equilibrium models, a literature study on agent-based models, a qualitative description of land-use dynamics in Brazil, a description of an agent-based model—constructed as a part of the Master's thesis project—and a discussion on the potential for these types of models to explain and quantify indirect land-use effects.

1.1 Background

The recent years' debate regarding whether anthropogenically induced climate change is a reality, is no longer a question (statement by the vice-chair of IPCC, van Ypersele, 2009), but the discussion is now more focused on what the effects will be, how large they will be and, most of all, what we can do to mitigate them.

As remedies for the climate problems there are several carbon-neutral

*Minor Field Study (MFS) is a SIDA financed program for conducting thesis projects in developing countries. More information can be found at `www.mfs.nu`.

technologies under development, all of which have their advantages and drawbacks. Energy costs and potentials vary considerably between technologies, as well as the adaptation costs for fitting the various technologies into the existing infrastructure.

Bioenergy is often highlighted as a promising option with relatively high potential, maturity level, and which fits well into the current infrastructure, requiring only, comparatively, small technical adaptations. Globally, bioenergy made up about 10% of the primary energy consumed in 2005, while more than 90% of the energy consumed in many developing countries comes from biomass, with solid biofuels (fuelwood, charcoal and animal dung, etc.) making up 99% of all the primary bioenergy used (FAO, 2008, p. 4).

A sector that has received much attention in the political debate as well as in the media, regarding climate change, is the transport sector which accounted for about 14% of global greenhouse-gas (GHG) emissions in year 2000 (Stern, 2006). Alternatives to fossil fuels for the transport sector tend to be more costly and complicated than alternatives for the stationary energy sector (UNDP and World Bank, 2005, p. 104) and the need to find alternatives to fossil oil is thus very urgent for the former (Zuurbier and van de Vooren, 2008, p. 23). The transport sector is also the sector where fossil fuels are hardest to remove since there the oil has a clear physical as well as an economic competitive advantage (Azar et al., 2003). The advantages of oil make it difficult for alternatives like electricity to enter the transport market. However, liquid biofuels, ethanol and biodiesel, are readily available alternatives that can be (and are) mixed with gasoline and diesel in order to improve the GHG performance of these fuels.

In the EU there is not sufficient land-availability for satisfying the market with domestically produced biofuels* and large-scale consumption of biofuels must thus be supplied through imports. The main driver for using biofuels for transport within the EU is to improve the GHG balance for the region and the environmental performance, from a life-cycle perspective, of the biofuels is thus fundamental for the biofuels to be an interesting alternative to fossil fuels.

This environmental performance of biofuels (mainly liquid biofuels for transport, which is what biofuels will refer to in the rest of this document) has recently been questioned and scrutinized by several research teams around the globe. The information and disinformation abound as there are

*At least not with currently available 1st generation technologies.

strong financial interest in favor of, and against, biofuels replacing fossil oil.

1.2 Problem discussion and research question

In the beginning of 2008 there were two articles published in *Science* (Fargione et al., 2008 and Searchinger et al., 2008a) questioning the climatic benefits from biofuels. Their calculations showed that land-use change (LUC) and indirect land-use change (ILUC) gave rise to large upfront GHG emissions, which would not be "repaid" within a foreseeable future. These articles have initiated an academic as well as political debate and their methods together with their quantitative assumptions and conclusions have been heavily criticized. Many more studies and estimations regarding LUC and ILUC have been made, with varying conclusions; most studies have used partial equilibrium models for their estimations.

One important response to these studies is a study by Nassar et al. (2008), that specifically investigates and models ethanol production in Brazil (the world's largest exporter of ethanol), and claim that there is no ILUC connected to expanded production.

Searchinger et al. (2008a) and Nassar et al. (2008) look at different systems (maize ethanol from the USA and sugarcane ethanol from Brazil), but they use the same type of modeling tool and reach conclusions that are too diverging to be explained by differences between the systems alone.

Deforestation leads to a loss of biodiversity and also large carbon emissions; these are indisputable facts. The large uncertainty lies in the connection between increasing production of biofuels and deforestation, and the scientific community is evidently far from reaching any consensus on the matter. The connection between biofuels production and deforestation is important from the European perspective, considering the importance of carbon performance of biofuels as the main factor determining if the EU should increase its biofuels consumption targets, or not. It is very hard for the politicians to make informed decisions considering the current level of knowledge on the connection between expanding biofuel production and deforestation.

The partial equilibrium models used by for example Searchinger et al. (2008a) and Nassar et al. (2008) provide important insights and are powerful tools for interpreting the complex world we live in. However, their models do not provide satisfactory results for being the sole base for political decisions and the discrepancies between them indicate that these partial equilibrium models can be constructed in ways to reach desired results. They may still be the best alternative for describing the complex reality, but other alternatives need to be considered. One important part in the cause-effect chain is land-use dynamics on the local scale and this is a very complex area that cannot be well described by the inherently simplified and aggregated descriptions of reality used in equilibrium models. In this study we therefore explore the possibilities of applying a different approach that might better capture this complexity of reality; the agent-based model.

In recent years the interest for using agent-based modeling (ABM) has increased in the land-use-change-research community (see for example Parker et al., 2002, 2003; Matthews et al., 2007). ABMs offer modeling possibilities the researchers believe to be better at describing and understanding the complex land-use dynamics which other modeling approaches offer little possibilities to incorporate. Agent-based modeling is a hot research field, that allows for modeling dynamic systems where heterogeneity is incorporated and the results from the models may show more, and different, dynamics than were initially foreseen by the modeler, so called emergent phenomena. On the other hand, these models are very data demanding (Verburg et al., 2005) and might be best used as research tools for better understanding qualitative aspects of reality; making predictive simulations or quantitative calculations with ABMs is often too hard.

Through an investigation of the above mentioned partial equilibrium models and by comparing them with the potentials of ABMs we will thus try answer the following research question:

> **Research question:** *Is agent-based modeling a good methodology for assessing the dynamics of expanding biofuels production and for quantifying ILUC?*

"Good methodology" here refers to the methodology adding new and vital understanding which the other methodologies fail to provide. It could be either by replacing the partial equilibrium models, or by complementing them.

1.3 Limitations

The focus of this report is on investigating methodologies for quantification of indirect effects connected to expanding ethanol production, and the geographical focus is on the state of São Paulo in Brazil. This area was chosen for a number of reasons: Brazil is the second largest producer of ethanol in the world and by far the main exporter* (FAOSTAT, 2009), São Paulo state is the main producer of ethanol in Brazil (Fischer et al., 2008) and we were given the possibility to work on the project at the Brazilian university ESALQ†.

1.4 Structure of the report

The report is structured as follows. In the next chapter our method for studying the research question is described. In Chapter 3, literature on the chosen partial equilibrium models and agent-based modeling is reviewed. In Chapter 4, a qualitative discussion on land-use dynamics in Brazil is presented. This discussion draws on both literature and our own findings from a field visit to Brazil. In Chapter 5, an agent-based model which we developed to test our theories, and come up with new ones, is described. In the last chapter, Chapter 6, some further analysis is offered and conclusions are presented.

*Brazil is the main supplier for the EU market.

†*Escola Superior de Agricultura "Luiz de Queiroz"* – agricultural university in Piracicaba, São Poulo state, Brazil. ESALQ is part of *Universidade de São Paulo* (University of São Paulo).

Chapter 2

Method

The study was performed in modules, where quite different approaches were used for each module. The first module consisted of a literature study of previously made models of land-use change connected to carbon balance of biofuels; on agent-based models in general; as well as on agent-based models connected to land use and land-use decisions. The analysis for the former was focused on limitations and potentials of the above mentioned partial equilibrium models (i.e. Searchinger et al., 2008a and Nassar et al., 2008). Based on information collected during the latter litterature study we, as the second module, created our own agent-based computer model for simulating land-use decisions in the São Paulo state area.

A third module consisted of studying the qualitative aspects of land-use dynamics in Brazil, through litterature studies and through field visits and interviews. During an 8 weeks long visit to ESALQ in Piracicaba, we performed various interviews with experts on the areas of land use, sugar-cane production, livestock production as well as with other stakeholders in the area. There were also some follow-up correspondence for clarifications of details with some of the interviewees. These interviews of course did not provide enough information to be statistically valid, but gave a good insight into qualitative aspects of the studied system, and pointed to areas of heterogeneity and economically irrational behavior – areas where more information is needed.

The data obtained during our stay in Brazil were partly integrated into the agent-based model and partly discussed at a qualitative level in this report.

The last module of the study consists of the discussion and comparison of advantages and drawbacks of ABMs compared to partial equilibrium models.

Chapter 3

Partial equilibrium models and ABMs for studies of LUC and ILUC

First in this chapter some terminology is clarified and in the second section the partial equilibrium models are described, compared and discussed. There is also a discussion about why these types of studies are conducted. In the subsequent section there is a description of agent-based models in general and how they can be applied to land-use studies in particular. The chapter ends with a discussion about what the modeling tools can gain from each other.

3.1 Nomenclature in different research fields

In the literature, we have encountered different terminologies for the same or similar concepts, some of which are pivotal to this study. To increase readability and decrease confusion we decided to stick to fewer concepts in this text and have therefore chosen one term for each concept. The two most important choices are presented in this section to clarify them for readers who are not familiar with our nomenclature.

LUC & ILUC vs. LUCC

The modeling of, and discussions about, land-use change and land-cover change have emerged from different disciplines and these different backgrounds have resulted in different nomenclature for the phenomena. The computer-modeling society talks about land-use/cover change (LUCC) and in the socioeconomic disciplines they talk about land-use change (LUC) or indirect land-use change (ILUC).

In this paper we chose to adopt the nomenclature from the socioeconomic side, since it is better for clearly distinguishing between the direct effects (i.e. LUC) and the indirect and more complicated effects (ILUC). The latter (ILUC) is the main focus of this study.

We may thus use the terms land-use change or indirect land-use change and acronyms LUC or ILUC while referring to what in a source paper was called LUCC.

ABM vs. MAS

What is called agent-based modeling in this text may be called many different things in the literature. Hare and Deadman (2004, p. 26) try to disentangle the terminology and find a number of different terms such as agent-based modeling; agent-based simulation modeling; multi-agent simulation; multi-agent based simulation; agent-based social simulation; and individual-based configuration modeling. They simplify this terminology to two terms, agent-based modeling (ABM) and multi-agent systems (MAS). The first has its roots in artificial life research and the other in distributed artificial intelligence (Hare and Deadman, 2004, p. 25).

These are also the two main terms that we have encountered in the literature. Bousquet and Le Page (2004, p. 313) treat them as interchangeable. In this paper we also treat them as interchangeable and of the two alternatives we chose the term ABM.

We may thus use the term agent-based modeling and acronym ABM while referring to what in a source paper was called MAS or any other similar term or acronym.

3.2 Partial equilibrium models

The political demand for quantification of the GHG released through ILUC connected to biofuels production was triggered by two articles published in *Science* early in 2008, both of which claimed that the environmental (mainly climatic) performance of biofuels was not as good as generally claimed and in many instances much worse than that of fossil fuels. In *'Land Clearing and the Biofuel Carbon Debt'*, Fargione et al. (2008) claim that the production system is fundamental for the performance of biofuels and calculated the carbon balance for several production systems and types of biofuels. Only direct land-conversion was taken into account, but their results still show very poor climatic performance for most systems.

The next article (in the same issue of *Science*) *'Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change'* by Searchinger et al. (2008a) has received far more attention and has stirred up emotions in the debate. Searchinger et al. used a partial equilibrium model to describe the global ILUC connected to a rapid growth in maize-based ethanol in the USA. From this global ILUC they deduce an exact figure for the carbon leakage that each marginal liter of ethanol gives rise to. Their results indicate very large ILUC and thus poor climatic performance of the fuel.

In an article in the recently published book *Sugarcane ethanol: Contributions to climate change mitigation and the environment*, Nassar et al. (2008) investigate the expansion of sugarcane-based ethanol production in Brazil, with a focus on economic; social; as well as environmental effects. They also use a partial equilibrium model but reach fundamentally different conclusions when they claim that there is no LUC or ILUC giving rise to GHG emissions due to expanded ethanol production; their focus is mainly São Paulo state.

Below is an in-depth analysis of the models, together with some critique against them and an emphasis on how they differ and what made them reach such different conclusions.

3.2.1 Searchinger et al., 2008a

Searchinger et al. (2008a) constructed a partial equilibrium model where ILUC and other dynamics are modeled as responses to economic incentives.

They start with the base year of 2004 for the "current" level of maize production and add almost double the U.S. mandates for ethanol for 2016 (Wang and Haq, 2008) to get an estimate of how much maize will be diverted from its current use to ethanol production. This increase in diverted maize has two side effects, domestic maize prices increase and the amount of by-products such as dry distiller grains (DDGS) rise. Rising maize prices create incentives for farmers to divert suitable land from other uses into maize production, or to expand into set-aside land and change crop rotations into mono-cropping maize, at the expense of mainly soybean and wheat production. DDGS can be used for the same purposes as soybeans and can thus reduce the demand for soybeans to some extent. They further assume that there will be a demand for all by-products from the ethanol industry.

The decreased production of wheat and soybeans increase their respective prices at the same time as DDGS somewhat reduce this effect, but the price-increasing effect prevails. These increased prices reduce the exports of wheat, maize, soybeans, chicken, pork and dairy, whereas beef exports increase somewhat. Food prices increase in their study even at the global level and producers and consumers respond according to their short-term price elasticities (Sylvester-Bradely, 2008). On the consumer side, there is a small decline in food consumption, mainly in developing countries, and on the demand side the response is to replace the diverted supply. Higher prices provide incentives for farmers to increase inputs to get higher yields at the same time as it becomes profitable to produce crops on lower-yielding land. Searchinger et al. (2008a) assume that these effects will be equally large and average crop yields will remain constant for each country in the study.

Crop yields in the USA are very high and most other crop-producing countries have lower yields, which means that the replacement of land is not 1:1 but there will need to be larger areas dedicated to replacing crop production than the initial area diverted in the USA (Searchinger et al., 2008b)

Results from the model

Based on global ILUC, and average carbon leakage from affected regions (e.g. the Amazon), Searchinger et al. derived potentially emitted CO_2 from deforestation and soil leakage, and used these numbers to calculate the number of years needed for the biofuels to "pay back" these upfront carbon emissions, the "carbon debt". This payback is then done against a baseline scenario of continued use of fossil fuels as the alternative fuel for a foreseeable future. The results from the model show that ethanol derived from U.S. maize does not have a 20% climate advantage compared to gasoline, which previously has been claimed from looking at the production system from a static perspective, but actually performs worse than gasoline for 167 years before the carbon debt has been repaid.

Searchinger et al. (2008a) thus not only claim that ILUC is an important factor which must be taken into account, but also that ILUC can be estimated with high precision.

Political and academic responses

Searchinger's model highlighted several important aspects regarding biofuels, aspects which until then had been overlooked or ignored by scientists as well as decision-makers. These aspects of ILUC initiated a heated debate in the academic as well as political world and the study has received a lot of critique regarding assumptions and methods. There have also been several other studies conducted in response to Searchinger's, some have reached similar conclusions and others have reached fundamentally different conclusions. Below, in this section, is some of this critique presented and in Section 3.2.2 is a different model presented.

Some of the critique raised against Searchinger's approach

Wang and Haq (2008) voiced much critique regarding quantitative assumptions made by Searchinger et al. (2008a), e.g. about the use of 30 billion gallons of ethanol in 2016 instead of the mandated 15 billion and low climatic efficiency for maize ethanol with no assumptions regarding improvements in conversion efficiency and too low displacement from the DDGS. They further criticized the low level of carbon leakage from soils; the carbon leakage was also criticized by Dale (2008) in that generalizations regarding soil carbon levels cannot be made. Wang and Haq (2008) further claimed that the U.S. exports level of maize could be maintained even if the mandate of 15 million gallons would be reached.

Searchinger (2008) replied to the above raised critique that the absolute amount of ethanol produced is irrelevant in the study since it looks at the marginal effect of an extra gallon of ethanol and not total emissions. Higher yields etc. would change the total impact, but not the marginal effect. He further claimed that the displacement of DDGS depends on the type of livestock and is very difficult to estimate. Regarding the exports level, Searchinger (2008) replied that they can be maintained, but at the cost of reduced exports of wheat and soybeans.

There has also been critique regarding the qualitative approach, e.g. that trying to estimate secondary and tertiary effects on the global economy from such a small perturbation is nothing but speculations (Dale, 2008). Dale further claimed that the environmental impacts from ethanol differ between production sites and that local LCA data should be used since U.S. farmers cannot influence foreign decision-makers. Another critique made by Wang and Haq (2008) is that a partial equilibrium model cannot catch all the relevant dynamics from such a complex system and that a general equilibrium model, taking supply and demand of agricultural products and land into account, must be used. Khosla (2008) meant that logging is the main driver for deforestation and that bioenergy expansion is more likely in other regions than in forests. The complexity behind deforestation commented on by Kline and Dale (2008) where they emphasized that *"interactions among cultural, technological, biophysical, political, economic, and demographic forces within a spatial and temporal context rather than by a single crop market"* should be taken into consideration in order to explain the dynamics.

The perspective of Dale (2008) is very different from Searchinger's as Dale emphasizes energy security and first-order effects. Using local data for LCA does not take time or scale effects into account, which can be very relevant for an upscaling of a large system over a long time. Background systems change over time, which alters the environmental performance and impacts from a system (Sandén and Jonasson, 2004).

Searchinger responded to Khosla that even though logging takes part in deforestation, the logging is selective and does not clear forests and regrowth of forests normally occurs after logging or fires except when agriculture expands onto the land.

The approach fails to take polices preventing deforestation, as well as trade agreements into consideration (Renewable Fuels Agency, 2008).

Among all of these attacks on Searchinger et al. (2008a) there was also a positive comment made by Sheehan (2008), claiming that Searchinger et al. (2008a) are taking a big step in the right direction and that much more research on the topic is warranted. Sheehan would like to see more researchers working *with* Searchinger et al. and Fargione et al. rather than criticizing them.

3.2.2 Nassar et al., 2008

To evaluate the environmental performance of sugarcane ethanol, Nassar et al. (2008) made a thorough analysis of the expansion of sugarcane all over Brazil and what types of land-uses it displaces in order to evaluate the direct land-use change (LUC). To assess the impacts from historic expansion the analysis was performed in three separate ways by using data from remote-sensing satellites, environmental licensing reports and secondary data based on planted and harvested area (Nassar et al., 2008, p. 64). They also created a partial equilibrium model with exogenous demands and prices with which they project the expansion of sugarcane production as well as expansion or reduction of other effected crops between 2008 and 2018. They also have a qualitative discussion regarding ILUC.

The results from the analysis of historic expansion point towards the vast majority of sugarcane expansion having taken place on land previously used for food-crop production or for cattle grazing and only a very small fraction of the expansion was done on virgin land. Carbon leakage due to LUC is thus small or negative as sugarcane can bind as much or more carbon as many food crops or degraded pasture (Gibbs et al., 2008).

The model

The partial equilibrium model Nassar et al. used for projection of future expansion of sugarcane is still under development by the International Trade Negotiations (ICONE) (Nassar et al., 2008, p. 73).

The model is based on demand and supply responses to changes in prices and returns on production. Market-clearing prices on national or regional level are achieved when supply and demand prices coincide (Nassar et al., 2008, p. 73), there is however no information on how they calculate the demand and supply curves for the model.

They use time-steps of one year and a time horizon of 10 years for which they calculate supply and demand for 11 product categories (sugarcane, soybean, maize, cotton, rice, dry beans, milk, beef, chicken, eggs and pork). Unlike Searchinger et al. they do not look at global dynamics and the model is confined to Brazil, which is divided into six regions according to biome.

Prices and demand for the products are exogenous for the model and taken from the FAPRI (2008) *U.S. and World Agricultural Outlook*. The area required to meet these demands for each crop (including sugarcane) is calculated according to yield trends (Nassar et al., 2008, p. 74). Brazil thus acts as a price-taker for all crops as well as ethanol in the model and the expected demands for all products are fixed, even though according to FAPRI (2008, p. 381) the global ethanol price is set mainly by the production level in Brazil.

According to historical data they define a competition matrix between activities with elasticities for change, which later shows results in land-use-change distribution between regions depending on the amount of land allocated for each activity (Nassar et al., 2008, p. 74).

Results from the model

The results from the model show that the total production area will increase for all crops, including sugarcane, but this will be compensated for by a reduction in grazing area (Nassar et al., 2008, p. 84). They further conclude that future expansion of sugarcane will follow the same pattern as in the past, which is not very surprising since they used historical data to calculate their land-competition matrix. The use of historical data for expansion patterns can however be well warranted considering the large difference in scale between grazing and cropping areas in Brazil, compared to the "small perturbation" from the ethanol industry. Sugarcane expands onto cropland and pastures and most of the displaced crops in turn expand onto pasture land. The pasture area is expected to decrease in all regions except for the Amazon Biome where it expands, but they claim that this expansion takes place without correlation with the reduction in pasture area in other regions (Nassar et al., 2008, p. 86).

Nassar et al. acknowledge the problems with defining and calculating ILUC especially in a case where the production of sugarcane is taking place far away from the agricultural frontiers and at the same time as production levels of other (displaced) crops increase. They point to the difficulty with proving the cause-effect relationships in such dynamics and the necessity of searching for *'arguments and data supporting the idea that sugarcane expansion is leading to an increase in the land productivity, rather than promoting incorporation of new land for food production, as grains and pasture land are displaced'* (Nassar et al., 2008, p. 88).

With numbers showing larger displacement of food crops and pasture by sugarcane than the expansion of the same in the Amazon and the fact that food crops, as well as meat and dairy production, are increasing more than sugarcane, they claim that ILUC cannot be quantified and is more than compensated for by yield increases and higher stocking rates.

3.2.3 Discussion of partial equilibrium models

There are some fundamental problems with equilibrium models, namely that they always assume totally homogenous agents and they only include the mechanisms the reseacher(s) put into the models. Normally these models are created by experts, who hopefully are aware of, and consider, the most important dynamics, but these experts are human and there may be some important factors that are intentionally, or unintentionally, omitted. Also by considering how diverse the results can be from such models (as the two examples scrutinized here show) the experts do not always agree on how these dynamics work. There is for example a large room for choosing equations, mechanisms and system boundaries in a way to achieve desired results.

The production systems in the USA and in Brazil differ in several important aspects, but there are also important similarities: They both take place far away from any agricultural frontier; they both displace other land uses; and they are both part of a global market. Such different conclusions as reached in these two studies thus seem unlikely for both to be valid.

Both Searchinger et al. (2008a) and Nassar et al. (2008) use historical data to construct their land-use-change equations and thus conclude that future distribution in land-use change will be the same as it historically has been. Of course they have to do this, because historical data are more likely to be close to the truth than a random guess would be, but this approach does not allow for any surprises or changes in behavior or newly implemented laws etc.

A partial equilibrium model does not include all dynamics in the world (which of course would never be practically feasible to do) and thus operates in a static surrounding where all else is assumed to be equal. In the current situation with rapidly growing economies in the most populous countries in the world, such an assumption is not likely to be valid.

One example is when Searchinger (2008) claims that the absolute volume of ethanol investigated is only a matter of a shifting baseline and that the marginal liter of ethanol will always cause the sa8me damage, he assumes that the agricultural frontiers always move in the same way over the same types of land, which is a crude assumption. There are likely some nonlinear phenomena when the expansion exceeds certain levels and indirect effects start changing behavior. This could be the case where sugarcane expands onto cropland which in turn expands onto "idle land", but when there is no more "idle land" to expand to, then the crops may expand into forestland and thus give a very different carbon balance.

Another example is when Nassar et al. (2008, p. 90) claim that sugarcane expansion gives no indirect effects when expanding onto land which has been "released" due to yield increases, when increasing demand is ignored. The demand for agricultural products is doubtlessly increasing and cannot be ignored. There is also an opportunity cost of land and the released land could of course have been used for something else, which may or may not have resulted in higher carbon savings.

Equilibrium models are based on the assumption that the world starts in equilibrium, then there are some perturbations, after which there is a new, different, equilibrium. The fundamental problem here is that the world is never in equilibrium. Things are continuously changing at a rapid pace and before any equilibrium is ever reached there are new perturbations changing the conditions.

3.3 Agent-based models

Standard equilibrium models involve little heterogeneity, assume global (not local) interactions and ignore space (Epstein, 2006, pp. xii - xiii). All of these attributes are drawbacks when modeling LUC since location is important for land-use decisions (Verburg et al., 2005, p. 8) and it involves heterogeneous landowners who interact on a local scale. As described above, we explore the possible benefits of using this modeling technique and this section provides some information on its characteristics.

Agent-based models focus on human actions and interactions in a given environment with a given set of rules. The agents are autonomous and their behaviors are tied to their environment and to the behaviors of other agents (Parker et al., 2003; Verburg et al., 2005). The agents themselves are fundamental for the models and it is their characteristics that determine the outcome of the interactions between them. Using their given characteristics they autonomously respond in a cognitive way to changes in their environment in order to achieve some predefined goals (Parker et al., 2003). The agents can be individuals, institutions, villages or any other group or organizational level (Verburg et al., 2005), with common goals and decision-making processes. By determining how the agents interact with their environment they can either be shaped to act as rational profit maximizers with perfect access to information and foresight, or they can be shaped to act with bounded rationality; according to other "softer" values; and with limited access to information, foresight and optimization capability (Parker et al., 2003; Verburg et al., 2005).

Autonomous agents acting on a simulated biophysical environment is a promising means of simulating disaggregated decision-making regarding land use and does not require any implausible equilibrium. Instead, recurring transient patterns emerge from the interactions between agents and their environments (Parker et al., 2003). Such emergent phenomena can be path-dependencies or other important non-linear collective behaviors (Verburg et al., 2005).

The construction of agent-based models where the agents show realistic behavior and diversity is however very data demanding and challenging. It is further fundamental that the researcher has detailed information about how the actual decision-making is done; and in many cases there are other alternatives (than ABM) that can provide satisfactory answers with much lower data requirements (Verburg et al., 2005).

Since the ABMs are so data demanding, to be justified they should offer new insights that other modeling approaches do not provide. The benefits of agent-based models mentioned in the literature are for example:

- No implausable static equilibrium is needed
- Important heterogeneities can be incorporated into the models
- Feedback effects and path-dependencies emerge
- Without including aspects of a particular phenomenon in the ABM, that particular phenomenon may appear in the outcome (emergent phenomena)
- The modeler need not use the much simplified Homo Economicus to represent important human behavior
- The models can be combined with real geographical data to correctly describe a landscape

An agent-based model generally consists of three key components; agents, an environment or space, and rules (Epstein and Axtell, 1996, p. 4):

Agents: The agents are autonomous decision-making entities (Parker et al., 2002, p. 1). Typically they represent human beings, but need not to; they can also represent for example institutions or companies. Each agent has characteristics that describe, and are subject to, behavioral rules (Epstein and Axtell, 1996, p. 4). Some of the characteristics, what Epstein and Axtell call internal states, are fixed while others can change. For example, the sex of an agent does not change, while its knowledge might.

Environment or space: The agents act in some kind of environment that can be a landscape but also something more abstract, like a communications network (Epstein and Axtell, 1996, p. 5). It is through this medium the agents interact with each other. We return to this in more detail when we discuss ABM of LUC (Section 3.3.1) as the landscape is considered to be of great importance when modeling land use.

Rules: The agents are subject to rules which describe their allowed actions and also their relationship with the environment (Epstein and Axtell, 1996, p. 5; Parker et al., 2002, p. 1). These can be rules on how agents act, for example, evaluate the choices of land-use for their plots every year; or on how agents interact, for example, check if somebody else is interested in renting the same plot before they bid for it.

3.3.1 Agent-based modeling of LUC and ILUC

Agent-based modeling has lately received much attention in many different fields (Bousquet and Le Page, 2004). One of these fields is land-use-change modeling where the earliest (according to Matthews et al., 2007) published use of agent-based modeling probably was Lansing and Kremer (1993). Since then, agent-based modeling has been much used during recent years (Matthews et al., 2007; Parker et al., 2003, 2002). Some of the reasons for this interest are the possibilities to model individual decision-making entities, non-monetary influences, and linking social with environmental processes (Matthews et al., 2007). In their review of agent-based modeling of LUC, Parker et al. (2003) consider other alternatives for modeling LUC. All of the techniques have some limitations and Parker et al. believe that agent-based modeling may have the potential for overcoming many of them.

Agent-based modeling of land-use change normally comprises two key components; an agent-based model of the key actors in the studied system; and a cellular model that acts as a landscape on which the agents interact (Parker et al., 2003, 2002). Who the key actors in the agent-based model are is not evident. Since an agent does not necessarily have to be an individual, it can represent any level of organization, such as a herd, a village, an institution, etc. (Verburg et al., 2005, p. 9). The modeler has instead the possibility to try to find the right scale on which to represent the agents. The data intensity goes down if higher-level agents are chosen, but it may be harder to simulate their decision-making.

The other important component, the cellular model, or some other representation of an environment, is essential in environmental modeling, but it need not be spatially explicit (Hare and Deadman, 2004). However, when modeling land-use patterns, and the spatial landscape pattern is important, Hare and Deadman propose that a spatially explicit model is required. This is also the view of Verburg et al. (2005); the majority of models of LUC *"are spatially explicit due to the general notion that 'location matters'"*. This notion can be understood by considering the importance in land-use management of soil fertility, distance to markets, topography, current land cover and so on. Especially when, as in this study, the interest lies as much in earlier land use as in current land use (deforestation being the area of interest) the spatial explicitness is of large importance.

The spatially explicit environment can also take many different forms; the environment can be represented by, for example, a set of vector polygons, a vector network or a raster grid (Hare and Deadman, 2004, p. 31). In the vector approach, areas can be represented by their real-world shapes. In a raster model, or a cellular automaton, the resolution will depend on the size of the cells. Most models use a raster grid of some kind, for example all the models studied in Hare and Deadman (2004).

3.3.2 The role of agent-based modeling of LUC as a research tool

An important aspect when developing a model is the purpose, or role, of the model, how it is going to be used and what it is supposed to accomplish. Parker et al. (2003) distinguish between explanatory approaches and descriptive approaches. The explanatory approaches aim to use the models as social laboratories in which the modeler can test theories and generate new hypotheses. The descriptive approaches instead focus on "empirical validity and/or predictive capacity" (Parker et al., 2003, p. 326). These latter models are supposed to mimic reality to facilitate empirical and policy scenario research.

In other words, it is not always necessary for a model to have empirical validity. In the explanatory approach the important part is to test theories and learn more about the system. Verburg et al. (2005) argue that two important reasons for why you model are that gaps in knowledge become obvious, and that priority areas for analysis can be identified. Verburg et al. observe that agent-based models which can predict changes for real landscapes (compare to the predictive approach in Parker et al., 2003) are very data demanding and the modeling of exact agent behavior and diversity is very hard. Verburg et al. suggest that different modeling approaches (referring not to explanatory vs. descriptive but to agent-based vs. other models) need not be competitors. They believe that a spatially explicit cellular automaton is probably incapable of exploring large agricultural transitions, but they can explore mechanisms that can later be included in other simulation models (Verburg et al., 2005, p. 9).

Matthews et al. (2007, p. 1447) propose the greatest use of models so far has been as tools for exploring theoretical aspects and for organizing knowledge from empirical studies. They believe that agent-based models still have to demonstrate that they can solve problems in the real world. Other simulation areas have been expected to provide many more answers than they later proved able to do. Agent-based modeling of LUC is still an emerging field and we do not yet know if the expectations will be reached, but Matthews et al. believe the outlook to be promising.

As a concluding viewpoint on the role of agent-based modeling of land-use change we can turn to Parker et al. (2008). They observe that human-environment interactions are so complex that we can be confident that our models will not accurately represent the real-world system. Is it then any idea to model at all? For an answer they fall back on the words of Box (1979): *"All models are wrong, but some are useful"* (cited in Parker et al., 2008, p. 800), and say that the relevant question is whether we can learn from our models.

In this study the modeling has been of the kind Parker et al. (2003) call explanatory and we have used the model as a tool to study the dynamics of a system and have come up with important questions pointing towards areas of interest and knowledge gaps, in the way proposed by Verburg et al. (2005) . Later some results from our model are demonstrated, but they are not supposed to give any predictions.

3.4 What ABMs can add to the knowledge acquired from partial equilibrium models

Regarding the critique against Searchinger et al. (2008a) presented above we tend to agree with Sheehan (2008) in that Searchinger et al. have made an important contribution to the knowledge about ILUC connected to expanding ethanol production. Much of the critique concerns details that may be improved, or investigated, to see if they really make a difference to the results. We believe that agent-based models can be used to better understand parts of the system studied by Searchinger et al. (2008a). The new knowledge can be used as input to other models, or hybrid models (Parker et al., 2003) can be used which combine different modeling techniques.

Constructing a spatially explicit ABM on the same scale as the partial equilibrium models described above would be extremely data demanding, and probably not worth the effort since the model would be too complex to be understood or to be verifiable. Another approach would be to model agents at a higher level, such as institutions or countries. The problem here would be to find the right level at which to model the agents, it should be on the level where decisions really are made.

As described above, we chose to study the land-use dynamics in Brazil to assess how ABM can contribute to the knowledge. In the following chapter we will present a qualitative discussion on important attributes we found about the dynamics in that country.

Chapter 4

Land-use dynamics in Brazil

This chapter offers a qualitative description of land-use dynamics in Brazil and begins with some history as well as an overview of the current state. In the second section there is a description of the ownership structure with a focus on the south-central region. Following is a short section explaining the role of sugarcane in agriculture in Brazil. After that comes a section describing the dynamics of deforestation in the Amazon region. Section 4.5 describes land-use dynamics in the south-central region, which is where sugarcane production is expanding. The chapter ends with a section looking at recent years' expansion of sugarcane production and offers a brief outlook into a possible scenario of future sugarcane expansion.

4.1 Introduction

Brazil is an exceptionally land-rich country with vast areas of fertile soil, regular rainfalls and strong insolation. The land is only partly exploited and the production on this land is dynamic with constant expansion, intensification and changes in crops and in production systems.

Some qualitative patterns have been more or less the same since the colonization, e.g. that land prices are linked to the proximity to urban centers and infrastructure and these land prices strongly influence the type of crops or other land uses in each area. The agricultural frontier, which makes up the border between the untouched natural land and the anthropogenically exploited land, is typically situated far away from any urban centers and infrastructure is poor and sparse. The main use of such land is for low-intensity systems like low-density cattle ranching based on grazing with very low input and low output.

As urban centers emerge and infrastructure improves, land prices go up and cattle are displaced by high-input-high-output land uses like crop production, e.g. soybeans or orange trees, and the agricultural frontier with cattle production shifts further into the previously untouched land (Sparovek et al., 2007).

In some areas also this crop production gets displaced by other land uses with even higher profits, mainly sugarcane production. This displacement is part of a very important interaction between different types of land uses in Brazil and no *one crop*'s environmental impact can be correctly evaluated without considering such inter-land-use interactions (Sparovek et al., 2007).

4.2 Structure of ownership

The ownership structure in Brazil has since the days of colonization been skewed in favor of large landholders (Sparovek et al., 2007). The size of landholdings vary significantly between farms and between regions, where family-owned farms coexist with industrially owned farms all over the country, but there is a predominance of smaller family farms in the north-east where the agriculture is less mechanized (Sparovek et al., 2007). Farm sizes are smaller in the "old" areas, which have been cultivated for many generations and subsequently divided up into smaller and smaller plots as they have been passed on from fathers to sons*. A typical cattle farm in São Paulo holds "only" about 100 heads, one in Matto Grosso do Sul typically holds about 500 – 1000 heads, when as many as 1000 – 5000 heads of cattle in one farm is not unusual in Pará*. However, there is a wide dispersion and some farms have much fewer heads than that.

In general, both the industrial landowners and the family farmers act as rational economic agents and let the relative income from different land uses be the main driver for deciding what to do with their land. According to Professor Sergio de Zen* there is a difference between how industrial landowners and family landowners reason; the majority of family farmers do not want to sell their land, but rather keep it and rent it out if the opportunity cost of their land exceeds their current land use. The industrial landowners, on the other hand, may well sell their land if it is economically rational to do so. They do this either to cease doing business in that area,

*Personal communication with Prof. Sergio de Zen at CEPEA - ESALQ, University of São Paulo, Brazil.

or in order to get capital and then rent the land back from the new owners.

An example of the latter is, according to Prof. de Zen, when Cosan, the biggest sugarcane company in the world, sold 180 000 ha of land to a teachers retirement fund in the USA, in a scheme to free money for other investments and consequently renting the land they just sold.

4.3 Sugarcane

Sugarcane production in Brazil is largely confined to two separate and distinctly different regions, the north-east and the south-central. The north-east has a fairly static production area, whereas production in the south-central is increasing rapidly (Nassar et al., 2008; Sparovek et al., 2007). The latter area is focus for investigation in this study. Expanding sugarcane is done on land previously used for cattle grazing or for food-crop production (Nassar et al., 2008; Sparovek et al., 2007; Goldemberg et al., 2008; Wilkinson and Herrera, 2008). Sugarcane production is not a major land use on a national scale; it only makes up 2.5% of the 264 million hectares used for agriculture in Brazil and almost 200 million hectares of this land are used for cattle grazing (Fischer et al., 2008, p. 41). A more important land use – which is also more directly connected to deforestation – is the production and expansion of soybeans, which since the early 1980's has increased from around 10 million hectares to 23 million hectares in 2008; this makes up close to a third of all cropping land in the country (Fischer et al., 2008, p. 45).

4.4 The arc of deforestation

Expansion of anthropogenically exploited land takes place at the agricultural frontier where cropland and pasture expands over natural vegetation, such as forests and savannas (Sparovek et al., 2007). The major part of this agricultural frontier is the "arc of deforestation" along the southern and eastern part of the Amazon in Brazil, which is the most rapidly deforesting area in the world, regarding both forest loss and fire activity (Morton et al., 2006). Deforestation of the Amazon leads mainly to extensive low-productive pastures (Sparovek et al., 2007), but the share of deforested land turned into mechanized agriculture is increasing (Morton et al., 2006). This deforestation of Amazonian rainforest is well monitored both by the Brazilian government and by NGOs, but the conversion of other natural habitats (such as the biodiversity hotspot the Cerrado) into pastures and cropland is not monitored and is poorly understood (Nassar et al., 2008).

Between 2001 and 2004 the total area deforested in the nine Amazonian states was 93 700 km^2 (an area larger than Portugal) and no less than 36 000 km^2 were turned into mechanized agriculture (Morton et al., 2006). The World Bank (2004, p. 9) however claim that cattle ranching is by far the most important economic activity connected to deforestation and that agriculture has very little to do with it, although they acknowledge that soybean plantations are responsible for a small share. Prof. de Zen* gives a third account when he claims that the logging industry is the most important driver for deforestation in the Amazon and that cattle ranching is a consequence of the already cleared land, not a driver for the clearing process.

According to the study by Morton et al. (2006) the annual conversion of forest into cropland in Mato Grosso between 2001 and 2004 was over 5 400 km^2 (of a total of 33 200 km^2 deforestation) and 90% of this land was planted with crops within a year of deforestation. They also found a direct correlation between the price of soybeans and the amount of deforestation for large-scale cropland for the years investigated, which indicates that increased profitability from land use directly leads to increased deforestation. Intensification and mechanization of agriculture which theoretically should lead to lower demand for land may thus instead increase the pressure on the forest due to lower production prices and hence better competitiveness on the growing global market (Morton et al., 2006). Morton et al. further claim that there is a large uncertainty regarding land use after forest clearing since no monitoring of land clearing has followed individual clearings over time. This is confirmed by World Bank (2004, p. 5).

Knowledge about the distribution between small-scale and large-scale land users also holds uncertainty since no direct measurements have been made, but the distribution has been deduced from the size of land-clearings (Morton et al., 2006; World Bank, 2004, p. 11) as monitored with satellites. The estimated number of land clearings made by large agents may therefore be too high if many small-scale producers have cleared adjacent land, or similarly the estimate of small-scale agents may be too high if the larger agents clear several separate fields (World Bank, 2004, p. 11).

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The deforestation and expansion of cattle ranching in the Amazon is dependent on several interlinked dynamics. The World Bank (2004, pp. 19-24) describe the process as generally starting with pioneering speculative agents who illegally deforest land, plant grass for livestock and then claim ownership for the land. These pioneers do not use their cattle for profit, but merely as a means to claim the land, since utilization of land is prioritized higher than official papers.

At a later stage the pioneers sell their land to cattle ranchers who use the land for production and who are willing to pay significantly more for the already prepared pastures, than what the speculative pioneers invested in them. This second group is called the consolidated frontier and they demonstrate a capitalist behavior with which they want to expand their business activities where it is profitable to do so.

The areas where this deforestation occurs have little or no law enforcement, rendering the risks for the speculators of loosing their land very small and the risk is subsequently almost non-existent for the cattle ranchers who purchase land from speculative agents.

4.5 Land-use dynamics in the south-central region

The majority of sugarcane in Brazil is grown in the south-central region of the country with the state of São Paulo as the main hub of production, with 58% of the country's total sugarcane area (Fischer et al., 2008, p. 40). Sugarcane has been produced in this region for centuries; it started shortly after the Portuguese colonization (Fischer et al., 2008, p. 40) together with livestock ranching and food-crop production.

The south-central region with São Paulo in the center is one of the "oldest" and most developed areas in Brazil and there is little pristine forest or other untouched land left; it is generally below the legal limit of 20% naturally forested land for every landholding. Land has been passed down in generations from fathers to sons and subsequently been divided into smaller and smaller plots*.

An increase in production of any crop has to come from either increases in yields or from expansion in cropping area, an expansion which in this highly developed area has to come at the expense of other land uses. In-

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creases in yields can be achieved through intensification with more inputs into the system; changing breeds/varieties; or through development of the breeds/varieties currently in use.

Most production systems in Brazil are low-intensity systems which do not use the highest yielding breeds/varieties, nor do they use much (or any) inputs into the systems. Yields and profits are thus low, as are land prices and maintenance costs.

The situation for sugarcane is however fundamentally different, where the long history of sugarcane cultivation has resulted in better varieties and production systems, giving ever increasing yields. The environmental conditions are also optimal for sugarcane production regarding temperature, radiation, precipitation and soil characteristics (Fischer et al., 2008, p. 40). Development of sugarcane varieties for further yield improvements is a slow process and the only feasible short-term response to increases in demand thus comes from area expansion.

The sugarcane industry in this area is well developed with defined roles for the actors involved; with the main actor being the processing industry which owns the mills and a large share of the area under sugarcane production. When there is a demand for increased production of ethanol, the industry applies for an environmental permission to build a new sugarcane mill, at the same time as they have dialogues with farmers and landowners in the area to get acceptance and secure a supply of sugarcane.

There are three separate types of suppliers of sugarcane to a mill: the industry itself, which buys land surrounding the mill and produces its own sugarcane; farmers who give up, or move, their current farming activity and instead rent out their land to the industry; and farmers who decide to switch production from their current activities into sugarcane production and thus sell sugarcane to the mill. Common for these three distinct ownership and administrative structures is that they all expand on former agricultural land – mainly grazing land – and thus directly displace mainly meat production, but also dairy and to some degree food crops and soybeans.

Income is the main driver for choice of activity for the farmers, but they generally do not want to sell their land*. The family farmers rather keep their land, but either choose to switch between cattle ranching and sugarcane production in accordance with changes in relative incomes, or they rent out their land to the sugarcane industry if they do not want to or do not have the capacity to invest in, and produce, sugarcane themselves*. The industry itself on the other hand buys and sells land according to an economically rational behavior.

Many of the large areas owned by industrial farms were bought in the past, as it is getting increasingly difficult to buy large areas of land, which have to be bought piece by piece*. In the mid-west it is much easier to buy large areas of land; some farmers sell their land in São Paulo and buy between three or four, and sometimes up to ten, times larger plots of land there; a process that was more common in the past than these days as land prices are increasing also in the mid-west*.

When the sugarcane industry rent land from farmers, they normally write contracts for 5 + 1 years, which corresponds to one sugarcane cycle. The producer thus plants the sugarcane and harvests for five seasons and if the quality of the sugarcane is good enough for yet another year without replanting, they have the right to keep the land for that extra year and harvest it once more. Roads, fences and other infrastructure normally have to be left intact and the land must be left bare (no sugarcane still on it) when the contract period ends; if they do not decide on extending the contract for another cycle of 5 + 1 years.

Prices are negotiated for each plot independently and depends on the soil quality and distance to the mill; the prices are paid in terms of the value of a predetermined amount of sugarcane for each hectare and year, normally between 10 and 40 tonnes in São Paulo*. The value given to the landowner then depends on the value of each tonne of sugarcane when it is delivered to the plant†, which is a function of its ATR (*Açúcar Total Recuperável* – total recoverable sugar). The price per ATR is decided on at a yearly basis by an

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†Each truck with sugarcane arriving at a sugarcane mill gets weighted on its way in and then again on its way out from the mill, to get the weight of sugarcane. A sample of cane is also taken from each delivery and is immediately analyzed in a laboratory, by personnel representing both the processing industry (UNICA) and the growers (Orplana), to determine the ATR of the cane.

organization called *Consecana*. Consecana is based on two main institutions, one that represents the mills, Unica; and one that represents the growers, Orplana*. The president of Consecana is changed every year; every second year the president is from Unica and the vice president from Orplana and every other year it is the other way around. The price of sugarcane is the same for everyone, but based on the ATR. The volume projections are based on previous years, but the prices per ATR on the current year. The latter depends on the market*.

Landowners can in the same way rent out land for cattle production or grain production and they then also get paid in the same way, i.e. the value of a predetermined amount of meat, dairy or crops†.

*Personal communication with *Tecnol. Ac. Álcool* José Rodolfo Penatti, AFOCAPI/COPLACANA.

†Personal communication with Prof. Sergio de Zen at CEPEA - ESALQ, University of São Paulo, Brazil.

4.6 Historical and future ethanol expansion

The total production of sugarcane has increased dramatically since the turn of the century, as can be seen in Figure 4.1. This increase started at just over 110 000 ha in 2001 and reached an incredible 567 000 ha in 2007 (FAOSTAT, 2009), an expansion that mainly has displaced pasturelands and some soybean production (BNDES and CGEE, 2008).

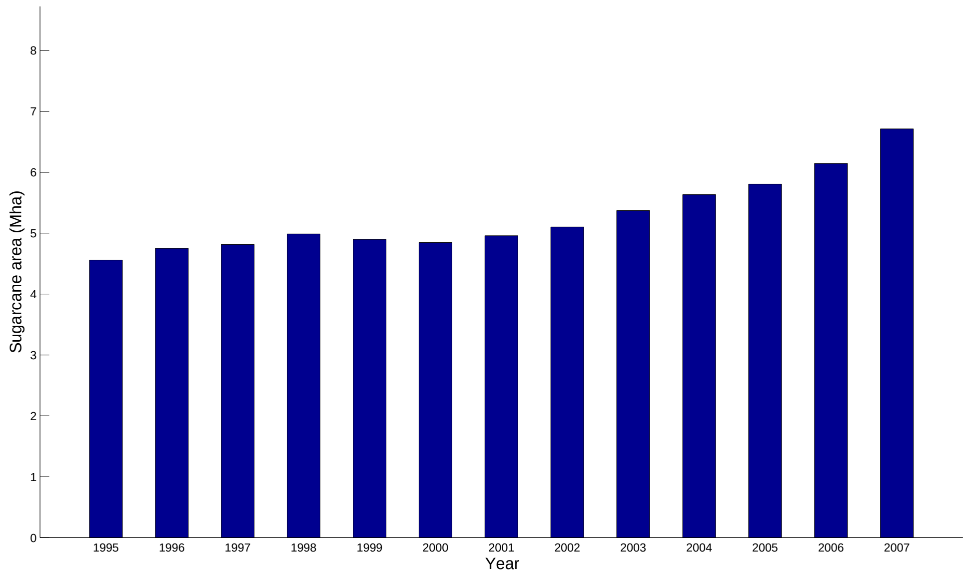

Figure 4.1: Total area devoted to sugarcane production in Brazil from 1995 to 2007. Source: FAOSTAT (2009).

The potential for future expansion of sugarcane production is very large, but there are of course limitations to the pace of expansion. The profitability of brazilian ethanol has been very high in recent years at the same time as the EU and the USA have introduced mandates for ethanol as a share in the transport fuel, which gives reason to believe that the potential pace of expansion probably was reached, or at least close to it. This profitability has decreased substantially in the latter half of 2008, following the economic crisis, resulting in revenues only barely paying for variable costs for ethanol production and leaving no room for profits. The sugarcane mills have also shifted their production to a larger share of sugar and a smaller share of ethanol* to increase their profits and according to the OECD and

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FAO (2009) *Agricultural Outlook* for the coming nine years (Figure 4.2), the expansion of ethanol production will increase at a similar pace in the near future.

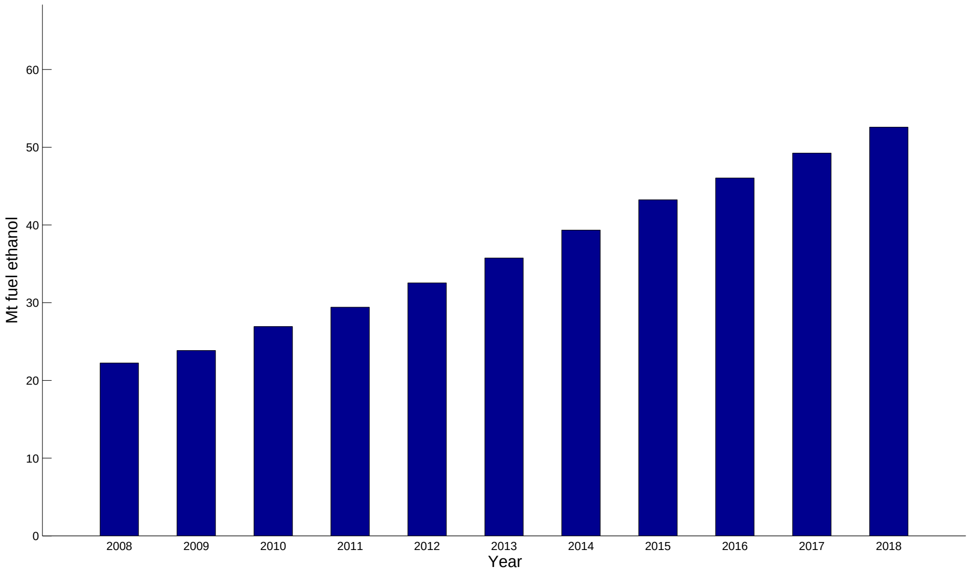

Figure 4.2: Estimated ethanol production in Brazil from 2008 to 2018. Source: OECD-FAO *Agricultural Outlook Database* (OECD and FAO, 2009).

Chapter 5

Constructed model

This chapter begins with a description of the model we developed to study the land-use dynamics in Brazil. The model was mainly used as a tool for understanding these dynamics and points towards gaps in knowledge as described in Section 3.3.2 above and we do therefore not present quantitative results from the model. After the description of the model we give examples of what we would have liked to have incorporated a more complete model, that could more fully be used as what Parker et al. (2003, p. 325) call "a social laboratory". These suggestions on important aspects to include are presented in Section 5.2.

5.1 Description of the model

There are three different types of agents in the model, sugarcane producers, cattle ranchers and food-crop producers, and the agents can also be made heterogeneous within each group since they are assigned different locations and can be assigned different risk aversions. The model was constructed as spatially explicit (using a raster grid). The raster was equipped with some GIS data, however, the geographical data were made up and does not represent any real area. The GIS data used were: type of land; inclination (inclined or plane land); yields for the three different land uses; and locations of agents and markets.

On this environment the agents act and interact as they strive to maximize their own profits.

Since this experimental model landscape was intended to represent only a small area, the prices are exogenously determined for the model. The yields are made heterogeneous by adding a random deviation from a mean yield (for the different land types) as the raster grid is initiated.

Present value calculations

The agents calculate the gross present value* for using each potential new plot as well as their current landholdings. They calculate these values based on yields, prices, costs and their discount rate (which can differ between agents). An investment horizon of 10 years is used in the calculations. There are four different kinds of costs withdrawn from the gross profits; running costs, transport cost inside the farm, transport cost from the farm to the market and finally a conversion cost. The running and transport costs are set low for cattle ranching to represent the traditionally low-cost and extensive beef-cattle production system described in Chapter 4. This makes the cattle-rancher agents choose remote areas for their production.

Conversion costs and time

Conversion costs are introduced for changing land-use to represent the initial investments needed when the land-use changes. This can, for example, be costs for clearing land and planting, as well as costs for changing production systems. Wassenaar et al. (2007, p. 90) use elasticities as indicators of these conversion costs, they set the highest elasticities for forest and the lowest for cropland. We use a different technique based on a conversion cost and a conversion time. The conversion cost is set higher and the conversion time (during which production is zero) longer for forest than for other land types. The conversion costs and conversion times introduce an inertia in the land-use choice and the farmers are thus more prone to stick to their former land use, as is observed in reality (in our study and also in earlier work, see for example Claassen and Tegene, 1999, p. 26). With the conversion costs, the observed pattern that, although monetary aspects are most important, also history matters, is reflected.

Equivalent annual return

To compare alternative land uses with different expected incomes; conversion costs; and conversion times, the agents calculate the equivalent annual return for their respective land use for each plot. This is done since it is hard to compare the irregular cash-flow streams during investment horizons and

*The present value before rental costs.

for agents to know how much they are prepared to pay in yearly rents. The equivalent annual return per year is a recurring cash flow each year during the investment horizon that will result in the same calculated net present value (NPV) as the irregular cash flow streams (Brealey et al., 2007, pp. 198-199). These annualized cash flows can be compared in a fair way, also for differing investment horizons. To calculate the equivalent annual return they use the fact that the NPV of a stream of annuities can be calculated by multiplication with the annuity factor (AF). By calculating the NPV of the irregular cash flows and the annuity factor the equivalent annual return can thus be calculated as:

$$\begin{aligned} \textit{Equivalent annual return} &= \frac{1}{AF_T} \cdot PV_T = \\ &= \frac{1}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^T}\right)} \cdot \sum_{t=0}^{T} CF_t \end{aligned} \qquad (5.1)$$

This equivalent annual return makes it possible for agents to compare returns from different plots yielding asymmetrical cash flows. This could have been done with regular PV calculations but the most important benefit, with this method, is that the rents the agents are willing to pay can be calculated as well. The rents are annuities and the equivalent annual return therefore shows which maximum rent each agent is prepared to pay for each particular plot.

Annual time step

We use an annual time step in this model, since most land-use decisions are taken on an annual basis and it has therefore generally been considered the relevant time step in earlier models (see for example Parker, 2002, p. 67 or Evans and Kelley, 2004, p. 58). In each time step the agents evaluate their land use; they consider the expected annualized return of all plots they currently do not rent, to consider if they want to expand, but also their currently used plots, to know if they want to hire them out. Each agent needs to know how much they expect to earn from their plots as they go into the yearly negotiations with the other agents.

Deciding on rents

In negotiations between the agents rents are set. Each agent wants to expand its land-use if it would increase profits by doing so. The agents start with trying to expand to the plots they believe would generate the highest profits. The rate of expansion is limited by the modeler since we do not consider it reasonable for agents to expand their landholdings too fast. In reality, this expansion is limited by access to capital and other, softer, factors and are discussed more in Section 5.2 below. The agents negotiate their rents until everyone has reached their respective expansion limit or do not want expand their land further; they stop expanding when they do not expect positive returns from additional expansion.

If only one agent is interested in a plot, the rent will be set half-way between the tenant's and the owner's equivalent annual return (as in Berger, 2001, p. 252, who uses the average of the offer and request). If there are several agents interested in a plot the situation is a bit more complex, Berger assigns the rental contract to the highest bidder, as do we, but it seems like he still fixes the rent at *"the average of the corresponding offer and request"* (Berger, 2001, p. 252). This does not seem plausible since another agent could then be willing to pay more in rent and still make a profit. According to economic theory the agents ought to bid up the price of land until all agents but one has withdrawn from the negotiations. We therefore chose to set the rent at the second highest offer, as long as this rent does not fall short of the average between highest bid and the minimum rent the owner request. The last rule was added since we did not want prices to be able to fall if more than one agent is willing to bid for the plot.

Most land in the São Paulo area has private ownership, but we still decided to develop a mechanism for deciding on rent for land not owned by any of the agents, i.e. exogenously (for the model) owned land. If several agents are interested in such a plot the rent is set half-way between the two highest offers. If there is only one interested tenant the rent is set at a default, representing a rent that is demanded by an owner other than our agents, and is thus exogenous to the model.

Reassessing land use and rents and writing contracts

In the beginning of each time step the agents reassess their land use since prices change, factories may have been built or closed down, etc. If they would not reassess their land use periodically, they could be producing on plots with a net loss. In this process the rents are recalculated, according to the same process as above, since we expect the tenant and owner to both have the right to renegotiate the terms.

However, the agents should not be able to give up or renegotiate rental contracts as soon as prices drop and then regain them immediately after prices rise again, there must be more inertia for the model to represent a real system. Therefore, we added the process of writing contracts, described in Section 4.5 above. The tenant and the owner enter into a contract with a duration of five years (base case); we have decided not to include the option of an extra year in the model, yet. During the length of the contract the rent does not change and the tenant stays on the land.

Model interface

The model was constructed using mainly the `MATLAB` programming environment. A graphical interface is used to display the progress of each model run. The graphical representation can be updated every time step or with a lower frequency, depending on the needs of the user. To facilitate testing of how different parameter settings affect the land-use dynamics in the model, `Excel` is used and all parameter settings are gathered in one file, that was designed to be more user-friendly than the m-files of `MATLAB`. Most parameters mentioned above are set in the `Excel` file and for transparency, also the GIS data can be entered in the file if the user desires. Settings from interesting model runs can easily be saved for later use, reruns and reviews. The model is also equipped with various tools for diagnostics which make it easier to analyze the model runs.

Below, in Figure 5.1, an example run of the model is shown to illustrates the model's interface. The figure shows the end result after 30 time steps. During these time steps the agents have initially expanded their landholdings from the initial land allocation; in year 10 a new factory was added at the coordinates (30, 30) and also some relative prices were changed around year 20. Figure 5.2, below, offers a graphical overview over the principal processes in the model.

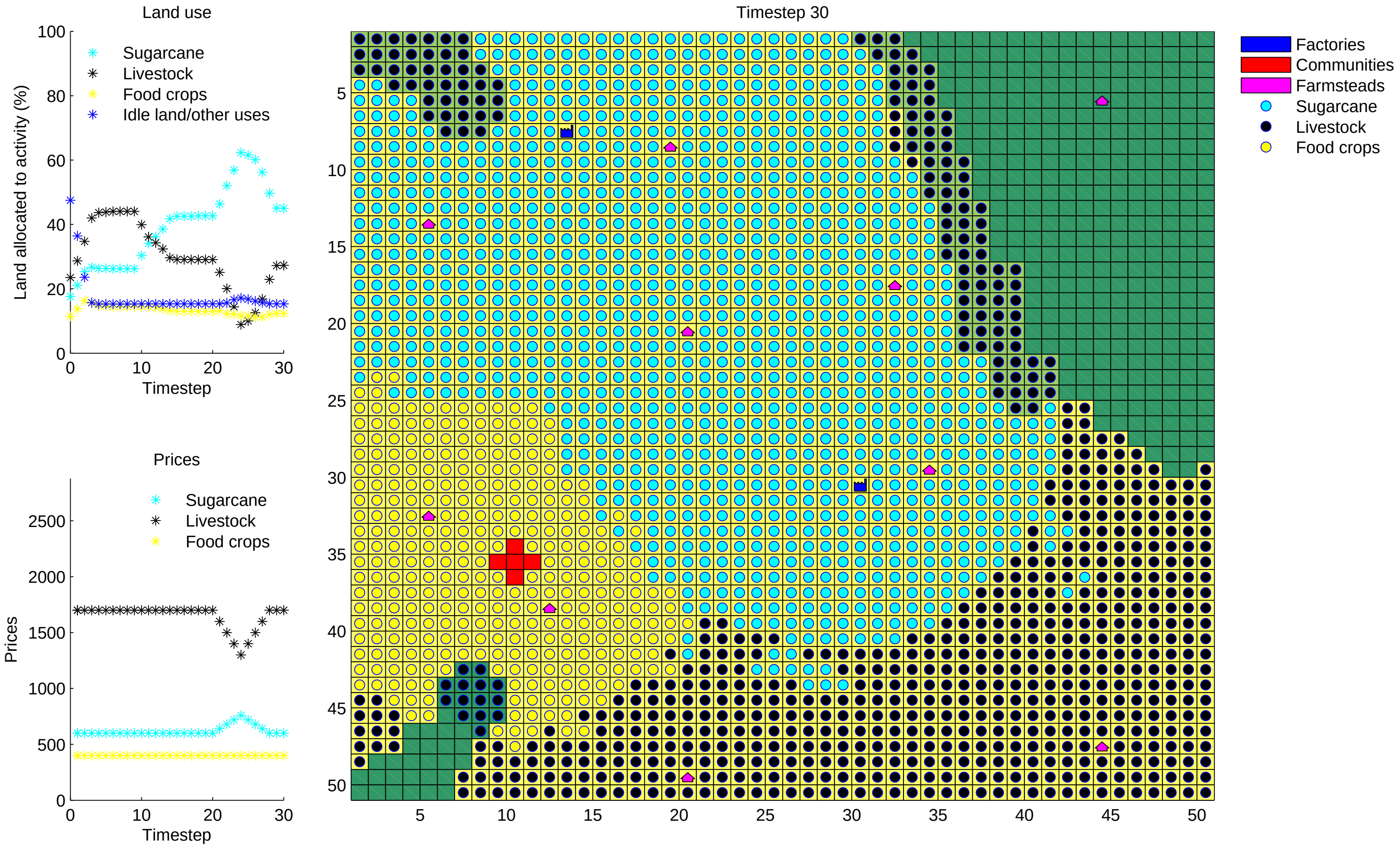

Figure 5.1: Example on a model run in our testing environment. Ten agents are included in this model run, represented by pink houses. The graphical interface displays land use (colored circles), land type (cell color), locations and some history (more information can be plotted but are here excluded to make the picture less cluttered).

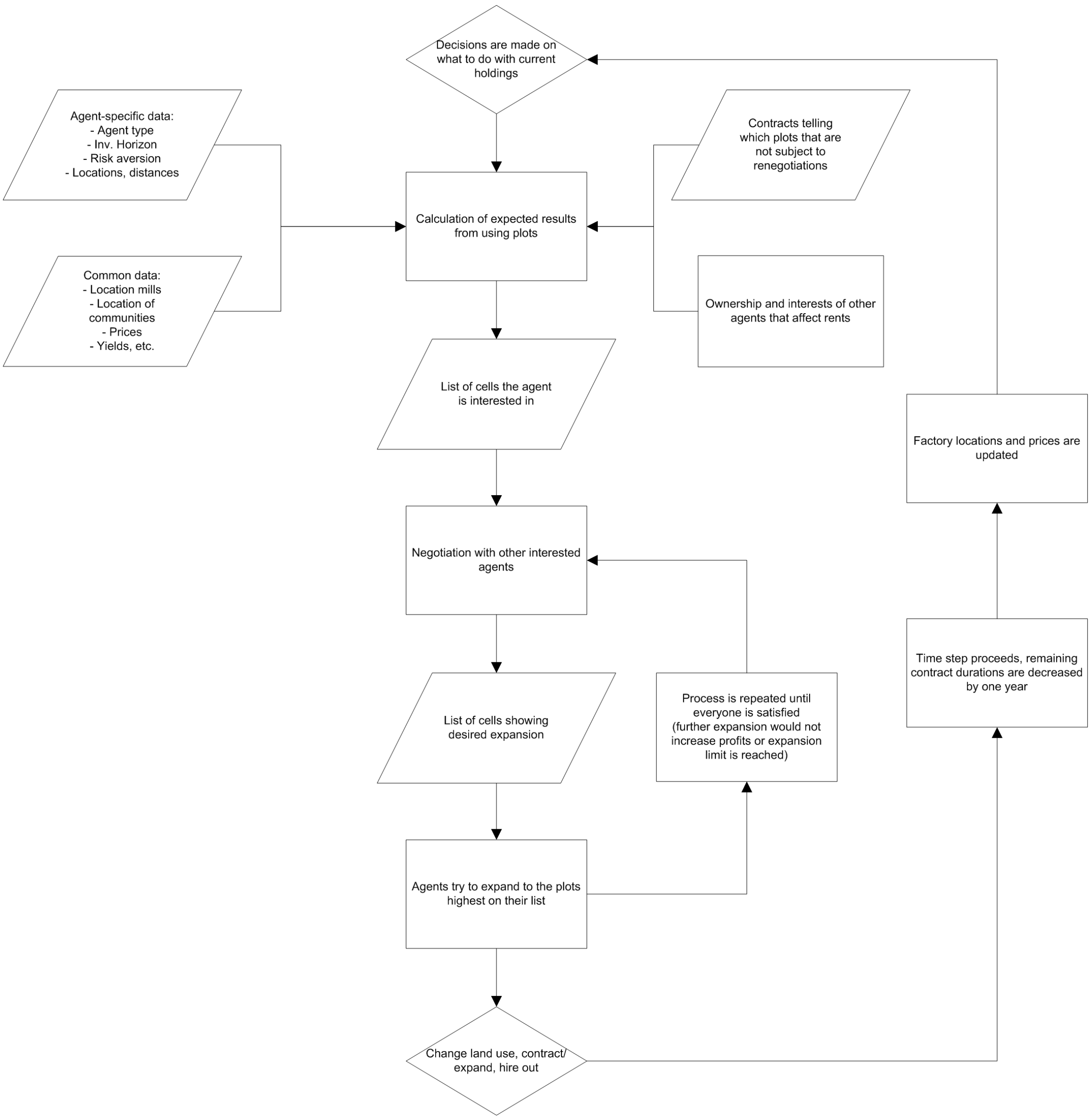

Figure 5.2: Process chart offering a graphical overview over the principal processes in the model.

5.2 Desired attributes

Construction of an agent-based model is a time-consuming process and the model constructed during the course of this project does not include all the attributes we would have liked to see in a more complete version. Some of these attributes, and the reasons for mentioning them, are presented in this section. These additions would help the model better describe the land-use dynamics which we seek to understand. In such a, more elaborate model, tests could be made to indicate or discard importance of many heterogeneities and other attributes not included in other models, i.e. the model could ideally work as a social laboratory for several aspects.

Non-monetary aspects: Other aspects than monetary affect decisions made by landholders. This was found in our studies on the systems and it has been pointed out by other authors. For a discussion on the subject see for example Parker et al. (2008, pp. 791-792) who describe how economic decision models cannot describe human decision-making since it is more complex than profit maximization and risk minimization, or Matthews et al. (2007) who argue that one of the most important reasons for using ABM for LUC is their ability to include non-monetary influences on decision-making.

Evans and Kelley (2004, p. 63) include what they call aesthetic enjoyment in the maximization problem every agent solves. This aesthetic enjoyment is measured on the same scale as the pecuniary aspects. Thereby, they stick to economic decision models, but manage to include non-monetary aspects. The importance of these non-monetary aspects are also made heterogenous between agents by using differing preference weights for activities such as aesthetic enjoyment and/or different types of farming. These preference weights can represent an influence of non-monetary aspects since they demand an extra economic profit before the agents change their land use, a monetary threshold. Also Deadman et al. (2004, p. 701) use a similar approach by assigning agents a random list of preferred crops.

Subsistence requirements: For poorer households, subsistence requirements are often very important and financial returns from farming are less important. This is a complex issue and opinions differ. Koontz (2001, p. 59) propose that financial returns are more important if the landowner depends heavily on his/her ownership for income. On the other hand, many poor households depend heavily on their land ownership for subsistence. Parker et al. (2008, pp. 791-792) suggest that for agricultural land managers subsistence requirements may supersede financial incentives in decision-making. Deadman et al. (2004) include subsistence requirements based on the number of adults and children in each household in their simple heuristics. Including such subsistence requirements would increase the data intensity of the model but may be necessary to correctly represent the dynamics.

Different decision rules: Many different kinds of decision rules have been applied and tested in agent-based models, from simple heuristics to full or bounded rationality (Verburg et al., 2005, p. 9). Deadman et al. (2004) explore if simple heuristics to represent decision-making in their model is enough and find that their model provides *"encouraging results"*. Parker et al. (2003, p. 317) question whether perfect rationality for decision-making in agent-based models for land-use change is reasonable. The perfect rationality would imply that the agents have access to much information and are able to solve complex maximization problems, which may seem questionable.

We believe that more surveys need to be made to see how the decision-making really is carried out. An interesting technique would be to build test models, as we have done, to see exactly what kind of information and calculations the agents would have to use for each decision-making approach and use these results as a basis for interview studies.

Strategic behavior: Just like Berger (2001), we did not include strategic behavior for the purpose of simplicity. Including strategic behavior would probably much improve the models ability to simulate human behavior, but would be difficult to model. Furthermore, as perfect rationality in agent-based models has been questioned, the agents ability to act strategically should be limited (Parker et al., 2003, pp. 317-318).

Capital and investment preferences: In our studies we found that access to capital and investment preferences were important for the investments made. However, we also found that this would be very hard to model. Investments in a production system for cattle could for example depend on the capital accessed by running a completely different business in e.g. a nearby city[*]. As the access to capital does not only depend on incomes from farming the need for data on agents would increase again.

However, if the model should be able to capture expansion limitations in a better way than by using an artificially set expansion limit, as in our model, capital needs and accumulation must be included in some way.

Institutions: As described in Section 3.3, the modeled agents need not be households or individuals but can also be groups or institutions. Some institutions should probably be included in the model if their actions are important for the model outcomes. These agents could for example be cooperatives or sugarcane companies. However, we believe the institutions should not be modeled as agents in the model if their actions actually are governed by processes outside of the model. In that case, their actions can rather be modeled as exogenous influences.

Diffusion of technology and information: Diffusion of technology and information and the following path-dependencies and other phenomena are important parts of complex systems (Parker et al., 2003). This area is one of the strengths of ABMs and one of the reasons for choosing ABM; for example, (Berger, 2001) used ABM to explicitly model technology diffusion. We believe this to be an interesting field of study for the São Paulo area, since the productivity of livestock production systems in Brazil is very diverse and the adoption of new technologies (and the diffusion of information about them) can greatly affect model outcomes. Some stakeholders we interviewed believed that much of the ILUC could and would be avoided by increased productivity in the livestock production systems, but the opinions about the prospects of productivity gains differed substantially between people we interviewed and further research is therefore warranted.

Transport costs and distances: The transport costs in our model depend on Euclidean distances as in for example Balmann (1997). In a better representation of reality the Euclidean distance is not always a good enough approximation but the access to, and type of, roads

[*]An example from a farm which we visited during a field visit just outside Piracicaba, São Paulo state, Brazil.

are more important for transport distances and costs. However, the question is if the effort of, and increased complexity from, including a better representation can be justified by the benefits.

Rental costs: Our model for deciding rents is quite crude and we would have liked to implement bargaining power as another variable affecting the outcome of the negotiations. For example, instead of fixing rental prices half-way between two offers, the result could be skewed in favor of the agent with more bargaining power.

Real-world data: Real-world GIS data and data on agents would of course be useful. The usefulness would depend on the purpose of the model and would be higher if the modeler aims to make predictions. However, also if the model is used in a more explanatory approach (see Section 3.3) the validity of the results would increase with real-world data since model outcomes depend on the choice of data input and real-world data would be both objective and representative of the studied system.

Chapter 6

Analysis and conclusions

From the discrepancies between the partial equilibrium models investigated in Section 3.2, it is evident that the partial equilibrium models alone do not provide the tool needed for quantification of indirect land-use effects. Equilibrium models, both general and partial, are based on economic theory, demanding simplifications of reality, simplifications that make complex dynamics possible to comprehend and help researchers focus on the important dynamics on and between markets. However, these models do not take location into consideration and they assume homogenous agents, agents who are economically rational, or at least behave in the same way as they have done before. They also allow for a subjective judgement regarding which dynamics and other aspects to include in the model.

Any model that can only produce results which are anticipated by the programmer, will be biased according to the preconceptions of the former. Only dynamics and links regarded as important *enough* are incorporated in such a model; other dynamics are omitted because the programmer does not regard them as important, or because he/she is not aware of them, or does not understand them.

This is an area where the methodology of ABM has proven very useful, in the way by which fundamental questions inherently arise during the modeling process. A qualitative understanding of the factors guiding decision-making among and between agents, is necessary to build an ABM representing any system.

The birds-eye view of the top-down macroeconomic perspectives used in equilibrium models have no possibilities of incorporating the micro-level dynamics of person-to-person interactions and individual decision-making. These microeconomic interactions and decisions can however be fundamental in finding cause-effect relationships and indirect effects; microeconomic interactions which are the core of an ABM.

During the process of constructing the ABM described in Chapter 5, we encountered several important gaps in knowledge regarding decision-making and land-use dynamics in the studied region.

An example of this is that most experts on land use in Brazil described monetary reasons as the main, or only, driver for land-use decisions. However, during a field visit we encountered a typical irrational behavior regarding land use: A farmer who chose to switch from sugarcane production to cattle ranching, with the motivation that he believe the cattle to be better for the soil and he thus wants to invest long-term in the land quality rather than in short-term high profit. Other irrational behaviors described by Prof. de Zen*, were that landowners generally never want to sell their land, but rather keep it and hire it out, even though this was not the most profitable option, neither long-term nor short-term. These types of behaviors are not typical of the *economic man* and are difficult to incorporate into equilibrium models. There would need to be studies made with a focus on these behaviors, not driven by economic profit, for incorporation in an ABM.

Heterogeneity like this can be incorporated into an ABM, together with thresholds for at which level of profit the cattle ranching farmer above rather would switch back to sugarcane production—even though his preferences in favor for cattle ranching—and what other factors that are at play. To do this, there would however be a need for extensive field research with interviews of large numbers of landowners, in order to get a statistical distribution of several preferential behaviors; a survey that would cost a lot of money and time. Another factor for using this information to quantify ILUC with an ABM is that such interviews may not even provide the truth; many people do not know what triggers their choices at certain points in time and they can definitely not foresee how they will act at future times in response to drivers they have never encountered before.

Even if the obtained information can be assumed to be plausible enough to hold more or less true in most cases, quantification of dynamics would be difficult. For the model to produce a quantitative output good enough to base any decisions on, the model would need to include so many aspects, interactions and "soft" values, so the complexity of the model would hide

*Personal communication with Prof. Sergio de Zen at CEPEA - ESALQ, University of São Paulo, Brazil.

all transparency and the model would turn into a *black box*. Such an opaque model is difficult to use and the output would be very difficult to interpret in a useful way.

6.1 Discussion

This leads back to the question of whether these models can replace or complement the equilibrium models; and what type of model would be best suited for quantifying ILUC.

Partial equilibrium models are evidently not perfect, considering their shortcomings regarding subjectivity in choice of dynamics; ABMs are not perfect either due to their inherent need for extensive data and tendency to become too complex and opaque.

With one model working on the macro-level and the other working on the micro-level, a hybrid model would probably be a good option for catching several of the important dynamics at different levels without making the model too large and/or complex. This hybrid model could use ABM at the micro-level to produce input for a partial equilibrium model used to study macro-level dynamics; results from the partial equilibrium model would subsequently make up the exogenous variables in the ABM.

By constructing such a model in a thorough way, it becomes necessary to ask fundamental questions – to one self and to interviewees – and to consider connections between important actors at different scales. This inter-scale approach would most likely also help the modeler to make plausible assumptions regarding both large-scale interactions and micro-scale interactions; resulting in good qualitative understanding of the system and its subsystems.

Such hybrid models would, however, not help to overcome one fundamental problem with modeling these indirect effects; the somewhat arbitrary choices of dynamics and their quantitative influence on other dynamics, made by the modeler.

For example, the pioneers speculating in land in the Amazon (described in Section 4.4) will of course continue to deforest land as long as the land use is dynamic and land prices continue to increase. However, quantifying what share of their incentives that can be accredited to displaced cattle production thousands of kilometers away, as compared to the share which is due to globally increased demand for beef, dairy and soybeans, etc. will likely never be possible to do in an unequivocal way.

Maybe the quarrel is a result from a question posed in the wrong way and the political, as well as academic, attention has been focused in the wrong direction since the Searchinger et al. (2008a) publication. After having studied this system and the different types of models, we believe that it is naïve to even try to quantify ILUC. It would be much better to produce biofuels in the most efficient way possible and at the same time focus on eliminating the incentives for deforestation at the agricultural frontiers; both where biofuel production is expanded and where the actual deforestation takes place. A thorough qualitative understanding of the system would be necessary to construct policies eliminating these incentives. If deforestation can be hindered *on-site* – as it should be – the Brazilian sugarcane ethanol has very good climatic performance compared to fossil fuels.

6.2 Conclusion

Before the concluding points we look back at the research question.

> **Research question:** *Is agent-based modeling a good methodology for assessing the dynamics of expanding biofuels production and for quantifying ILUC?*

Our answer to that is yes *and* no. Agent-based modeling is a good methodology for assessing the dynamics of expanding biofuels production, but not for quantifying ILUC.

Computer models, both ABM and equilibrium models, are very useful for studying the systems to qualitatively understand them and thus learn where to direct policies or actions. For such use, an ABM can be used for what they do best – as a social laboratory.

This social laboratory could optimally be constructed in an iterative manner, where a model first is constructed to come up with appropriate questions concerning decision-making, for use in interview studies. Information from the interviews is used to improve the model etc.

By using the results from this ABM as inputs into a partial equilibrium model, a great understanding of the systems may be obtained. This will however not be sufficient for quantitative results.

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