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Norwegian School of Economics and Business Administration

Tropical Agriculture and Deforestation:

Economic Theories and a Study from Indonesia

by

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A dissertation submitted for the degree of dr.oecon.

at the Norwegian School of Economics and Business Administration, Bergen

To the next generation: Jonas, Julie and Sofie

Acknowledgement

Writing a thesis is a solitary journey. A number of people have, nevertheless, contributed to the completion of the work presented here. My main supervisor has been Karl R. Pedersen of the Norwegian School of Economics and Business Administration (NHH). I am grateful for his advice, support and quick response to my draft papers. At times, he gave the necessary pushes to make me move forward and not become too distracted by other commitments (which, by the way, were very interesting). The other members of the advisory committee have been Rögnvaldur Hannesson, NHH and Karl O. Moene, Department of Economics, University of Oslo. I thank Hanneson for his detailed comments, drawing on his broad knowledge of resource economics, as well as his attention to deficiencies in the mathematics. The contact with Moene dates back to the mid-1980s when I was studying for my Master's degree in Oslo, and his influence on my interests and focus underlies the work of this thesis. His insistence on formulating one or a few research questions in each paper, and answer them - and *only* them, has clarified the analysis and made the presentation more focused.

In 1993-94 I spent one year at the Department of Agricultural Economics, University of Wisconsin, Madison, USA. In many ways that year was the "take off" stage in the thesis writing. I am very grateful to Ian Coxhead for arranging my stay in Madison, and for sharing his insights into agricultural and development economics. Moreover, his family's hospitality made the stay all the more pleasant.

The fieldwork in Sumatra during 1991-92, which forms the main empirical basis for the thesis, was part of a multi-disciplinary research project with several European and Indonesian participants (NORINDRA). The year in the "sump" of Pangkalan Kasai was a mixed experience, but the memories become sweeter as time passes. Beyond a doubt, it had a large impact on my understanding of shifting cultivation and the processes behind deforestation. Øyvind Sandbukt and Lene Østergaard shared their insights into the local economy. Stein Holden gave useful advice on the household survey, and also provided valuable comments on later work. Simon Rye deserves honourable mention for being an unforgettable house-mate during that year. We shared the same fate when malaria mosquitoes decided to sample any project member taller than 1.90. When not fighting off insects or killing rats (*rattus norvegicus*), we could spend the small hours indulging in stimulating anthropology *v.* economics conversations. Also the other members of the project created a good working and social environment. Special thanks are due to Yuyu Arlan and Suardi Tarumun for their assistance in the implementation of the household survey. The 196 farm households included in the survey shared willingly information about their household economy and agricultural practices. I am not so sure I would have liked an inquisitive foreigner in my hut asking all those questions we did.

My institutional base during the writing of the thesis has been the Chr. Michelsen Institute (CMI) in Bergen. I am grateful to former director Arne Tostensen and current research director Gunnar Sørbø for their support. I have benefited from their strategy which has included an emphasis on academic merits and a strengthening of the economist milieu at CMI. This has provided the necessary space and freedom in my work towards the completion of this thesis. My economist colleagues have contributed to a stimulating professional and social environment, and I would like to thank Turid S. Bøe, Odd-Helge Fjeldstad, Hildegunn K. Nordås, Ussif Rashid Sumaila and Arne Wiig for comments to my draft papers and numerous discussions. Working at a multi-disciplinary institute has also made me focus on factors often overlooked by economists, in particular, institutional aspects. I thank, among others, Eyolf Jul-Larsen and Are Knudsen, for a renewable flow of anthropological insights and literature on resource management.

In addition to those mentioned above, many people have made comments on the papers included in this thesis. In addition to my supervisors and colleagues at the institute, I would in particular like to thank Stein Holden of the Norwegian Agricultural University at Ås, and Ottar Mæstad of NHH/SNF for detailed comments to various drafts. During the last year or so, my contact with the Centre for International Forestry Research (CIFOR) in Bogor, Indonesia has widened my perspective on deforestation. I have in particular benefited from joint work with David Kaimowitz.

Funding for the work was generously provided by the Research Council of Norway through a three year PhD grant. The Norwegian Ministries of Foreign Affairs and Environment also provided financial support to the fieldwork through the NORINDRA project.

My profound gratitude goes to my family. The support from Gunn Tove has been of vital importance in completing the thesis. I am very grateful for her patience with an -- at times -- absent-minded husband, and for accompanying me to Bergen, Indonesia and USA. Jonas, Julie and Sofie have made me fully aware of the concept of time constraints, but also the values of devotion and love. Their warm "welcome-home-hugs" in the afternoons are invaluable. And they have shown a unique understanding for their father's obligations: "Dad must work now so that no one will come and cut down the rainforest". I gratefully dedicate this thesis to the next generation.

Bergen, March 1997

Contents

Chapter 1
Introduction and overview

1 Aim and focus of the thesis[1]

What are the driving forces behind tropical deforestation? The essays of this thesis focus on the behaviour of agricultural households, their management of natural resources in general, and their expansion of agricultural land by clearing of primary forest in particular. The aim is to understand and predict farmers' behaviour, in order to explore how market conditions, poverty, property regimes, and national policies affect their decisions and thereby the rate of deforestation.

A related aim is to undertake a *structural sensitivity analysis,* that is, to investigate how the model results depend on differing assumptions about the economy. Which policy recommendations to limit deforestation are *robust* with respect to changes in the underlying assumptions? Which policies are *sensitive* to the characteristics of the region in question, and therefore could be counterproductive if the model is wrongly specified.

The debate on the causes of tropical deforestation is characterized by uncertainties and controversies. I argue that some of the controversies in the debate can be understood as a disagreement about the underlying model assumptions. This is highlighted in chapter 2, which compares population and market based explanations of deforestation. Counterproductive policies may originate in a failure to fully include the particular characteristics of frontier agriculture into economic modelling and policy formulation. Agricultural price policies, intensification programmes and land reforms are examples of policies which might yield unintentional outcomes.

The thesis analyzes the problem of resource management and deforestation using different analytical approaches: resource economics, spatial economics, institutional economics, game theory, overlapping generations models, as well as the general body of applied microeconomics in the form of agricultural household models. Some of the chapters represent new applications of these theories to the analysis of deforestation, for example, the combination of forest rotation and spatial models to study shifting cultivation (chapter 3), and the use of formal models to study state - local community interaction in games of forest land appropriation (chapter 6).

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[1] Thanks to Turid S. Bøe, Are Knudsen, Armindo Miranda, Ottar Mæstad and Arne Wiig for comments on a draft version of the introduction.

The empirical part of this thesis is based on a one year field work in Seberida district, Riau province, Sumatra, Indonesia. The district is characterized by traditional shifting cultivation and smallholder rubber. In recent years the competition about forest resources has become more intense due to a large inflow of transmigrants (government resettlements programme), logging, mining, and plantation projects. The study area is in many ways representative for the various actors and forces involved in the process of deforestation throughout the region.

I have tried to use this empirical basis as well as a large empirical, often ethnographic, literature on deforestation in the formulation of analytical models. The application of theories from different fields of economics, when the particular empirical setting of frontier agriculture is incorporated in the models, is a powerful tool in the analysis of the causes of deforestation. This combination yields some unconventional results and produce new hypotheses for empirical testing. It can therefore shed new light on the process of deforestation, and provide alternative explanations of observed phenomena.

The thesis focuses on deforestation caused by agricultural (peasant) households or smallholders. It pays limited attention to other agents of deforestation (commercial farmers, logging companies, etc.), except for their interactions with smallholders. This focus was a natural choice given the selected area for the field work, but can also be justified by two stylized facts. First, expansion of agricultural land by smallholders is estimated to account for roughly half of tropical deforestation, even though there is some controversy regarding the estimates and the role played by peasants, cf. chapter 4. Second, about one quarter of the world's population belongs to peasant farm households (Ellis, 1988).

Parts of the thesis (chapters 3 and 4) deal with shifting cultivation in particular, a group of smallholders practising a cropping - fallow rotation agriculture. Shifting cultivation, also referred to as swidden or slash-and-burn agriculture, is practised by some 250 million people in developing countries. This agricultural practice is normally found at or close to the forest margin where land is relatively abundant (low population density), and is therefore particularly relevant for the study of tropical agriculture and deforestation.

2 Why should one be concerned with tropical deforestation?

Tropical deforestation has in recent years become a global environmental concern, but the exact formulation of the nature of the problem is still inadequate and it also remains a controversial issue. Some analysts are concerned with the consequences of tropical deforestation on global warming, or worried about the effects of habitat destruction on biodiversity; others are preoccupied with the consequences for local communities and poverty; still others fear its effect on the future supply of tropical hardwood. Underlying the general worry about high rates of tropical deforestation, there are also strong conflicts of interests, which result in alternative proposals for the use of tropical forests.

The valuation of environmental services provided by tropical forests -- and thereby the economic costs of deforestation -- is still in its infancy, but there is an emerging consensus on some issues. Climate change related to the greenhouse effect is a major area of concern. The value of carbon storage in the biomass of tropical forests may be several thousand dollars per hectare, assuming that the alternative is emission reductions in rich countries (Pearce, 1994). Panayotou and Ashton (1995) use as a best guess USD 3.000 for the carbon storage function of one hectare of tropical forest, far more than any other functions.

The consequences of biodiversity loss is surrounded by great uncertainty. Tropical forests are estimated to shelter between 50 and 90 percent of the planet's plant and animal species (WCED, 1987), but "extraordinary little is known about the diversity of species on the planet. Even less is known about the rate at which diversity is being lost, and the implications this has for the resilience of the biosphere" (Perrings *et al.*, 1995: 3). The complexity of the ecosystems makes it hard to make even rough estimates.

One aspect of biodiversity has recently been subject to some investigation, namely the pharmaceutical potential of rainforests' biodiversity. The studies indicate that these values are modest, not exceeding 2-3 dollars per hectare (Simpson *et al.,* 1996; Simpson, 1997; Pearce, 1994). "Preserving biodiversity may have little bearing on whether the next miracle drug is found. Better arguments should be stressed in developing conservation policies" (Simpson, 1997: 12).[2]

The value of standing timber appears to be the single most important local or national value of tropical forest, at least among those functions for which quantitative estimates exist. The *aggregate* values of non-timber forest products are in general much less than the carbon storage or timber value (Panayotou and Ashton, 1995). However, these products are mainly extracted by local communities, and may therefore be very significant for some communities. Among the most forest-dependent communities in the study area in Sumatra, some 35 percent of the income is derived from the collection of forest products (see chapter 4).

The key forest conservation problem is that both biodiversity and climate stabilization are *global* benefits which are not captured by the millions of farmers or governments who utilize

[2] The estimates of the pharmaceutical value are, as in economics generally, based on *marginal* values: what is the economic loss in terms of reduced number of species if one additional hectare is lost? The rich diversity of tropical forest is, paradoxically, one reason for the low per hectare value: "With millions and millions of species, sources of useful products are either so common as to be redundant or so rare to make discovery unlikely. Either way, the sheer number involved weaken the argument that biodiversity prospecting generates any appreciable economic value" (Simpson, 1997: 12).

the forest resources and make the decisions. There is a "global appropriation failure" (Brown and Pearce, 1994). Mechanisms for transfers of global willingness to pay to the local resource users could, *in principle,* be established, but there are enormous obstacles of both political and practical nature (cf. Bergesen, 1995). Some schemes have been tried out, mainly on an experimental basis, e.g., debt-for-nature swaps.

The divergence between private and social costs is the fundamental problem underlying excessive deforestation, and also a major reason why one should be concerned with the economic forces of deforestation. An interesting topic would, of course, be how to create mechanisms which enable farmers to capture some of the non-local conservation benefits. This collection of essays does not deal much with this issue. The aim is rather to use economic theories to understand smallholders' behaviour in relation to deforestation. Global benefits of forest conservation are *not* particularly relevant for understanding the variation in behaviour among smallholders, and are therefore ignored in most models. They are externalities for which there are no markets.

The chosen focus of the thesis can also be justified by the difficulties of creating mechanisms for transfer of global willingness to pay for forest conservation to local resource users. At least for the short term remedies to limit excessive deforestation, it may be more useful and policy relevant to focus on national policies which affect farmers' decisions.

3 Deforestation and economic modelling: getting the microeconomics right

A major aim of this thesis is, as already stated, to analyze how the model results depend on the underlying assumptions about the economy. The thesis highlights four crucial aspects in the modelling of agricultural households' behaviour: the market assumptions, in particular for the labour market; the existence of poverty; the property regime or more generally the institutional framework; and the type of resource management problem in question. Each of these topics is examined below.

Market assumptions: the existence of a (perfect) labour market

Agricultural households should be understood in the light of their dual role: they are both a production unit (a farm firm) and a consumption unit (a home of labourers and consumers) (Nakajima, 1986). The combination of these functions is central in the economic theory of agricultural households. A well-known result in this theory is that when households face competitive markets (all relevant prices are given in the markets and the household is not quantity constrained), the decision process in the household is *recursive* (e.g., Singh *et al.*, 1986). First, the production problem (including labour demand) is solved as a profit maximizing problem. Then the profit from agricultural production is carried over to the consumption problem (including labour supply), which is solved as one of maximizing utility. For the study of resource use, labour inputs in different activities play a key role, and the assumption of a perfect labour market is particularly important to get "the recursive property".

In other words, when a household participates in competitive markets, the production problem of a utility maximizing household is one of maximizing profit. The production decisions are the important ones for the study of deforestation, thus we are allowed to ignore the consumption side. This simplifies the modelling exercise significantly. Indeed, many models would be hard to solve and would yield ambiguous analytical results without this assumption. It is therefore commonly used, but as shown in chapters 2, 6 and 7, it also carries strong implications for the results which the reader and even the model builder may not be fully aware of.

When the assumption of perfect markets is violated, the production and consumption decisions must be solved simultaneously as a problem of utility maximization. Internal (endogenous) *shadow, subjective* (Nakajima, 1986), or *virtual* (Neary and Roberts, 1980) *prices* replace market (exogenous) prices. The analysis of farmers' response (comparative statics) can be done in two steps. First, the effect of a parameter change is analyzed assuming constant virtual prices. We refer to this as the *farm firm effect* because it is similar to the response of a farm firm operating in competitive markets. Second, the effect on the virtual price (e.g., shadow wage rate) and, in turn, those prices' effect on the endogenous variables is analyzed. This two-step procedure both simplifies the analysis and clarifies the implications of not assuming perfectly competitive markets.

Virtual prices reflect (also) the consumption side of the agricultural household economy. Many households live close to the subsistence level of consumption and the concern about survival plays a critical role, hence the second effect is labelled the *subsistence effect.* The farm-firm and subsistence effects are equivalent to the substitution and income effects, respectively, in the standard theory of the consumer. Removing the assumption of perfect (labour) markets, and thereby introducing endogenous prices, makes it possible to include in the model a number of new aspects which can affect behaviour, for example, the effects of household composition and poverty.

Poverty and survival constraints

The poverty - environment thesis suggests that poverty causes or escalates environmental degradation because the immediate needs for survival override long-term environmental considerations, often expressed as high discount rates or short time horizons. The poor may also lack the surplus of resources necessary to undertake environmental investments; they are "investment poor" (Reardon and Vosti, 1995). While intuitively appealing, the relative importance of this explanation could be questioned. Furthermore, the causal links are not always clear. It could well be some underlying factors, for example, resource access and control, contributing to both poverty and environmental degradation. Yet, there is an accumulating body of evidence suggesting that poverty plays a critical role in people's management of natural resources.[3]

The poverty - environment thesis has been put forward mainly by economists. It is, therefore, surprising that poverty is rarely integrated in economic models of resource use in developing countries. The common way to introduce poverty has been to add some *ad hoc* reasoning about the effect of high discount rates or low opportunity costs of labour, without including poverty linkages as an integrated part of the formal model. One obvious reason for this is the difficulty of integrating poverty into models which assume exogenous prices, as the subsistence (income) effect is not present, cf. the above discussion of the labour market.

In the thesis I use an additive utility function incorporating a subsistence level of consumption. This formulation is able to capture some essential aspects of how poverty may affect resource use. In chapter 2 (model II) the focus is on the allocation of time between labour (consumption) and leisure. When the consumption level is close to the subsistence level, the shadow price of labour is relatively low, and the subsistence (income) effects will dominate in the response to, for example, technological progress or higher output prices. Chapter 7 models the choice between consumption in two periods when the discount rate for consumption (the consumption rate of interest) is endogenous. If the household is close to the subsistence level in the present period, the discount rate will be high and the subsistence effects will dominate the farm firm effects.

Consumption level	*Labour market assumption*	
	Do not exist (autarky)	*Perfect (open economy)*
Low (poor)	Subsistence (income) effects dominate	Only farm firm (substitution) effects apply
High (rich)	Farm firm (substitution) effects dominate	

Table 1: Subsistence (income) and farm firm (substitution) effects under different assumptions.

The discussion about market assumptions and poverty is summarized in Table 1. The effect of higher agricultural output prices (or equivalently: Hicks neutral technical progress) is central in the deforestation debate, and can be used to illustrate the importance of the underlying assumptions for the results and policy implications. Consider first the case of a perfect labour market. Higher prices will increase deforestation as frontier agriculture becomes more profitable, and therefore attracts more labour, for example, through migration.

3 See Leach and Mearns (1992) and Kates and Haarmann (1992) for overview studies.

In an autarky with no off-farm labour market there will be two opposite effects of an output price increase.[4] The farm firm effect suggests increased agricultural production as the value of marginal productivity of labour has increased, whereas the subsistence effect pulls in the opposite direction: the subsistence target can be met by less labour input and a smaller land area. The model in chapter 2 suggests that for poor households the latter effect will dominate. The need to survive rather than income maximization determines their behaviour. Such poverty conditioned behaviour is also analyzed in chapters 6 and 7.

Property regime: deforestation as an investment and title establishment strategy

At least since Gordon (1954), the issue of property rights has had a central position in economic theories of resource management. Common property and open access regimes are generally thought to be predisposed to overexploitation of resources: the incentives to the individual users for conservation are small when the resource is shared by many.

Some caveats to this general proposition are necessary when applied to the issue of tropical deforestation. First, it is necessary to distinguish between common property and open access. Various forms of communal management of common resources do exist.[5] Hardin's (1968) "tragedy of the commons" should have been coined the "tragedy of open access", as repeatedly stressed in the post- and anti-Hardin literature.[6]

Second, communal management regimes are commonly termed "common property". This confuses the issues of (1) the level of enforcement of the rules (the community), and (2) the agent holding the important property rights. In communal management systems the income and use rights typically rest with individual households, whereas transfer rights are restricted and rest with the community. The latter right (i.e., the possibility to sell the land) is generally less important to farmers than the income and use rights. Hence we may have *communal management of mainly individual rights*, and therefore a strong resemblance to a system of formal private property (freehold).

More generally, the particular institutional framework for the utilization of forest resources should be taken into account. This topic is discussed at some length in chapter 5, but also in the other chapters. The institutional setting in general, and the property rights regime in particular, strongly affect the resource use incentives, i.e., the costs and benefits of different resource use options.

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4 As shown in chapter 2, the critical factor is whether the household is constrained or not in the labour market, rather than the existence of an off-farm labour market. To simplify the overview we consider the extreme cases with a perfect labour market and with no market.

5 See Baland and Platteau (1996), Ostrom *et al.* (1994), and Sethi and Somanathan (1996) for game theoretic discussions of the existence of such cooperative outcomes.

6 See Knudsen (1995) for a review.

Most tropical forest is *de jure* state property, but the remoteness and lack of institutional capacity to enforce government regulations commonly make forests *de facto* open access resources, unless some form of local/communal management exists. There are few restrictions on migration to the frontier, and property rights to virgin forests -- if they exist on paper -- are rarely enforced effectively. Further, in many frontier areas forest clearing and cultivation give farmers land rights. This way of gaining land rights is common in customary law throughout the tropics, and is also manifested in statutory law in some countries. Forest clearing is a way for farmers to acquire new land, and should therefore be modelled as an *investment*. It can also be a first step in a process to obtain formal titles to the land, and deforestation becomes a *title establishment strategy*. This has significant implications for the model results and policy recommendations, as discussed below.

Two types of resource management

Resource management is often considered a problem of balancing the various services provided by a resource or an ecosystem, both between short and long term uses, and between different kinds of services, e.g., productive *v.* protective functions of a forest. This approach is useful for normative analysis, that is, for an almighty social planner that shall determine the optimal plan for resource utilization. To apply this approach to descriptive studies of actual resource use may, however, be misleading because of the existence of market failure. Closely related to the previous section, and as elaborated particularly in chapters 2 and 3, it is critical to distinguish between two broad classes of issues of resource management in tropical agriculture:

First, the use of resources which the farmers already control. An example is the management of soil fertility (erosion) of existing agricultural land, which appropriately could be modelled using a social planner's approach. Soil conservation is an investment to the farmer as well as to the society at large.

Second, the use of resources which the farmers do not have established property right to, as exemplified by clearing of new forest land. From the farmers' viewpoint, forest clearing (deforestation) is an investment, whereas it may be a disinvestment from a social viewpoint.

Factors which in general promote higher investments (e.g., lower discount/interest rates, and higher tenure security) may have favourable environmental effects on the first set of environmental problems (soil conservation), but negative effects on the latter (promote deforestation). Again, the distinction appears simple and obvious, but many deforestation models fail to clearly distinguish between these two cases (cf. chapter 2: section 10). Typically, models suitable for problems within the first category are applied uncritically to the problem of deforestation.

These results have important policy implications. For example, land reforms which increase tenure security may enhance soil conservation, but also promote deforestation in a situation where land rights in the first place are based on forest clearing (as often is the case). Land investments become less risky and therefore more attractive. Land titling can therefore stimulate a local race for property rights to forest land and fuel deforestation.

4 Outline of the thesis

The chapters of this thesis approach the problem of local resource use and deforestation from different perspectives. Table 2 gives an overview of different issues dealt with in the six chapters. First, I want to clearly distinguish between the type of resource management being analyzed, as just discussed. Second, the chapters -- reflecting the deforestation debate -- focus on different driving forces behind changes in local land use practices. The focus is often linked to key modelling assumptions, for example, the distinction between the population and market approaches is closely related to the labour market assumption.

Local resource use problems:	*Driving forces:*		
	Population and poverty (population approach)	*Relative profitability (land rent) (market approach)*	*State - local conflicts (political economy approach)*
Management of present agricultural land (intensity, soil conservation, titling, etc.)	7	3, 5 (7)	5
Expansion of agricultural land (deforestation)	2 (4, 6)	2, 3, 4 (6)	5, 6 (4)

Table 2: Main issues being analyzed in different chapters of the thesis.

Chapter 2 provides a broad overview of different approaches related to agricultural land expansion, comparing the population and market approaches. Chapter 3 narrows the market assumptions (only the case with exogenous prices), but extends the analysis to also include labour input and fallow period (intensity of production) as decision variables in addition to land area (deforestation). Based on the theories developed in the two previous chapters, chapter 4 discusses the recent development in the study area of Seberida, Sumatra.

The discussion in chapter 5 focuses on two driving forces in the development of private property rights in traditional agriculture: increased land value, and state-local community conflicts. The effects of these forces are manifested both by changes in the use of land already in agricultural production (intensification, crop choice and titling), and by an expansion of agricultural land. The formal model of chapter 5 discusses only the effect on land under cultivation. Chapter 6 uses game theoretic models to study the effect of state-local community conflicts on land expansion.

Chapter 7 differs from the previous chapters by not dealing with deforestation, but only the first set of local resource use problems. It shares, however, some analytical features with chapters 2 and 6 in its explicit recognition of farm firm and subsistence effects, and their relative strength being dependent on the existence of poverty.

More specifically, *chapter 2* compares four different models of agricultural expansion and deforestation. The paper explores the policy implications of different assumptions regarding the household preferences and level of poverty, the labour market integration, and the property rights regime. The four approaches are:

1. *The subsistence or "full belly" approach:* the households' objective is to reach a certain subsistence target, with the minimum labour input. No off-farm labour market exists.
2. *The Chayanovian approach:* a utility maximizing household, balancing consumption and leisure, is introduced. The household is quantity constrained in the labour market.
3. *The open economy, private property approach:* off-farm employment is available at a fixed wage rate, thus production decisions can be studied as land-rent maximization.
4. *The open economy, open access approach:* the market assumption is as in 3, but forest clearance gives property rights.

We label the first two approaches *population* based explanations of deforestation, whereas the third and fourth are *market* based. To illustrate the magnitude of the effect of exogenous changes and the differences between the models, a numerical simulation is presented. In addition, a discussion of the results and their policy implications is included.

Chapter 3 studies decision making in shifting cultivation related to labour input, length of rotation or fallow period (intensity of production), and the area of cultivation or agricultural frontier. The analytical models combine forest rotation (Faustman) and spatial (von Thünen) approaches. All prices, including the wage rate, are exogenous in the models (small, open economy). Three different property rights regimes are discussed: social planner's solution with secure rights to all forest land, open access, and homesteading where property rights are established through forest clearance. The main force towards intensification in terms of shorter fallow periods and land expansion (deforestation) is lower effective real wage, which in turn is determined by five variables: agricultural output price, nominal wage, technological level, transport costs, and distance from the centre. Many governments aim to both intensify cultivation and limit expansion (deforestation) of traditional agriculture. The paper suggests a trade-off between these objectives; policies which stimulate intensification will also lead to an expansion of agricultural land.

Chapter 4 reports on a field study in the Seberida district, Riau province, Sumatra, Indonesia, which is part of the largest remaining lowland rainforest area on the island. The chapter first discusses the role of traditional agriculture (shifting cultivation) in the deforestation process. It questions the share of responsibility assigned to traditional agriculture, estimated to about half of total deforestation. It may well be overestimated because of unclear definitions, uncertain estimates, and potential political biases. The framework for land rent capture developed in the two previous chapters is used to explain recent changes in shifting cultivators' adaptations. Increased rubber planting and expansion into primary forest are seen as a response to increased rubber profitability and (expected) land scarcity, and as a race for property rights. Government land claims have had significant multiplier effects on forest clearing through changes in farmers' expectations and in initiating a self-reinforcing land race.

Chapter 5 takes as its starting point a universally observed tendency of common property to be replaced by private property in traditional agriculture, termed the evolution of private property rights (EPPR) hypothesis. This process is closely interlinked with expansion of agricultural land. The chapter seeks to explore the forces behind EPPR. Four different theoretical approaches are discussed: neo-institutional economics, which focuses on increasing land value; Marxian, class-based explanations; a state-local perspective, focusing on predatory state intervention and lack of respect for local, customary law; and a cultural explanation based on a "commoditization of land" hypothesis. These approaches are discussed in relation to the development in the study area in Sumatra. A framework which integrates elements of all approaches is outlined, using a "demand and supply for institutional change" metaphor. In particular, the neo-institutional and the state-local approaches are found to be relevant to explain the evolution of private property rights. The paper also develops a formal analytical model which endogenizes farmers' decisions about tenure security. It illustrates how the results of conventional economic models can be modified when institutional factors are included in the analysis. Higher risk of losing land due to an increase in external claims to local land, for example, could result in higher intensity due to the security-enhancing effect of high intensity of cultivation. Similarly, land titling programmes do not necessarily increase the intensity, as land titles and high intensity are alternative means of securing land rights.

Chapter 6 analyzes strategic interactions between the local community and the state. Two key questions are addressed in the paper. First, how does the structure of the game affect the total level of deforestation? Second, under which circumstances does higher forest appropriation by the state promote local deforestation? Three different cases are discussed, corresponding to a development over time towards increased forest land competition and integration of the local community into the national economy. Particular attention is given to the assumptions made about the local economy and the local costs of state deforestation. The local response to more state appropriation depends critically on these assumptions, and less on the structure of the game (Cournot or Stackelberg). The state will fuel local deforestation if state deforestation is associated with provision of infrastructure (roads) which reduces the local costs of agricultural expansion, or if the local economy is isolated (autarky) and local behaviour is determined by survival needs rather than maximization of income (income effects dominate substitution effects).

Chapter 7 explores the incentives for resource conservation and long term resource dynamics in a traditional agrarian economy, i.e., a resource dependent economy with no external markets for labour and credit. The paper develops an overlapping generations (OLG) model: the young generation is responsible for production and resource investments, while the old receive a share of the output. This structure provides incentives, although not perfect, for resource conservation which are not found in conventional OLG models. In this way the paper adds to the debate on why a strong emphasis on resource conservation appears to be an important feature of such societies. The second main theme is the impact of poverty on resource investments and the resource dynamics, and how the consumption level affects the response to exogenous changes. The paper shows how a vicious circle of poverty may lead to resource exhaustion if the initial resource stock is below a critical level.

5 Some major conclusions and policy implications

A major theme of the thesis is how different assumptions about the structure of the economy (markets, poverty, and property regimes) and the formulation of the resource management problem affect the model results and policy recommendations? A first and apparently trivial conclusion is that these assumptions matter, although the exact implications often are not readily seen. Compared with the existing body of literature on economic models of deforestation (see Kaimowitz and Angelsen (1997) for a review) and the conventionally received wisdom on policies to reduce deforestation (e.g., World Bank, 1992), this conclusion is, nevertheless, not a trivial one. The thesis demonstrates the importance of "getting the microeconomics right".

One implication is then that there is no blueprint solution to the problem of deforestation. The policy design must take account of the particular economic structure of the region. If, for example, the region is relatively open with good opportunities for migration, the effect of policies which increase the profitability of agriculture will be to promote deforestation. In this case there may be an unpleasant conflict between poverty reduction and reducing deforestation: policies which aim to improve the conditions for the poor living at the forest frontier will also attract more people and thereby increase deforestation.

If, on the other hand, the region is relatively closed with widespread poverty and little off-farm income, policy measures which increase the income from agriculture could reduce deforestation. The households' adaptation and response are determined by survival considerations (subsistence effect dominates farm firm effects). In the presence of poverty the survival constraint dominates in the decision making. Applying standard economic measures such as Pigouvian taxes on a resource degrading activity (e.g., agriculture) will in this case *increase* the environmental problem. The poverty problem must be solved before one can expect a "normal" response to economic policy measures.

A major lesson from this discussion is the need to focus on the structural properties of the economy, in particular how the labour market operates. The role of property rights has been a key issue in the debate on natural resource management in tropical agriculture, and rightly so. This thesis shows that for the effect of some economic policies, the labour market assumption may, in fact, be more important than the property regime assumption. This may suggest a change in the focus of empirical research in this area.

All said and done, what drives deforestation? We summarize some major lessons in the following points:

First, one should question any simple and universal answer to the question. In the open economy or market approach, relative profitability is the key notion; in the subsistence or population approach the subsistence demand of the population is the driving force.

Second, technical progress, higher agricultural output prices, subsidized inputs, intensification programmes, etc. can be expected to have mixed effects on deforestation. The overall evidence suggests, however, that higher output prices promote deforestation.[7] "Full belly" determined responses may exist at the farm level, but are much less likely at the aggregate level when medium and long term migration effects are taken into account.

Third, property regimes where land rights are established through the felling of trees create perverse incentives for forest conservation. Land titling programmes may therefore have unintentional effects on deforestation by stimulating local "land grabbing".

Fourth, improved accessibility, in particular new and better roads, appears to be among the single most important factors in fuelling deforestation and in explaining differing rates of deforestation between regions.

Fifth, creation of alternative employment (off-farm jobs) will reduce the pressure at the forest margin. As for the role of roads, this is a robust policy conclusion in the different models, and is also supported by several empirical studies.

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[7] See Kaimowitz and Angelsen (1997) for a summary of empirical studies.

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Chapter 2

Deforestation: Population or Market Driven?

Different Approaches in Modelling Agricultural Expansion*

Abstract:

The debate on causes of and remedies for tropical deforestation is often confused because the underlying assumptions of the arguments are not made explicit. This paper compares four different modelling approaches to agricultural expansion and deforestation, and explore the implications of different assumptions about the household objectives, the labour market, and the property rights regime. A major distinction is made between population and market driven approaches, and the labour market assumption is critical in this respect. Many of the popular policy prescriptions are based on the population approach. The paper shows that within a more realistic -- particularly for the long term effects -- market approach, well intentioned policies such as intensification programmes may boost deforestation. Many frontier agricultural systems are also characterized by open access where forest clearing gives farmers land rights. Deforestation therefore becomes an investment to the farmer and a title establishment strategy. In this situation, land titling and credit programmes may increase deforestation.

* An early version of this paper was presented at the CIFOR and UNU/WIDER workshop on "Theories and Modelling of Tropical Deforestation", Bogor, Indonesia, 20. - 23. January, 1996, and is published as CMI Working paper 1996: 9. I am grateful to the workshop participants, and David Kaimowitz in particular, for several useful comments. I have also received valuable suggestions from Neil Byron, Turid Bøe, Richard Culas, Odd-Helge Fjeldstad, Stein Holden, Karl O. Moene, Richard Moorsom, Ottar Mæstad, Karl R. Pedersen, Fred Schroyen, Bertil Tungodden, Jerry Vanclay and Arne Wiig. The usual disclaimer applies.

1 Introduction

A major dividing line in the debate on the causes of tropical deforestation is between explanations emphasizing poverty and population growth as the driving forces (the population approach), and explanations emphasizing market factors such as prices, access costs and property rights (the market approach). Much confusion is created because the underlying assumptions are frequently not clearly described, and the arguments jump from one approach to the other. Moreover, some debates could be understood as differences in the approach applied, such as the debates on the effects of aid programmes targeted on poor farmers, of artificially low agricultural output prices, and of boycotts of tropical timber in Western countries.

The public and partly also professional debate on tropical deforestation is also bewildered because a number of distinguishable issues are pooled together. It is imperative to distinguish between different agents or sources of deforestation. This paper will focus on the share of tropical deforestation that relates to agricultural expansion, estimated at about 50 percent (UNEP, 1992; Myers, 1992). This is the result of decisions taken by numerous farming households in response to the prevailing economic environment. These decisions are generally beyond the direct control of governments, and are often referred to as "unplanned" deforestation. The paper will not consider the other main source of deforestation, that is, large-scale, (often) state-sponsored projects such as logging, plantations and infrastructural developments. This "planned" deforestation is commonly linked up with vested interests, and is more appropriately studied within a political economy perspective.[1]

Another source of confusion relates to the framing of the decisions of agricultural households. This paper argues that decisions about agricultural expansion (deforestation) in many frontier areas should be modelled as an investment decision, because forest clearing commonly gives farmers rights to the forest. Deforestation is a title establishment strategy. This contrasts with a conventional framing of resource use decisions which emphasises the trade-off between different forest services, and the intertemporal aspect of these. It is critical to distinguish both in theoretical models and in policy analysis between land expansion (deforestation) and management of resources which the farmers already control (e.g., soil erosion). The models presented in this paper only deal with the first set of decisions.

Closely related to this distinction, the paper challenges some conventionally held views on the causes of and remedies for tropical deforestation. In particular it shows how well intentional programmes for intensification, land titling or credit expansion may increase deforestation.

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[1] The terms "unplanned" and "planned" deforestation that are frequently used by governments, may be misleading, partly because they represent a state-centred perspective which indicates that planned deforestation is socially desirable whereas unplanned is not. Others have coined the terms "the needy and the greedy" to describe the two main groups of actors in the deforestation process, a term which captures some characteristics, but the poetic appeal is stronger than the analytical.

An aim of this paper is to contrast the assumptions, conclusions and policy implications of four different approaches in the modelling of agricultural expansion and deforestation. "The lack of empirical evidence [on the links between deforestation and government policies] magnifies the importance of using an explicit analytical framework when drawing conclusions about this important policy issue" (Deacon, 1995: 17).

The four approaches are defined by varying the assumptions related to three factors: the household's preferences, the labour market integration, and the property regime. A major reason for focusing on these factors is that these show great variation throughout developing countries, and the models should reflect this. Moreover, the policy implications may depend critically on the assumptions made. An additional aim is therefore to identify policies which are *robust* in the sense that the effect on deforestation does not depend on the modelling approach.

The outline of the paper is as follows: section 2 gives the basic assumptions and structure of the models. Section 3 discusses further the differing assumptions in the four models. Sections 4-7 present the four different models:

I. *The subsistence or "full belly" approach:* the households' objective is to reach a certain subsistence target, with the minimum labour input. No off-farm labour market exists.

II. *The Chayanovian approach:* a utility maximizing household, balancing consumption and leisure. Off-farm employment exists, but the household is constrained in the labour market.

III. *The open economy, private property approach:* unconstrained off-farm employment is available at a fixed wage, thus production decisions can be studied as land-rent maximization.

IV. *The open economy, open access approach:* the market assumption is as in 3, but forest clearance gives property rights.

We label the first two approaches *population* based explanations of deforestation, whereas the third and fourth are *market* based. Section 8 compares the four models, and discusses how the models can be extended, particularly to include general equilibrium effects. To illustrate the magnitude of the effect of exogenous changes and the differences between the models, a numerical illustration is given in section 9. Section 10 provides a further discussion of some policy implications, while section 11 suggests some extensions of the models. Section 12 gives some remarks on empirical testing of different approaches. The final section concludes.

2 Preliminaries

Farmers make a number of decisions that are potentially relevant for the management of natural resources: area .of cultivation, crop choice, labour and other inputs, soil conservation investments, cropping and fallow periods, etc. In this paper we will focus exclusively on the determination of the area of cultivation and thereby the extent of deforestation. The simplification is justified on several grounds. First, we are able to derive explicit results and formulas for the extent of deforestation, which should also permit empirical testing. Second, the models illustrate the main differences between the approaches, and the approach chosen initially is normally more important than later refinements within the different approaches.[2]

In addition to the option of being converted to agricultural land, forests provide a number of services, including protective functions (biodiversity, carbon sequestration, climatic and hydrological stabilization, etc.) and the provision of non-timber forest products. These are not included in the models. This does not, of course, imply that they are unimportant, but for the understanding of agricultural expansion they are less relevant. Most of these functions have strong public goods characteristics, and are therefore mostly ignored in individual decision making. It would be relevant to include these in a discussion of optimal rates of forest conversion and first best solutions with markets for environmental public goods, but this is beyond the scope of this paper.

Yield and area of cultivation

The yield or output per hectare (ha) of land (x) represents the optimal crop (or crop mix), and is taken as exogenous in the models. Thus one important aspect not covered is the crop choice, which is a significant variable for the environmental effects of forest conversion. x also reflects the technological level. This formulation further implies that the elasticity of total production (X) for a household with respect to land is one. This may be a strong assumption in models I and II where only family labour is used.

(1) $X = xH$

H is the total land area. We use the output price as numéraire in the models; thus x is also to be interpreted as the *value* of output per ha. We assume that x increases per time period at a rate g, due to technical progress or higher output prices. As it turns out, this assumption is relevant only in model IV.

The models take the von Thünen (1826) approach: land is abundant and homogeneous, and the limit on expansion is costs related to accessibility (walking, transport, etc.), as measured by distance from a centre.[3] The approach can be given both a micro (village) and a macro (regional) level interpretation. At the micro level, one may think of a village centre, where all people live, surrounded by forest of equal quality. The main distance costs will be to walk back and forth to the fields. Locations beyond a certain point have too high costs to make cultivation worthwhile. A macro level, and more abstract, interpretation would be to rank all forest land according to

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2 Including more endogenous variables would complicate the models significantly, but not change the direction of the main conclusions when it comes to the effect on deforestation of various exogenous changes. See Angelsen (1994) for a discussion of the open economy case with labour input and fallow period as decision variables in addition to the area of cultivation.

3 This does not apply to model I, where transport costs are unimportant.

accessibility. Under the micro-interpretation, *total* agricultural land will be a circle around the village;

(2) $$H^T = \pi(b^{\max})^2 = \int_0^{b^{\max}} 2\pi b \, db$$

b is distance from the village centre to the field, and b^{max} is the maximum distance at which cultivation takes place, that is, the agricultural frontier. In models I-III the focus is on a representative household, hence we assume that land is shared equally between the N village households, such that each household gets a $1/N$ fraction of the circle (see discussion on property regimes in next section). Land is not necessarily under continuous cultivation. We define m as the inverse of the share of land under cultivation; $m \equiv \frac{C+F}{C} \leq 1$, where C and F are the length of the cropping and fallow periods, respectively. m is Boserup's (1965) land use intensity factor. Land area under cultivation by the household is then given by;

(3) $$H = \frac{\pi}{mN}(b^{\max})^2 = \int_0^{b^{\max}} hb \, db; \quad h \equiv \frac{2\pi}{mN}$$

The assumptions reflected in (3) are important i models I-II, where the total agricultural income plays an important role. In an open access situation, it is more reasonably to assume that new migrants have to occupy land at the forest margin, and the focus should then be at the migration equilibrium under this assumption.

Labour input and distance costs

We include two types of labour cost in the models. First, there is on-the-field labour related to clearing and preparation of the field, weeding, pest control, harvesting, etc. Given the assumption of fixed yield, on-the-field labour is exogenous and set to one. Second, there are costs related to the location of the field, as measured by the distance from the village (b). These may be thought of as time spent on walking between the fields and the village, and is therefore also a kind of labour cost. A number of alternative formulations of the distance (transport) cost function is possible. We have chosen a specification which is both simple and has some intuitive appeal. It assumes distance costs to be proportional with both distance and time working on the field per unit land.[4] Total labour input per hectare (both walking and on-the-field) is; $l = 1 + qb$, where q is labour time spent on walking or transport per km per unit labour on the field. Total labour input for a representative household is then;

(4) $$L = \int_0^{b^{\max}} (1 + qb)hb \, db$$

Note that unlike for total production we cannot simply multiply total labour input per hectare (l) by total area (H), as l varies with distance.

[4] The linearity assumption has could easily be modified in the models, but would not change the qualitative results. In the numerical simulation we test the implications of assuming that time spent on walking per km is convex in distance (section 9). See also Angelsen (1994) for a further discussion of this formulation.

The location costs are key elements in the models. In reality, there are several dimensions to such costs. Chomitz and Gray (1994) use both distance to the nearest road and travel time to the nearest market as determinants of the output and input prices. In our model, the cost related to a distant location from the village centre is included, whereas the disadvantage of a remote location of the village from a regional trading centre is not. This could appropriately be included by adjusting the output price. This would certainly be an important element in empirical models, but it adds little to our analytical model where the key feature is declining land rent as agricultural area expands.

3 Differing assumptions in the four models

The four models presented differ in three critical assumptions regarding (i) the household's preferences and objective function, (ii) the market assumptions -- in particular the labour market integration of the village economy, and (iii) the property regime. The assumptions are summarized in Table 1, and elaborated below.

Model	*Households' objective: utility maximization*	*Labour market*	*Property rights regime*
I: Subsistence ("full belly")	Minimize labour, given subsistence target (lexicographic)	No labour market	Private (or communal)
II: Chayanovian	**Trade-off between consumption and leisure**	**Labour market exist, but households are quantity constrained**	Private (or communal)
III: Open economy, private property	Maximize profit from production	**Perfect labour market**	Private (or communal)
IV: Open economy, open access	Maximize profit from production	Perfect labour market	**Open access, property rights established by forest clearance**

*Table 1: Different assumptions in the four model (changes compared to previous model in **bold**).*

Household's preferences and objective function

A widespread view is that people in "traditional" societies are less oriented towards material consumption than in "modern" ones. People are only interested in income as a means to cover their basic consumption needs; when these are covered they prefer more leisure to higher consumption. This implies lexicographic preferences; the households' objective is to reach a subsistence target with the minimum of labour effort. Stryker (1976) and Dvorak (1992) are examples of rural economy models applying this objective function. Model I in the paper uses this assumption.

The standard formulation in the agricultural household literature is to assume that households maximize utility, allowing for substitution between consumption and leisure (see particularly Singh *et al.*, 1986; Nakajima, 1986). The households face a trade-off between the drudgery or disutility of work, and the utility of consumption. The main tenet is that the household, even without being in touch with markets, will reach a "subjective equilibrium" (Nakajima, 1986), which resembles the equilibrium when facing competitive markets for labour and output.[5] A subsistence level of consumption could be included in the utility function. Models II-IV are based on this approach, with the modification for models III and IV as given below.

Market assumptions: labour market integration

Peasant economies are characterized by their *partial integration into imperfect markets* (Ellis, 1988). We focus on the labour market assumption, which is the most critical one for the purpose of this paper. We employ three different assumptions: no off-farm labour market exists, and self-employment on the family farm is the only option (model I); a labour market exists, but the household is quantity constrained (model II); and a perfect labour market exists where the household can hire or sell the desired amount of labour at a fixed wage rate (models III and IV).

By assuming a perfect labour market, the *production* decisions of a *utility* maximizing household can be studied as a *profit-maximizing* problem. This is a key result in the agricultural household literature, see particularly Singh *et al.* (1986). The model becomes *recursive* in the sense that first the production decisions are made, then the consumption decisions. The production decisions are the relevant ones for the study of deforestation, thus we are allowed to ignore the consumption side. The households in models III and IV are as a result of the recursive property assumed to maximize profit, even though the preference structure could be identical to model II.

The logic of the recursive property is as follows. Assume the household is price-taker in all relevant markets, and farm and off-farm labour are perfect substitutes both in the production and utility functions. The production decision (including labour demand) then has no links to the consumption decision (including labour supply), except one: the household should maximize the surplus from agricultural production to be included in the household's budget. The recursive character of the decision-making process in the agricultural household significantly simplifies the model, but also carries some strong implications for the results, as seen below and discussed further in appendix 1.

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[5] According to Chayanov, the main factor influencing the trade-off between consumption and drudgery is the *demographic structure* of the household (the ratio between consumers and workers); it is "a demographic model of household decision-making" (Ellis, 1988: 106). We do not focus on this aspect in our model, even though this may be relevant for comparative studies at the household level. For more aggregate models of tropical deforestation, however, it seems less relevant and feasible to include it.

In all models we assume for simplicity that the entire output is sold in a competitive market. An increase in x is therefore due to either increased productivity (physical output) or increased output price. An alternative assumption would be to let output be consumed directly, hence changes in x would represent productivity changes only. If production is partly for consumption and partly for sale, the effect of a price change in a non-recursive model is more complicated as the change affects both output and a consumer good.

Property regime

The importance of property rights in resource management is well established. We consider three different property regimes: (i) private (or communal) property rights to both cultivated land and virgin forest, (ii) "pure" open access, and (iii) a version of open access where forest clearing gives the farmer property rights (homesteading).

In models I-III we assume, in line with (3), that each farm household has the right to expand their agricultural land in a *1/N* fraction of the circle of land surrounding the village. These rights could be vested in a communal forest management regime (cf. Angelsen, 1996). It is commonly argued that such systems have a fairly egalitarian way of distributing resources, hence the assumption of equal sharing and identical households may be a reasonable one (cf. Stryker, 1976: 348).

Most tropical forests are *de jure* state property, but the remoteness and lack of institutional capacity to enforce government regulations often make forests *de facto* open access resources, unless some forms of communal management exist. The case of open access is discussed in model IV. An interesting result is that in its pure version (forest clearing does not give permanent land rights), open access yields the same level of deforestation as a regime with private or communal property rights.

A characteristic of many frontier systems is, furthermore, that forest clearing and cultivation give farmers some rights to the land. This way of gaining land rights is common in customary law throughout the tropics, and is also manifested in statutory law in some countries. In this situation farmers will not only look at the immediate benefits, but also at the future gains from having obtained rights to the land. This assumption is applied in model IV. Forest clearing is an *investment*, and should be modelled accordingly. This distinguishes the model from a large share of the literature on deforestation, and it produces some unconventional results.

Property rights are never certain. In order to account for uncertainty we introduce an exogenous probability for losing the land in each period (λ), for example, through appropriation by the state. This corresponds to a homogenous Poisson probability distribution. The level of λ will be affected by, *inter alia*, the protection provided by the state.[6] Including risk has the same effect as

[6] The security of land rights is also influenced by decisions made by the farmers themselves. In

adding λ to the discount rate, thus it is commonly termed *risk discounting* (e.g., Clark, 1990: 351). For simplicity we assume risk neutral farmers, which allows the use of expected values.

Given these assumptions, models I-III become static (one period) optimization problems. Optimal forest clearing is determined by considering the present period only; the farmers have full property rights to forest land, and there is no competition. Model IV, however, becomes dynamic because of the changed assumption about the property regime.

4 Model I: The subsistence or "full belly" economy[7]

The *subsistence models* assume in the extreme case that no markets exist. The households produce only for their own consumption, with family labour as the only input besides land. The objective of the household is to minimize labour efforts (maximize leisure) given a subsistence target, implying that consumption beyond that level has no value. This is the *"full belly"* version of the subsistence model (e.g., Dvorak, 1992).

This approach can generally be formulated as a Lagrangian problem. In our case with only one decision variable, however, it can be presented in a simpler way. Given the assumption of fixed inputs, there is not much of a choice left to the household: the family has to expand the area of cultivation until the subsistence target (c^{min}) is met. Production for one household (xH) must equal c^{min}, hence area of cultivation is simply given by;

$$(5) \qquad H = \frac{c^{\min}}{x}$$

Combining this with (3) gives the agricultural frontier;

$$(6) \qquad b^{\max} = \sqrt{\frac{mNc^{\min}}{\pi x}} = \sqrt{\frac{2c^{\min}}{hx}}$$

Under the subsistence approach the agricultural frontier is determined by productivity, population, and the subsistence requirement. Distance costs (q) are irrelevant for deforestation in this model.[8] [9]

The effect on the agricultural frontier of changes in the exogenous variables is readily seen from (6), see also appendix 2. First, an increase in the value of production from one hectare (increased

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Angelsen (1996) a simple model with endogenous property rights security is developed. The security is assumed to be a function of the intensity of production, and the enforcement efforts, for example, in obtaining a land certificate.

[7] The term *subsistence* is used in this context to refer to a situation where farmers' main objective is to reach a subsistence level of consumption, and not necessarily in the other, and frequently used, meaning of the term as an economy where the output is consumed directly and not sold in a market.

[8] One aspect not included in the model is that the subsistence target, if defined in nutritional terms, will depend on the labour input. Higher distance costs will then actually *increase* deforestation.

[9] The land use intensity (m) is also important for the agricultural frontier. A lower m will, however, affect x negatively -- an aspect not included in the model.

productivity or higher output price) will reduce the extent of deforestation. The subsistence income can be obtained from a smaller area. Second, given a subsistence requirement per capita, total area of cultivation is proportional to population.

Third, an increase in the subsistence requirement will also expand the agricultural frontier. Whereas a basic subsistence requirement could be defined in nutritional terms, it also has strong cultural and social elements. It was evident in the field study area in Sumatra that there has been a change in what was considered "necessary expenses" over the last two decades, for example, in the form of higher pressure to send all the children to school and paying their fees (Angelsen, 1995). We may hypothesize that integration into a larger "modern" economy and national culture will increase the subsistence requirement, and therefore contribute to deforestation in the subsistence model.

5 Model II: The Chayanovian economy

Models in agricultural economics assuming household to maximize utility and not being integrated into perfect markets are commonly labelled Chayanovian (1966) models.[10] Normally no off-farm labour market is assumed to exist, but we discuss the more general case when the household can sell a fixed amount of labour (*E*) in the labour market at a given wage (*w*). We assume that the labour market constraint is binding; the case when the constraint is not binding is model III. Only family labour work on the family fields.

The household maximization problem can then be written as;

$$(7) \qquad \underset{b^{\max}}{Max} \quad U(C,T) = U\left(\int_0^{b^{\max}} x\, hb\, db + wE, \int_0^{b^{\max}} (1+qb)\, hb\, db + E\right)$$

C is total consumption in real terms, and *T* is total labour time. For analytical convenience we have formulated the problem as one of determining the agricultural frontier; as seen from (4) this is equivalent to maximizing with respect to agricultural labour input. The optimality condition is;

$$(8) \qquad x = z(1+qb^{\max});\ z \equiv -\tfrac{U_T}{U_C}$$

In optimum, the production increase from clearing one more unit of land for cultivation (x) is equal to the labour inputs required at the agricultural frontier ($1+qb^{max}$), multiplied by the household's shadow or virtual wage rate (z). An alternative interpretation is that at the frontier the shadow wage should equal the output value per labour unit, including travelling time ($x/(1+qb^{max})$). Rearranging (8) yields;

$$(9) \qquad b^{\max} = \tfrac{x-z}{qz} = \tfrac{x}{qz} - \tfrac{1}{q}$$

[10] The name is taken from the Russian agricultural economist Chayanov who used this approach to study the adaptation of Russian farmers early this century.

The frontier is determined by three factors: the value of yield (x), the travel efficiency (q), and the shadow wage rate (z). It is, however, critical to note that unlike in the three other models (equations (6), (13) and (15)), the expression on the right hand side of (9) depends on b^{max}: z is a function of b^{max} as b^{max} affects both X (C) and L (T). Thus the effect of a change in, say x, cannot readily be seen from (9). This complicates the comparative statics, given in appendix 2.

To produce some more specific comparative statics results as well as for the numerical simulation in section 9, we introduce an additive utility function incorporating a subsistence level for consumption (c^{min}) and a maximum level of labour input, given by the total time available to the household (T^{max}).

(10) $$U(C,T) = (C - c^{\min})^{\alpha} + v(T^{\max} - T)^{\beta};\ v > 0;\ \alpha, \beta \in (0,1);\ (C - c^{\min}), (T^{\max} - T) > 0$$

$$z \equiv -\frac{U_T}{U_C} = \frac{v\beta\left(C - c^{\min}\right)^{1-\alpha}}{\alpha(T^{\max} - T)^{1-\beta}}$$

This function yields positive and declining marginal utility of consumption, and increasing marginal disutility of labour, whereas the cross derivatives are zero. z is the marginal rate of substitution between consumption and labour, or the shadow wage rate or virtual price of labour. z increases in both consumption and labour, which ensures that the indifference curves are upward sloping and convex in the C-T space (see appendix 2). T^{max} determines an upper bound and c^{min} a lower bound on the area of cultivation. The formulation implies that the shadow wage becomes very low when consumption approaches the subsistence level, and very high when leisure approaches zero. We assume that the parameter values are such that the subsistence target can be met with the labour available.

This function may be seen as a combination of the standard (multiplicative) Stone-Geary utility function and the Houthakker additive function. By setting $\alpha = \beta$ the function is, in fact, equivalent to using a CES function with subsistence level for consumption and maximum labour time. The chosen formulation yields some interesting results as seen below and further discussed in appendix 2. The appendix also briefly reviews the implications of using different functional forms.

Comparative statics

In discussing the comparative statics results, it is useful to distinguish between the dual role of agricultural households: the family farm is both a producer or a *farm firm*, and a labourer's and consumer's *household* (Nakajima, 1986) In its first role the household acts like a profit maximizing producer, whereas in its second role it acts as a consumer. This is elaborated further in appendix 1.

The full derivation of the comparative statics results is given in appendix 2. The most interesting case is when the output price or productivity (x) increase. The total effect of a change in x on b^{max} can be split into two sub-effects, cf. (35). First, for given z it will be beneficial for the household to expand the area of cultivation. They get higher output per unit labour input, thus they will cultivate a larger area. We shall label this the *farm firm* effect. The second effect relates to the fact that production on land already under cultivation will increase. From (34) it follows that z will increase, that is, on the margin the cost of labour is now valued relatively higher than the benefit of more consumption. This effect will induce the household to reduce the area under cultivation. We shall refer to this as the *subsistence effect*, which is related to the mechanism at work in model I, cf. appendix 1. Note the parallel between the farm firm and subsistence effects, and the textbook discussion on substitution and income effects, respectively, of a wage increase. The farm firm or substitution effects refer to the fact that leisure has become more expensive, thus farmers will work more. The subsistence or income effects refer to the increased consumption following the productivity increase, which makes the households wish to consume more leisure and work less.

The magnitude of the elasticity of z with respect to x, $\frac{\partial z}{\partial x}\frac{x}{z}$, determines which effect will dominate. This logic of this is seen by considering (8). Given our specific utility function, this elasticity can be specified further, and as a key result in the Chayanovian model we get;

$$(35)\quad \frac{db^{\max}}{dx} = \frac{1}{\mu}\left[1 - \frac{\partial z}{\partial x}\frac{x}{z}\right] = \frac{1}{\mu}\left[1 - \frac{X(1-\alpha)}{C-c^{\min}}\right] \begin{cases} >0 \Leftrightarrow X > \frac{c^{\min}-wE}{\alpha} \\ =0 \Leftrightarrow X = \frac{c^{\min}-wE}{\alpha} \\ <0 \Leftrightarrow X < \frac{c^{\min}-wE}{\alpha} \end{cases} ,\ \mu > 0, \text{ see appendix 2.}$$

If the elasticity is larger than one, the subsistence effect dominates. This will be the situation when $X < (c^{min} - wE)/\alpha$. For levels of agricultural income above this limit the farm firm effect will dominate. This yields a backward-then-forward sloping or C-shaped labour supply curve, which is the inverse of the commonly assumed shape for rich economies.

The model produces an interesting and intuitive result which directly relates the sign of the net effect of an increase in x to the consumption level (poverty). Consider the case with no off-farm employment; the condition is then $X < c^{min}/\alpha$. If the household is close to the subsistence level and working hard to survive, z will be low. Higher income will have a relatively large impact on z; "it will allow them to relax a little bit more". In a wealthier economy, the subsistence considerations are less important, and the household behaves more like a farm firm.

Second, the condition can be related to the household's dependence on farm *v.* off-farm income: the lower farm income and the higher off-farm income are, the weaker the subsistence effect, *ceteris paribus.* The result is rather intuitive: when only a small proportion of the total income is from agriculture, the income increase and therefore the income (or subsistence) effect will also be small. If the off-farm income is higher than the subsistence requirement, we see that the farm firm effect will always dominate.

Third, the condition for the subsistence effect to dominate can also be related to an intuitive interpretation of α. $(\alpha-1)$ is the elasticity of marginal utility with respect to surplus consumption $(C-c^{min})$. A low value of α means that the valuation of consumption above subsistence declines rapidly. This may be representative for societies without a strong materialistic orientation. In this case the subsistence effect will predominate: higher productivity will make the household cultivate a smaller area, as priority is given to increased leisure.[11]

Furthermore, the integration of traditional agrarian societies into the larger economy and "modern" culture may imply that more emphasis is put on material consumption relative to leisure. This could be related to a higher value of α. If the value of α is close to one, the farm firm effect will dominate even for consumption levels relatively close to subsistence. The model thus provides a possible explanation of how the integration into a "modern" society will make the household act more like a profit maximizing firm rather than a survival oriented household, in addition to the above argument about the growth in non-farm income.

The other comparative statics results are straightforward as the subsistence and farm firm effects -- when both are present -- pull in the same direction. The effect of higher transport costs (q) can be split into two sub-effects, cf. (36). For a given z the net benefit from cultivation is reduced, thus the agricultural frontier will contract (farm firm effect). The subsistence effect is that higher q increases the amount of labour required on land presently under cultivation, thus the shadow wage (z) increases.

An increase in the availability of off-farm employment (E) or the wage (w) will also unambiguously reduce deforestation. Higher off-farm income reduces the marginal utility of consumption, that is, z increases. In the case of higher E we also get an effect from increased disutility of work.

A population increase (lower h, cf. (3)) will lead to a lower z: for a given b^{max} the area per household is reduced, and therefore also consumption and labour input, both effects which reduce z. A lower shadow wage augments the net benefit of cultivation on the margin, thus the agricultural frontier will expand. The relative increase in area under cultivation will be less than the population increase, because new land is brought into cultivation at increasing costs.

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[11] $(1-\alpha)$ is also the Arrow-Pratt measure for *relative* risk aversion, if defined only with respect to consumption. α can then be interpreted in terms of the household's attitude towards risk. A more intuitive interpretation of the household's risk preferences in the model is, however, found by using the measure for *absolute* risk aversion, given by $(1-\alpha) / (C-c^{min})$: for consumption levels close to subsistence the farmers become very risk averse.

6 Model III: The small, open economy with private property[12]

The small, open economy formulation takes all prices as exogenously given. In particular, we introduce a perfect labour market in the sense that any amount of labour can be sold or hired at a constant wage rate (w). The recursive property of the model (section 3) gives that the production problem then can be formulated as;

(11) $$\underset{b^{\max}}{Max}\; R = X - wL = x\int_0^{b^{\max}} hb\, db - w\int_0^{b^{\max}} (1+qb)hb\, db$$

R is total profit or land rent. The FOC is given by;

(12) $$x = w(1+qb^{\max})$$

or;

(13) $$b^{\max} = \frac{x-w}{qw} = \frac{x}{qw} - \frac{1}{q}$$

The interpretation of (12) and (13) is similar to (8) and (9) in model II. There is, however, a crucial difference: w is exogenous, unlike z in the Chayanovian model. As the subsistence effect in model II relates to changes in z, the replacement of an endogenous z with an exogenous w implies that there is no subsistence effect in the small, open economy model; only the farm firm effect is present.

The effect of a change in x, w or q is readily seen (see also appendix 2). An increase in the productivity (x) will increase deforestation, as frontier farming becomes more profitable. The same effect would result from a decrease in transport costs (q), or in the real wage rate (w).

Figure 1 illustrates the rent gradient as a declining function of distance. In this static model (III) this is labelled annual land rent, to be distinguished from the discounted land rent of the next model. An increase in x will move the curve upwards, thus b^{max} expands. An increase in q or w will move the rent gradient downwards, and reduce b^{max}.

[12] The open economy case of a shifting cultivation economy has been dealt with in a relatively comprehensive way in Angelsen (1994). In that model both the fallow period, labour input and the agricultural frontier are determined endogenously. In this paper we continue to limit the model to the case where only the agricultural frontier is endogenous. Note, however, that this simplification is more justifiable under the open economy (exogenous prices) assumption as the comprehensive model is recursive: the optimal fallow period and labour input are first determined, then the agricultural frontier (see Angelsen, 1994). This is not the case in the two previous models.

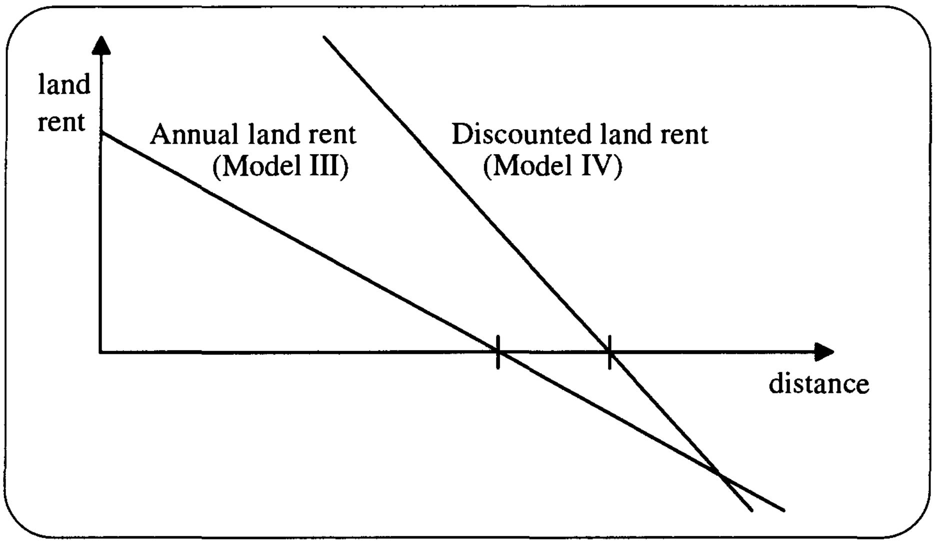

Figure 1: The determination of the agricultural frontier in the open economy cases.

The new labour market assumption changes the underlying logic of the model dramatically compared with models I-II. The key variable for the determination of the agricultural frontier in the open economy model is the *relative profitability* of frontier farming, as determined by output price and productivity (x), roads and accessibility (q), and alternative employment opportunities (w). The initial size of the population has no effect; migration will level out any income differences, and labour in agriculture (or population) is thereby determined endogenously.

7 Model IV: The small, open economy with open access

In model IV the property rights assumption changes, and we assume a situation where no one has property rights to virgin forest. We discuss two versions of open access: first, we assume a shifting cultivation system where forest clearing does not give any permanent rights, the land goes back to the common pool of forest resources after the period of cultivation is over ("pure" open access).

Open access in combination with the perfect labour market assumption imply that labour will migrate to the forest frontier as long as there is a non-negative rent in frontier farming. The migration equilibrium is defined as a situation where land rent on the margin is zero. But this is exactly the solution in (12) of the previous open economy model. Thus, model III applies both to a situation with private (or communal) property rights as well as a *static* open access situation.[13]

The next case to consider is when forest clearing gives permanent land rights, which has a historical parallel to *homesteading* in the US. New settlers will cut forest as long as there exists a

[13] Generally, open access may also drive the *overall* resource rent to zero. This is impossible in this model as the output per ha is constant. In, for example, a model of endogenous labour and fallow period (Angelsen, 1994), the fallow period will be shorter for land inside the agricultural frontier in the open access model, making the resource rent zero for land at all distances.

non-negative discounted rent, and the migration equilibrium and agricultural frontier are defined where the *discounted* rent is zero. The agricultural frontier is implicitly given by;[14] [15]

$$(14) \quad \int_0^\infty e^{-\lambda t} e^{-\delta t}[e^{gt}x - w(1+qb^{\max})]dt = \frac{x}{\delta+\lambda-g} - \frac{w(1+qb^{\max})}{\delta+\lambda} = 0$$

λ is the probability of loosing the land in each period[16], δ is the discount rate, and g is the rate at which farmers expect the gross value of output (x) to increase per time period.[17] We assume that $\delta + \lambda > g$.[18] We use (for simplicity) continuous time, infinite time horizon, and let all relevant parameters (except x) be constant over time. Rearranging this expression yields;

$$(15) \quad b^{\max} = \frac{\theta x - w}{qw} = \frac{\theta x}{qw} - \frac{1}{q}; \quad \theta \equiv \frac{\delta+\lambda}{\delta+\lambda-g} > 1 \textit{ for } g > 0$$

Compared with the solution for the "pure" open access or the open economy with private property in (13), we have an additional element here - θ. As this parameter is greater than one, given expectations about an increase in x, this model implies that the agricultural frontier will be pushed further away compared with model III, cf. Figure 1. Because x increases over time, we also get that the agriculture frontier will steadily expand. Note that we would have got a similar story if farmers expected q or w to be reduced over time.

The intuition behind this result is simple. Forest is cleared even if it has a negative rent in the early years. This would have been even more intuitive if we included some initial costs of forest clearing and migration in the model. The initial loss will be outweighed through a positive land rent some time in the future. Early clearing is necessary to establish property rights; otherwise the land will be taken by others. This situation has been described as "the race for property rights" (Anderson and Hill, 1990). Such a land race is unproductive from a social viewpoint because it gives a negative contribution to overall production (as land rent will be negative for the first years), and is a kind of rent-seeking. The reason for the inefficiency is the link between resource use (forest clearing) and allocation of property rights.

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[14] Note that one could arrive at exactly the same condition by formulating the problem in a similar manner as in model III; each household maximizes discounted profit. It is, however, more problematic to use the assumption about land allocation underlying equations (3) and (4) in the open access case.

[15] We ignore any possible capital gains which may result from future land sale, and assume that the land value (price) is determined only by future land rent. Self-fulfilling expectations of capital gains ("rational bubbles") could be important in situations when there is an active land market, as in some regions of Latin America. See Clark *et al.* (1993) for a theoretical discussion, and Kaimowitz (1995) for a discussion of the empirical evidence from Central America for such speculative forces of deforestation.

[16] An empirically relevant modification would be that λ declines over time as the length of occupancy increases. This could be included in the model, see Angelsen (1994) for a case when $\lambda = \lambda(t)$.

[17] If soil degradation is expected to be important, g should be adjusted downwards. In this case model III will remain the relevant one.

[18] If this condition is not met, we are back to model III.

The adaptation is illustrated by the discounted land rent curve in Figure 1. Because land rent is expected to increase over time, the curve for discounted rents lies above the annual rent curve, and therefore intersects the x-axis to the right of the equilibrium point of model III.

The conclusion that the open access situation will lead to more agricultural encroachment than the private (or communal) property situation rests on two critical assumptions: (1) Expectations about increasing land rent per hectare, for example, an increase in x as in our formulation. (2) Property rights are established by forest clearing. Open access in itself will *not* generate more deforestation than a situation with well defined property rights to all forest (model III). If there is no expectation about higher land rent in the future, the discounted rent curve in Figure 1 will intersect the x-axis in the same point as the annual rent curve.

The effect of changes in x, q and w is similar to model III, cf. appendix 2. The effect on deforestation of a higher discount rate is negative. This contradicts the conventional wisdom which holds that lower discount rates will help preserve the environment. The intuition behind our result is nevertheless simple: a lower discount rate implies giving relatively more weight to the future positive land rents. Farmers are willing to clear forest further away when the discount rate is lowered. Again, this result must be seen in the light of deforestation being an investment for the decision maker, and not an issue of conservation of a resource to which the agent has well established property rights.

It also follows that higher tenure security in terms of reduced probability of losing the land will increase deforestation. Again, this contradicts a conventional hypothesis on the impact of more secure property rights, as will be discussed further in section 9.

The effect of an increase in the expected productivity (or price) growth (g) is as to be expected: higher g leads to more deforestation. The latter result highlights the role of *expectations* in the deforestation process. Expectations about increases in x or reductions in q or w can initiate a process of deforestation. Moving beyond the strict model assumptions, we could interpret expectations about increased land scarcity as a decline in w. Angelsen (1995) in a case study from Sumatra suggests that such expectations have been important in initiating a self-reinforcing land race. It could be considered a kind of "self-fulfilling prophesies".

To summarize, anything that increases the expected rent will boost deforestation: improved technology, higher output prices, lower transport costs, lower opportunity costs of labour, more secure claims to cleared forest land, or lower discount rates.

8 Comparing the models

Summary of comparative statics results

The effects of changes in various parameters on deforestation in the four models are summarized in Table 2. We note in particular the different effects of a productivity or output price increase. Whereas higher x reduces deforestation in the subsistence and possibly also in the Chayanovian models, it increases deforestation in the two other models. For the discussion of this effect the Chayanovian model can be considered the most general model as it includes both the farm firm and subsistence effects.

The alternative employment opportunity is a critical variable in the open economy models, and to some extent also model II. Population growth has important effects on deforestation in the subsistence and Chayanovian models, but is endogenous and determined by relative profitability of frontier framing in models III and IV.

Whereas the subsistence model focuses exclusively on the agricultural sector, the open economy model draws the attention to the development in the rest of the economy. In particular, it underscores the role of alternative employment. The open economy models also highlight the (possible) counterproductive effect of intensification programmes which increase productivity in frontier agriculture, cf. section 10.

Effect on deforestation of an increase in:	*Model:*			
	I. Subsistence ("full belly")	*II. Chayanovian*	*III. Open economy, private property*	*IV. Open economy, open access*
Population (N)	increase	increase	no effect	no effect
Subsistence requirement (c^{min})	increase	increase	n.a.	n.a.
Productivity or output prices (x)	reduce	reduce (poor) increase (rich)	increase	increase
Transport (distance) costs (q)	no effect (increase[1])	reduce	reduce	reduce
Alternative employment (E or w)	n.a.	reduce	reduce	reduce
Discount rate (δ)	n.a.	n.a.	n.a.	reduce
Land tenure security ($1-\lambda$)	n.a.	n.a.	n.a.	increase
Expectations about future productivity or output price (g)	n.a.	n.a.	n.a.	increase

[1] If subsistence requirement depends on labour efforts.

Table 2: The effect on deforestation of various factors in different models.

The realism of the models depends both on the characteristics of the economy in question and on the time horizon for the analysis. The population based models (I and II) may better reflect the short term response, and situations with high transaction costs and low mobility of the labour force. One possible interpretation of the small, open economy formulation in models III-IV is that the frontier agriculture sector is small compared with the rest of the economy. In particular, there exist sufficient outside employment opportunities (non-frontier agriculture and off-farm) which make it realistic to assume an exogenously given wage rate and households to be unconstrained in the labour market. For this reason, this model assumption may be considered more realistic for the study of long-term adaptations when migration is a real option. Migration tends to level out differences in the (expected) wage level between various sectors and regions.

A graphical illustration

Figure 2 gives a graphical illustration of the optimality conditions in the four models.[19] The $x/(1+qb)$-curve gives the output per unit labour input (including transport costs), whereas the other curves represent the (shadow) wage rate in the four models.[20] In the comparative statics (with the exception for the first model), changes in the first curve refer to farm firm effects, whereas changes in the other refer to subsistence effects. For example, an increase in x leads to an upward shift in the $x/(1+qb)$-curve, which in models III and IV is the only effect, and therefore gives higher b^{max}. In the Chayanovian model (II) the z-curve also shifts northwest, and in a poor and agriculture dominated economy the shift is sufficiently large to reduce deforestation. In model I the shift to the left in the $1/\gamma$-curve will always make b^{max} decline.

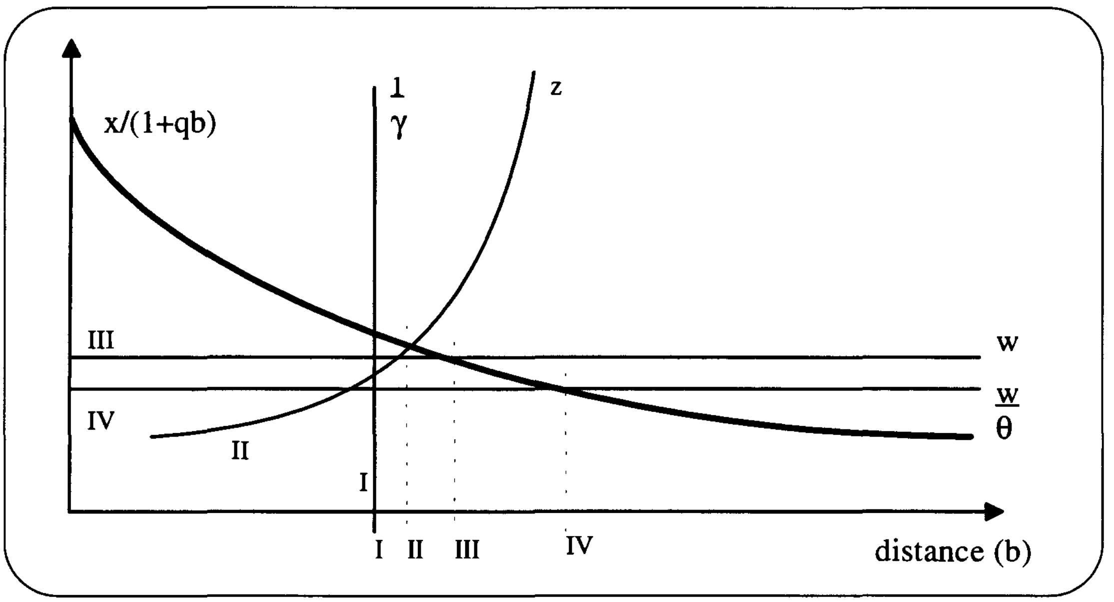

Figure 2: The adaptation in the four models.

[19] Formulating model I as a Lagrangian problem, the FOC is $x/(1+qb^{max}) = 1/\gamma$, where γ is the Lagrange multiplier, that is, the labour input required to increase consumption by one unit.

[20] We know that b^{max} is greater in model II than I, and greater in model IV than III, otherwise we cannot say if there is more or less deforestation in the market based than population based models.

Household preferences

One reason for including the "full belly" model was to highlight the rather rigid assumptions underlying some popular policy prescriptions to the deforestation problem. The subsistence approach dominates the thinking on the causes of and remedies for deforestation within the development aid community. The popularity of the "full belly" approach should be understood both in view of its simple and clear logic, and its policy implications. FAO (1992), which provides the most widely used estimates of tropical deforestation, employs a deforestation model to interpolate data where population density is the only explanatory variable. The Alternatives to Slash-and-Burn programme, initiated by a number of international development organizations, is based on the *intensification hypothesis:* increased productivity will reduce the pressure on forests. "For every hectare put into these sustainable soil management technologies by farmers, 5 to 10 hectares per year of tropical rainforest will be saved from the shifting cultivator's axe, because of their higher productivity" (ASB, 1994: 11). This hypothesis is discussed further in section 10.

The Chayanovian model provides a more general (and realistic) description of the household's preferences. The "full belly" model implies that the shadow wage rate is zero up to the subsistence level, and infinite above it. The most significant implication of the new assumption for household behaviour is to open up for the opposite effect on deforestation of an increase in productivity or output price: higher x *may* lead to more deforestation if the farm firm effect dominates the subsistence effect, which will be the case when the household is relatively rich, has a significant share of off-farm income, and/or have strong preferences towards consumption.

For poor, agriculture dependent and/or "leisure-oriented" economies the Chayanovian model gives the same qualitative result as the "full belly" model. In fact, model I could be seen as a special case of model II. As seen from (35), the subsistence effect will be very large and dominate completely when α approaches zero, the household is agriculture dependent, and close to the subsistence requirement (which is implied by a low α).

Labour market integration

There is a qualitative jump when moving from model II to model III, that is, when the household is not constrained any more in the labour market. The household model becomes recursive, and the subsistence effect disappears in the comparative statics. One should note that the critical factor is not whether an off-farm labour market exists or not, but whether the household is constrained or not in that market. When the household is constrained, the shadow wage rate is endogenous and changes in that rate represents the subsistence effect.

Economic development is associated with a gradual reduction of the agricultural sector's share of the total economy. Given this historical pattern, it is interesting to explore what happens when the availability of off-farm employment expands. When the household is constrained in the labour market, the shadow wage rate is by definition below the market wage: $z < w$. If the employment opportunity (E) increases, z will also increase, as seen from (38) in Appendix 2. Hence the household's shadow wage rate will move closer to the market wage rate when off-farm employment increases.

Furthermore, as shown formally in Appendix 3, the subsistence effect gets weaker relative to the farm firm effect as E increases. In other words, the response in the Chayanovian model becomes more and more similar to the open economy model as the availability of off-farm employment increases. Thus, even if there is a qualitative jump between the models, the household's response is more gradual as the market integration increases.

Property regime

The shift from a private property regime to a "pure" open access situation does not have any implications on deforestation. This may be a surprising result in light of both the general resource economics literature and the popular environmental debate. This result is partly due to the fact that no benefits of forest conservation are included in the private property models. There may be some *private* benefits of standing forest, for example, various forest products. Most forest conservation benefits are, however, *public* environmental goods, either at the local, regional or global level. In order for private property to result in less deforestation than an open access regime, one must therefore argue that there are important conservation benefits which the decision-makers capture and therefore include in their decisions.

An argument for a private (or communal) property regime resulting in less deforestation is found when comparing the homesteading case of model IV with model III. An open access situation where forest clearing gives the farmers land rights may boost deforestation. This result premises that farmers expect higher land rent in the future. If they do not, even the homesteading case will *not* result in more deforestation than private property. The comparison of different models therefore clarifies some of the requirements for open access to result in more deforestation than other property regimes.

9 A numerical simulation

In order to get an indication on the magnitude of the different effects in the models, we present a simple numerical simulation.[21] The values of the different variables are meant for illustrative purposes, but are as far as possible based on a household survey done in the Seberida district, Sumatra (Angelsen, 1995). The parameter values for the initial situation are given in appendix 4.

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[21] The simulation was done using a spreadsheet model in Lotus® 1-2-3®.

Effect on b^{max} (km) of an exogenous change	*Model:*			
	I. Subsistence ("full belly")	*II. Chayano-vian*	*III. Open economy, private property*	*IV. Open economy, open access*
Initial situation	2.50	2.72	2.50	2.82
Population increased by 20 % (from 82 to 98 households)	2.74	2.96 / 2.94		
Subsistence requirement increased by 20 % (c^{min} from 1200 to 1440)	2.74	2.88 / 2.87		
Productivity increased by 20 % (x from 500 to 600)	2.28	2.58 / 2.92	5.00	5.39
Transport costs reduced by 20 % (q from 0.1 to 0.08)		2.74 / 2.79	3.13	3.53
Off-farm labour introduced (model II) (E from 0 to 0.5)		2.52 / 2.54		
Real wage reduced by 20 % (w from 400 to 320)			5.63	6.03
Discount rate reduced from 20 to 10 %				2.89
Tenure security increased ($(1-\lambda)$ from 70 % to 90 %)				3.00
Expectations about a 2 % points increase in x (g from 0.01 to 0.03)				3.52

Table 3: A numerical illustration of the effects of changes in the exogenous variables.

The numerical simulation is presented in Table 3.[22] In model II two different situations are reported, depending on whether the subsistence or farm firm effects dominate, cf. appendix 4. These serve to illustrate the differences in the response to a productivity increase. In the first situation a 20 percent increase in x will reduce the agricultural frontier from 2.7 to 2.6 km, in the second it will expand to 2.9 km. For changes in the other parameters there are only minor differences between the two situations.

The introduction of a fixed amount of off-farm employment in model II reduces the agricultural frontier from 2.72 to 2.52 and 2.54 km, respectively. Total labour input and consumption increase only slightly.[23] In other words, in this simulation model providing alternative jobs directly replaces agricultural income rather than contributing to higher consumption.

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[22] In interpreting the results, one should be aware of the fact that most economic models, including those presented here, assume friction free adaptations and no adjustment costs. Because such costs may be considerable, simple economic models tend to overestimate the effects, particularly for the short term responses.

[23] The consumption level before and after the introduction of off-farm employment was 1415 and 1419 in the case when subsistence effect dominates ($\alpha = \beta = 0.2$), and 1413 and 1436 in the case when

More generally, we note that changes in the parameters which determine the agricultural frontier in the "full belly" and Chayanovian models have relatively modest effects on deforestation. This contrasts the open economy models (III and IV), where small changes in exogenous variables give quite dramatic effects on deforestation.[24] Deforestation is very sensitive to changes in productivity or output price, and the wage level. A one time shift in x of 20 percent will move the frontier from 2.5 km to 5.0 km in model III, and from 2.8 to 5.4 km in model IV. A drop in the wage rate by 20 percent has an even larger effect; the agricultural frontier moves to 5.6 and 6.0 km in the two models.

Expectations are important in model IV. An increase in the expected growth rate for the yield value (x) from 1 to 3 percent will move the agricultural frontier from 2.8 to 3.5 km away from the village centre. Changes in the discount rate and the land tenure security have relatively modest effects on deforestation in the model. This result is, however, sensitive to the relatively low initial expected growth in x. Combining the last three changes in Table 3 ($\delta = 0.1$, $\lambda = 0.1$ *and* $g = 0.03$) would move the agricultural frontier to 4.9 km. The results indicate, however, that the single most important factor to explain deforestation is the real wage rate, and that the main story is told in model III.

The results are not only sensitive to the parameter values, but also to the model specification. If we introduce convex distance costs, $l = (1 + qb^{\beta})$, $\beta > 1$, in model III, the agricultural frontier is;

$$(16) \qquad b^{\max} = \left(\frac{x-w}{wq}\right)^{\frac{1}{\beta}}$$

This will dampen the effects on deforestation of, say, an increase in the output price compared with the original model. The effect of a 20 percent increase in productivity with *linear* distance costs was to increase b^{max} from *2.5* to *5.0 km*. With *quadratic* distance costs ($\beta = 2$) the agricultural frontier will be extended to "only" *3.5 km*.[25]

10 Policy implications

Deforestation as an investment

In a situation where forest clearance gives land rights, deforestation should be modelled as an investment in land and a title establishment strategy. Much confusion is created in the literature and debate on agricultural expansion and deforestation because the issue of expansion (deforestation) is not clearly distinguished from the issue of management of resources which the

farm firm effects dominate ($\alpha = \beta = 0.9$).

[24] One should note that the effects on the area of deforestation (km^2) are much larger than the effect on distance (km). For example, an increase in b^{max} from 2.5 to 5.0 km implies an increase in the total area (H^T) from 1 968 to 7 854 hectares.

[25] The results are also sensitive to the assumption of uniform land quality. Assuming lower productivity (soil qualify, slope, etc.) of new land would further dampen the effect of exogenous changes.

farmers already control (e.g., soil conservation), as also argued in the case of logging by von Amsberg (1994). The general debate on environmental degradation in developing countries will be substantially clarified when this distinction is made, and more unambiguous results produced. Some of the unconventional results in the model on the effect of increased tenure security and reduced discount rate, and partly also technological progress, should be understood in this perspective.

Model IV should therefore be contrasted not only with the subsistence approach, but also with a conventional economic approach with the following framing of the deforestation problem: a social planner who maximizes the discounted benefits of various forest uses, in particular, between short and long term benefits, and -- related to this -- between productive and protective functions.[26] Deacon (1994) provides an example of such an approach, where "deforestation is a form of disinvestment" (page 427). Whereas this may be true from a social planner's point of view, it may give a misleading description of the forces behind agricultural expansion and deforestation, and may yield conclusions and policy implications contrary those derived from model IV.

This point also concerns the micro level modelling of smallholder deforestation. Persson and Munasinghe (1995), in a CGE model for Costa Rica, have two versions of squatters' behaviour. When property rights are undefined (misleadingly called "common property" rather than open access), the model is similar to model III of this paper. In the second case "when property rights are well defined, there is a market for the forest" (page 282). The future value of forest is then included in the decision problem, and the conclusions follow conventional economic theory: higher discount rates and tenure insecurity lead to more deforestation. There are at least two objections to the relevance of this approach. First, markets in forest land are generally rare. Second, most values attached to standing forest has strong public goods characteristics, thus the incentive for individual farmers to include these in their decisions are very limited, even with secure property rights.

The intensification hypothesis

The subsistence approach focuses on high population growth, low agricultural productivity and people's struggle to reach the subsistence requirement (poverty) as the main causes of deforestation. A number of international reports are based on this framework, including the Brundtland report "Our Common Future" (WCED, 1987). The Alternatives to Slash-and-Burn (ASB) project headed by the International Centre for Research on Agroforestry (ICRAF) is based on the intensification hypothesis: "Intensifying land use as an alternative to slash-and-burn

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[26] Examples of studies which use this approach include Strand (1992), Barbier and Rauscher (1994), Brazee and Southgate (1992) and Kahn and McDonald (1995). It should be added that some of the studies using this approach are intended for other purposes, for example, discussing optimal levels of deforestation; the argument is that for understanding the process of smallholder expansion this approach can be misleading.

agriculture can help reduce deforestation (thereby conserving biodiversity and reducing greenhouse gas emissions) and alleviate poverty" (Tomich and van Noordwijk, 1995: 4; see also ASB-Indonesia, 1995: 119; ASB, 1994; Bandy et al., 1993). As noted in these reports the validity of the hypothesis depends on certain conditions, including effective monitoring and enforcement systems of the boundaries of the forest. This assumption is commonly violated. Thus we may have a very unpleasant conflict between reducing deforestation and increased agricultural production (poverty reduction), as Tomich and van Noordwijk (1995) also discuss.

An obvious response to the dilemma is to work at several levels to ensure that these necessary conditions for the intensification hypothesis to be valid are met. Establishing management and enforcement systems is, however, difficult and takes time. One option would then be to give priority to poverty reduction, and accept some deforestation. The argument could be that conversion to agroforestry preserves many of the natural forests' functions, which indeed is a valid argument (cf. Angelsen, 1995). Alternatively, priority is given to limiting deforestation. This implies that one should be very careful with implementing any projects (including agroforestry) which increase the benefits of frontier farming.

This potential trade-off is often ignored or not explicitly dealt with. Others are aware of the potential conflict, but it is downplayed, for example, by discussing how the extent of deforestation depends on farming methods, crop choices, farm investments, etc. (e.g., Deacon, 1992: 25ff; Panayotou and Sungsuwan, 1989). Whereas such factors may play a role, we still maintain as a general hypothesis that increases in productivity and/or output prices in frontier farming in the medium or long term lead to more forest being converted to agricultural land. This would also be in line with the general equilibrium model of Deacon (1995).

Land titling programmes

Possibly the most provocative and unconventional result of model IV is the potential counterproductive effects on deforestation of land titling programmes, which have as one of their prime objectives to increase tenure security. In a situation where rights to forest land are obtained through forest clearance, then facilitating more secure land rights, for example, by offering cheaper land titles and more legal protection by the state, would increase the net present value of the deforestation investment.

Again, the result must be seen in light of the way smallholder deforestation is framed in our model. The conventional wisdom is that a secure property right is a prerequisite for taking long term environmental effects into account in the decision making. This is still relevant for the management of land already in production, or for the decision about forest conversion by an almighty, well informed social planner. Our argument is simply that neither of these approaches is appropriate for describing smallholder deforestation. Even with full tenure security there will be small incentives to include the effects on the protective functions of the forests.

How does this argument correspond with the empirical evidence? According to Kaimowitz (1995: 43) "recent land titling programmes initiated by Central American governments to provide secure rights for land occupants without legal title have fuelled the speculative drive for land".[27] Other countries in Africa and Asia have had similar experiences. This should serve as a strong caution for initiating land titling programmes in situations where land rights can initially be obtained by forest clearing.

The fundamental problem is the unofficial rules of the game, where forest has to be cleared first in order to be eligible for titling. If it was possible to obtain a title without clearance, the farmers might consider retaining the forest, depending on the return of this option compared to alternative land uses. At least this would remove the incentive to cut the trees in order to stake an enforceable claim and capture a *future* positive land rent.

Discounting - credit markets

High discount rates are commonly blamed for environmental degradation, and this is confirmed within the social planner's approach to deforestation. In model IV, however, the effect of a lower discount rate is to augment the net present value of future land rents, and to boost deforestation. This result is analytically parallel to the discussion of tenure security. The empirical relevance of this is not yet fully explored. If farmers have no access to any credit market, the relevant discount rate will be the consumption rate of interest (*CRI*), reflecting pure time preferences, and the effect of diminishing marginal utility of consumption combined with (expectations about) consumption growth. *CRI* is likely to be positively related with the degree of poverty, which again could be seen as a reflection of alternative employment opportunities (w). It may not be unreasonable to assume that the latter effect on deforestation will predominate among poor people.

A discussion of the role of the discount rate seems more relevant in a situation of commercial agriculture, where the credit market interest rate may be the relevant discount rate. The effect of a change in the discount (interest) rate here follows the simple logic of investment theory. This also implies that getting access to credit, that is, replacing the *CRI* by a generally lower market interest rate as the relevant discount rate, may increase deforestation. Credit can be used to "finance deforestation", as many argue has been the case in Brazilian Amazon (e.g., Mahar and Scheider, 1994). Again, this contradicts conventional wisdom about improved access to credit being important to enhance environmental preservation. One modification of this result is in

27 See also Mahar and Scheider (1994: 163) for the Latin American evidence.

order. Credit will often be important in the efforts to intensify cultivation on existing agricultural land (the intensive margin), and could in this way reduce the pressure at the forest frontier.

Alternative employment

The opportunity for off-farm employment to (potential) frontier farmers is a variable of critical importance to understand the process of deforestation. We found in the numerical example deforestation to be very sensitive to changes in the wage rate. This result is in line with Bluffstone (1995) in a study from Nepal. He concludes that the availability of off-farm employment, albeit at a low wage rate, has prevented further deforestation, and makes the agroforestry practised a stable system. The deforestation record of Malaysia also illustrates the importance of providing alternative employment. During recent decades, high economic growth and the creation of new jobs have attracted a number of people from rural areas into the cities, thereby reducing the pressure on forests from smallholder agriculture, although but not necessarily from other agents of deforestation.

This situation should be contrasted with the Philippines, where economic crisis and unequal land distribution in the lowlands have initiated a massive flow of migrants from the lowlands to the uplands (World Bank, 1989). This push-migration has resulted in significant pressure on forest resources in the uplands, including high rates of deforestation.

Accessibility (roads)

Road construction is among the most indisputable and unambiguous factors in promoting conversion of forest to other uses (e.g., Kaimowitz, 1995: 37; Chomitz and Gray, 1994: 2; Schneider, 1995: 16; Mahar and Scheider, 1994: 161, Tomich and van Noordwijk, 1995). Chomitz and Gray (1994), integrating the spatial dimension into an economic model of land use in Belize, find strong support for market access and distance to roads being key determinants of the type of land use, particularly for commercial agriculture. Kummer and Sham (1994: 154) in a study from Philippines find that 75 percent of the variation in forest cover is explained by road density. Yet, better market access, including new roads, is often included in aid projects which aim to limit deforestation.

This has led Schneider (1995) and others to suggest that road building should be intensive rather than extensive. Decisions on road construction are normally not made based on their impact on deforestation. Construction often takes place in relation to logging operations, plantation developments, mining, or similar large-scale, (often) state sponsored projects. In other cases, as in Northern Thailand and several Central American countries, the rationale has been to facilitate military access and control of areas influenced by opposition groups.

11 Extensions

The basic model could be extended in several directions. One possible extension would be to endogenize the fallow period and/or the labour input. In models I-II this will dampen the effects on deforestation of, say, a population increase. The need for increased production can be met by both higher labour input and shorter fallow period, as well as an area expansion. The former is in line with the Boserup (1965) and Ruthenberg (1980) hypothesis about increased population pressure leading to intensification of agricultural systems. The case with endogenous fallow period and labour input in the open economy models is discussed in Angelsen (1994).

The inclusion of other inputs would further highlight the fundamental difference between the population and market approaches. In the former lower input prices, e.g., on fertilizers, will reduce deforestation as fertilizers are substituted for land. Under the market approach it will augment the profitability of frontier framing and therefore increase deforestation, provided land and fertilizer are complementary inputs (see Angelsen *et al.,* 1996).

The effects of including risk in frontier agriculture are also very different in the two modelling categories. In the open economy models increased risk makes risk-averse farmers reduce the scale of the risky activity (farming) and therefore reduce deforestation.[28] In the subsistence case increased risk implies a larger area under cultivation as risk-averse farmers would aim to be on the safe side of the subsistence requirement (safety first models).[29]

Another extension is to include the crop choice, and explore the effects of relative output prices on deforestation, depending on their land intensity. Moreover, it may be important to distinguish between annuals and perennials, particularly in model IV as perennials often would give higher tenure security than annuals (Angelsen, 1995; 1996). A further relevant disaggregation of the model is to split the agricultural sector into frontier (extensive margin) and non-frontier (intensive margin) agriculture. This could help clarify the deforestation effect of different policies, as it depends critically on the relative impact in the two sub-sectors.

General equilibrium effects

The four models presented are stylized descriptions, and real-life situations contain elements from all of them. One way of unifying the models would be through a general equilibrium approach, in particular, to endogenize the wage and output price (i.e., the real wage rate in models III-IV).[30] In this way population could be included in models III-IV via effects in the labour and output markets: an increase in the labour supply would reduce the wage rate, and

[28] This hypothesis is supported by, among others, Elnagheeb and Bromley (1994) in a study from Sudan.

[29] See, for example, Roumasset (1976) for a more detailed discussion of safety first models.

[30] See Deacon (1995) for an example of a general equilibrium model of deforestation, focusing particularly on tax instruments. The logic and conclusions of his model are similar to model III of this paper.

higher population would increase the prices for agricultural products.[31] These effects have been found to be important in empirical studies (e.g., Kaimowitz, 1996).

Including general equilibrium effects would modify some of the conclusions in models III-IV. Increased productivity in frontier agriculture will cause a downward pressure on domestic food prices, which will dampen the effects on agricultural expansion. Now it also becomes critical to distinguish between different sub-sectors within agriculture: a productivity increase in, for example, wet-rice production will limit deforestation through lower agricultural output prices. A general increase in agricultural productivity will boost deforestation if the market share of frontier farming is relatively small and/or food demand is price elastic.

Similarly, there may be important labour market feedbacks. Technological progress in frontier agriculture gives an upward pressure on wages, which also would dampen the effects on deforestation. The price elasticities in the output and labour markets will determine the net effects of, say, a technological jump. Yet, we could expect the qualitative results of the open economy models to remain valid.

Besides including general equilibrium feedback, another reason for extending the models would be to include more policy variables in them, and link a realistic description of micro level decisions to macro level and international economic variables. This represents a major challenge for future research.

12 Some remarks on testing of the models

The policy recommendations depend critically on the approach chosen. It is therefore important to know which approach gives the most realistic description of the frontier economy. Unfortunately, the discussion of this question in the literature is limited (López, 1992), but the above review of models provides some important lessons.

A major lesson is that the *labour market assumption* is vital. When unconstrained off-farm employment and migration are included in the model, the logic changes in a fundamental way. If alternative employment is available locally, or migration is an option, the open economy approach is more realistic. This depends, of course, on the time horizon: the open economy assumption is more relevant the longer the time horizon of the analysis. The review also suggests that for the purpose of analyzing deforestation, the usefulness of a conventional focus on the households' objectives for classifying different modelling approaches could be questioned.

The different models of deforestation should, in principle, allow for empirical testing and falsification/verification. There are at least two possible routes to pursue. Macro level statistical

[31] The Chayanov model resembles a general equilibrium (GE) model in the way that the shadow wage rate is determined endogenously. Thus it gives predictions that are similar to those one would get in a GE model.

analysis has been attempted in a large number of studies.[32] This approach suffers from some serious deficiencies. The quality of the data used seems to be very poor, in particular for rates of deforestation. The latter are commonly based on FAO (1992), which is derived from national forest inventories in 90 tropical countries. Only 18 of the countries have undertaken two or more inventories, which, in principle, makes it possible to estimate *changes* in forest cover. For the remaining 72 countries the deforestation in the period 1980-1990 is based on only *one* inventory (some as old as from 1965). Forest cover and deforestation are then extrapolated by using a deforestation model where population density is the only explanatory variable (FAO, 1992: 11). In effect, the estimates reflect changes in population density more than actual changes in forest cover. Not surprisingly, population is the only variable that is consistently significant in the regression models, cf. the summary in Brown and Pearce (1994).

A regression model assumes implicitly that the independent variables have a similar effect on the dependent variable in all countries, which is highly questionable. An example is foreign debt, which is found to be very weakly correlated with deforestation at the aggregate (global) level. At the same time, micro level studies show that debt may have significant effects on deforestation in particular areas, in either direction (e.g., Reed, 1996). Partly related to the above, one should question the appropriateness of focusing on macro level variables in cross country analysis. The agents of deforestation make their decision based on a number of -- to them -- exogenous variables. The way in which these variables are affected by macro level variables (such as GNP per capita, economic growth, population growth, debt, etc.) varies significantly between countries. Thus we should expect to find a much stronger correlation between deforestation and the micro level decision parameters, than between deforestation and macro level variables. A relatively rare example of a detailed analysis based on micro data is a Mexican study by Deininger and Minton (1996).

A second line of inquiry would be to derive some general conclusions and policy guidelines based on micro level field studies. Unfortunately, no comprehensive and systematic aggregation of micro level studies has been attempted, thus the evidence is scattered. The evidence from such relatively different settings as Brazil (Deacon, 1992; Schneider, 1995), Central America (Kaimowitz, 1995), and Sumatra (Tomich and van Noordwijk, 1995; Angelsen, 1995) seems, however, to support the explanatory power of model IV. Studies on the effects of structural adjustment programmes suggest, however, that the short term response of poor, subsistence farmers, particularly in African countries, is more in line with the population approach (e.g., Reed, 1996: 329).

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[32] See Brown and Pearce (1994) for the most comprehensive collection of such studies.

13 Summary and conclusions

The main purpose of this paper has been to illustrate some fundamental differences of four different approaches to modelling agricultural expansion. The approaches differ both with respect to which variables are important for deforestation, and in the case of productivity or output price increases, the direction of the effect. Because these differences are often not made explicit, the intention has been to highlight the differences in assumptions and their consequences for the conclusions, rather than exploring in detail what an empirical model of deforestation should look like.

The paper has also argued that the open economy, open access model (IV), possibly extended to include general equilibrium effects in the labour and output markets, will give the best description of many frontier economies, particularly when focusing on the long term effects. Because forest clearing gives the farmers land rights, deforestation is for them a title establishment strategy and an investment.

This framing of smallholder deforestation challenges not only the subsistence or population driven approach to deforestation, but also a conventional economic approach based on a social planner's perspective. Intensification, land titling and credit programmes -- commonly suggested remedies for reducing environmental degradation -- *may* enhance deforestation, although there are effects pushing in both directions. This approach also makes us face some potential and unpleasant conflicts, for example, between poverty reduction and reducing deforestation.

The paper has identified two sets of policies which are robust to a wide set of modelling assumptions. First, both this paper and empirical evidence suggest that lower access costs fuel deforestation. Second, provision of alternative employment and income opportunities reduce the pressure at the forest frontier. These results suggest a redirection of the focus, away from ambiguous intensification programmes and price policy reforms towards road building and the off-farm sector, in the efforts to reduce the rate of deforestation.

Appendix 1: Farm firm (substitution) and subsistence (income) effects in agricultural household models

The appendix aims to give a brief summary of some major points in the economic theory of agricultural households, discuss different assumptions and their implications, and relate this to the models of deforestation developed in the paper. Further, we want to link this theory to the standard theory of the consumer and the firm. Finally, some particular concepts (curvature effects and virtual prices) are discussed.

The distinction between farm firm and subsistence effects is central in model II of this paper. This refers to the dual role of an agricultural household as both a farm firm and a labourers' and consumers' household (Nakajima, 1986). In its first role it acts like a profit maximizing firm, in its second it acts like a utility maximizing consumer. The combination of these two roles is the key to the economic theory of agricultural households, see particularly Nakajima (1986) and Singh *et al.* (1986). A major result in this theory is that when the household is not constrained in the labour market (i.e., markets are competitive), the decision process is recursive. First, the production problem is solved, including the determination of labour demand. Then the profit from the agricultural production is carried over into the budget constraint, termed the profit effect, and the consumption and labour supply problem is solved. When the household is constrained, the household's labour demand on the farm must equal the household's labour supply, subtracted any exogenous off-farm sale of labour. The production and consumption problems must then be solved simultaneously.

Since labour demand is directly related to the extent of deforestation, our focus is on demand rather than supply. The aim of this appendix is to apply a simple model for an agricultural household, and clarify the effects of an output price increase on the labour demand under different assumptions. Not that the model is not identical to model II as the off-farm income (I) does not require any labour input, hence we get explicitly the income effect when I increases.

The classical (primal) approach

We consider the simple case with one commodity produced and sold in a competitive market at a price (p), using only family labour in production (L). There is no alternative use of labour, except leisure. The income consists of farm income and an exogenous income (I).[33] All income is used for consumption (C). The price of consumption goods is set to unity (numéraire).[34] We form the Lagrangian of the household's utility maximization problem;

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[33] For simplicity we assume, unlike in model II, that there is no labour input attached to this exogenous income.

[34] To simplify the study of price changes we have to think of the output as a cash crop which does not enter the consumption basket; or we interpret p to be a parameter reflecting the technological level in an autarkic economy where all output is consumed. See, for example, Singh *et al.* (1986) for models where the output is partly consumed.

(17) $\Omega = U(C, L) - \gamma(pf(L) + I - C)$

The utility and production functions are assumed to be well behaved. The FOCs are;

(18) $U_L - \gamma pf_L = 0$

(19) $U_C + \gamma = 0$

(20) $pf(L) + I - C = 0$

The differential form of this system is;

(21) $$\begin{bmatrix} U_{LL} - \gamma pf_{LL} & U_{LC} & -pf_L \\ U_{CL} & U_{CC} & 1 \\ pf_L & -1 & 0 \end{bmatrix} \begin{bmatrix} dL \\ dC \\ d\gamma \end{bmatrix} = \begin{bmatrix} \gamma f_L & 0 \\ 0 & 0 \\ -f(L) & -1 \end{bmatrix} \begin{bmatrix} dp \\ dI \end{bmatrix}$$

This is the Fundamental Matrix Equation of Consumer Demand as applied to an agricultural household (see, for example, Barten and Böhm, 1982). For simplicity we shall assume an additive utility function ($U_{CL} = U_{LC} = 0$). The effect on labour input of a change in exogenous income and in output price is then given by;

(22) $\frac{dL}{dI} = \frac{1}{D}[-U_{CC}pf_L] < 0$

$$D \equiv U_{LL} + U_C pf_{LL} + U_{CC}(pf_L)^2 < 0$$

(23) $\frac{dL}{dp} = \frac{1}{D}[-U_C f_L - U_{CC} f(L) pf_L]$

D is the determinant of the coefficient matrix (Hessian). The effect of higher income is negative, as it makes the household demand more leisure and therefore work less.

The sign of the effect of higher output price is ambiguous. The first term reflects the fact that value of marginal labour input has increased when the price has increased. This is a substitution effect, which is positive. We shall refer to it as the *farm firm effect* for reasons elaborated below.

The second term reflects the effect of an income change, which is identical to the effect in (22), multiplied by the actual change in income -- *f(L)*. Because of declining marginal utility of consumption this effect is negative. If the household is poor and close to its subsistence constraint, the net effect of reduced output price may be to increase its labour supply in order to survive, cf. appendix 2. Thus we label the second effect in (23) the *subsistence effect,* keeping in mind that it is similar to the income effect.

Curvature effects

Compared to the consumption-leisure choice of standard demand theory, where the consumer faces an exogenous wage rate, the main difference here is the element $-\gamma pf_{LL}$ in the coefficient matrix. In their discussion of agricultural household models, Hymer and Resnick (1969) and

Barnum and Squire (1979) refer to this as a *curvature effect* (CE), which comes as a third effect in addition to the standard income effect (IE) and substitution effect (SE). The curvature effect is due to the non-linearity of the budget constraint. This may provide an intuitive explanation of the difference between the standard consumer theory and the theory of agricultural households. The response to a price change is then written on implicit form: $dL/dp = IE + SE + CE\, dL/dp$, cf. Hymer and Resnick (1969: 497).

The curvature effect is, however, not commonly used in the literature. One reason may be that the straightforward and explicit solution of the system is simpler. Further the curvature effect is already included in D, and does in this way affect both the SE and IE even though its not included in the numerator. The curvature effect increases the absolute value of D, hence the effect of a price increase is smaller compared to the standard theory with a linear budget constraint. The intuition is clear: suppose the farm firm effect dominates and L increases. The declining marginal productivity of labour will dampen the effect. Similarly, if the subsistence effect dominates (L is reduced), the reduction will be smaller because increasing marginal productivity of labour will restore the equilibrium faster as we move down on the production frontier. Thus the curvature effect is more logically seen as an effect which reduces the magnitude of both the IE and SE, rather than as a third effect. Finally, one should note that the curvature effect has no impact on the sign of (23).

Profit maximizing

Next we want to highlight the difference between the utility maximizing approach (endogenous shadow wage) and the profit maximizing approach (exogenous wage) on the labour input. Under the profit maximizing approach the agricultural household behaves like a farm firm. The simple profit maximizing problem is given by;

$$(24) \quad \pi = pf(L) - wL$$

The FOC is given by $pf_L - w = 0$. The response to an output price increase is;

$$(25) \quad \frac{dL}{dp} = -\frac{f_L}{pf_{LL}} > 0$$

We see that this expression resembles the first term in (23), hence the name farm firm effect. In fact, the profit maximizing case can be viewed as a special case of the utility maximizing one, that is, when the marginal utility of consumption and labour is constant; in the case when $U_C = 1$ and U_L is constant, the expressions in (23) and (25) are identical.

Full belly

The full belly problem is rather trivial in the case with only one choice variable. The problem is simply to minimize labour efforts given the subsistence constraint: $\overline{C} = pf(L) + I$. The labour response to a price change is in this case given by;

(26) $\frac{dL}{dp} = -\frac{f(L)}{pf_L} < 0$

This effect resembles the income effect in the general utility maximizing case. Multiplying the expression by $U_{CC}pf_L$, we see that the numerator becomes identical to the income effect in (23), whereas the denominator lacks the first two elements, which implies that the absolute value is smaller. Thus even if there is some resemblance to the income effect, the change in labour supply will always be larger in the full belly case. As a special case, when the marginal productivity of labour is constant (no curvature effect) and the disutility of labour is constant, the income effect in (23) is identical to (26).

The Nakajima approach and virtual prices

Following Nakajima (1986), the FOC of the agricultural household model can alternatively be written as;

(27) $pf_L - z = 0;\ z = z(C, L) \equiv -\frac{U_L}{U_C};\ C = pf(L) + I$

z is the marginal rate of substitution between L and C, or the subjective or shadow wage rate (Nakajima, 1986), or the virtual price of labour (Neary and Roberts, 1980). Virtual prices are defined as those prices which would induce an unrationed household to behave in the same manner as a rationed household (no access to an off-farm labour market). The use of virtual prices greatly facilitates the comparative statics analysis, as we can use a two step procedure; first we trace the effect of exogenous changes on virtual prices, then we study how the change in virtual prices affects the allocation (Schroyen, 1991).[35] We shall therefore make heavy use of this in both this paper and chapters 6 and 7.

The response to a change in the exogenous income and the output price can then be written as;

(28) $\frac{dL}{dI} = \frac{\frac{\partial z}{\partial p}}{pf_{LL} - \frac{\partial z}{\partial L}} = \frac{z_C}{pf_{LL} - z_L - pf_L z_C};\ z_C \equiv \frac{U_L U_{CC}}{U_C^2} > 0, z_L \equiv -\frac{U_{LL}}{U_C} > 0$

(29) $\frac{dL}{dp} = \frac{-f_L + \frac{\partial z}{\partial p}}{pf_{LL} - \frac{\partial z}{\partial L}} = \frac{-f_L + f(L) z_C}{pf_{LL} - z_L - pf_L z_C}$

Multiplying by U_C and using (27), it is straightforward to verify that this gives the same result as in (22) and (23). Compared to the latter, (29) gives a more intuitive interpretation of the effects: the first term in the numerator, the farm firm (substitution) effect, refers to the effect on L keeping z constant, whereas the second, the subsistence (income) effect, gives the effect on L of changes in z following a change in p.

When comparing the above results with Singh *et al.* (1986: appendix), note that our concern is with the *demand* for labour, which is the relevant one for deforestation. We compare a situation

[35] For a general treatment of virtual prices and household behaviour under rationing, see Neary and Roberts (1980), using the dual approach, and Schroyen (1991), using the primal approach.

where the household is constrained in the labour market (and therefore household supply equals demand) to a situation with a perfect labour market. The effect of an output price increase on the labour *supply* is in the latter case similar to the *income* effect in the constrained case (negative), whereas the effect on labour *demand* is similar to the *substitution* effect (positive).

Except for the curvature effects, the farm firm and subsistence effects are similar to the substitution and income effects in standard consumer theory. We shall therefore use the terms interchangeably.[36] We find it, however, useful to introduce the terms farm firm and subsistence effects, as it directly refers to the dual role of agricultural households, and serves to highlight the importance of the labour market assumption. Moreover, as discussed above, they also include a curvature effect which is not included in standard consumer theory.

The elasticity of the shadow wage rate

Using (27) the numerator in (29) can be reformulated to explore which effect will dominate when the output price changes. The condition for the subsistence effect to dominate, i.e., (29) being negative, is;

$$(30) \quad -f_L + f(L)z_C = -\tfrac{z}{p} + f(L)z_C > 0$$

$$\Leftrightarrow \frac{\partial z}{\partial pf(L)} \frac{pf(L)}{z} > 1$$

The subsistence effect will dominate if the elasticity of the shadow wage rate or virtual price of labour with respect to farm income is larger than unity. With the specification of the utility function used in this paper we find that this will be the case for income levels sufficiently close to subsistence, cf. appendix 2.

[36] See the appendix by Strauss in Singh *et al.* (1986) for a dual approach to the derivation of the income and substitution effects in the theory of agricultural households.

Appendix 2: Comparative statics

Model I

(31) $\frac{db^{max}}{dx} = -\frac{b^{max}}{2x} < 0$

(32) $\frac{db^{max}}{dN} = \frac{b^{max}}{2N} > 0$

(33) $\frac{db^{max}}{dc^{min}} = \frac{b^{max}}{2c^{min}} > 0$

Model II

We use the following functional form for household utility;

(10) $U(C,T) = (C - c^{min})^{\alpha} + v(T^{max} - T)^{\beta};\ v > 0;\ \alpha, \beta \in (0,1);\ (C - c^{min}), (T^{max} - T) > 0$

The first order condition, and the virtual price of labour marginal rate of substitution (z) are then given by;

(8) $x - z(1 + qb^{max}) = 0$

(34) $z \equiv -\frac{U_T}{U_C} = \frac{v\beta\left(C - c^{min}\right)^{1-\alpha}}{\alpha(T^{max} - T)^{1-\beta}}$

$$\frac{\partial z}{\partial C} \equiv z_C = \frac{v\beta(1-\alpha)\left(C - c^{min}\right)^{-\alpha}}{\alpha(T^{max} - T)^{1-\beta}} > 0$$

$$\frac{\partial z}{\partial T} \equiv z_T = -\frac{v\beta(\beta-1)\left(C - c^{min}\right)^{1-\alpha}}{\alpha(T^{max} - T)^{2-\beta}} > 0$$

The effect of a change in the value of agricultural yield (x) is given by;

$$\frac{db^{max}}{dx} = \frac{1}{\mu}\left[1 - (1 + qb^{max})\frac{\partial z}{\partial x}\right]$$

$$\mu = zq + (1 + qb^{max})hb^{max}[xz_C + (1 + qb^{max})z_T] > 0$$

Using (8) and (34), and that $\frac{\partial z}{\partial x} \equiv z_x = z_X H = z_C H$, we get;

(35) $\frac{db^{max}}{dx} = \frac{1}{\mu}\left[1 - \frac{\partial z}{\partial x}\frac{x}{z}\right] = \frac{1}{\mu}\left[1 - \frac{X(1-\alpha)}{C - c^{min}}\right] \begin{cases} > 0 \Leftrightarrow X > \frac{c^{min} - wE}{\alpha} \\ = 0 \Leftrightarrow X = \frac{c^{min} - wE}{\alpha} \\ < 0 \Leftrightarrow X < \frac{c^{min} - wE}{\alpha} \end{cases}$

The magnitude of the subsistence effect is determined by the elasticity of z with respect to x, as given by second element in the [ ]. The size of it depends on the level of agricultural income, off-farm income, the elasticity of marginal utility with respect to surplus consumption (α-*1*), and the subsistence level. For values of X below $(c^{min} - wE)/\alpha$, the elasticity is larger than one, and the subsistence effect will predominate the farm firm effect.

The implications of using different functional forms for utility should be noted. Consider the case with no off-farm employment: $E = 0$, and $X = C$, $T = L$. Using the standard (multiplicative) Stone-Geary utility function, $(C - c^{\min})^{\alpha}(T^{\max} - T)^{\beta}$, the expression in (35) becomes $\frac{1}{\mu}\left[1 - \frac{X}{X - c^{\min}}\right] < 0$, thus the subsistence effect will always dominate. Reducing this further to a linear logarithmic (or Cobb-Douglas type) utility function, i.e., $c^{min} = 0$, gives that the net effect of an increase in x on b^{max} will be *zero*.

Using the Houthakker additive function implies setting $c^{min} = 0$ in our original formulation. It is readily seen that the elasticity is always less than one, and (35) simply becomes $\frac{\alpha}{\mu} > 0$. With this functional form the farm firm effect will always dominate. In summary, the chosen functional form provides the most flexible form which allows the elasticity of z with respect to x to be either above (Stone-Geary) or below (Houthakker) unity. This clearly highlights what Stern (1986: 157) underscores in his review of labour supply functions: "inflexibility in the functional forms used may produce very misleading predictions and policies".

Finally we should note that the function used is equivalent to using a CES function if we assume $\alpha = \beta$, as done in the numerical simulation. The CES function with subsistence level and maximum labour input is given by $\left[\tau(C - c^{\min})^{-\rho} + (1-\tau)(T^{\max} - T)^{-\rho}\right]^{-1/\rho}$. Since positive monotone transformations are allowed, we find by assuming $\alpha = \beta = -\rho$, and setting $v = (1-\tau)/\tau$ that this is equivalent to the function used.

(36) $$\frac{db^{\max}}{dq} = -\frac{1}{\mu}\left[zb^{\max} + (1 + qb^{\max})\frac{\partial z}{\partial q}\right] < 0$$

$$\frac{\partial z}{\partial q} = \int_0^{b^{\max}} hb^2 db\, z_T > 0$$

(37) $$\frac{db^{\max}}{dh} = -\frac{1}{\mu}\left[(1 + qb^{\max})\frac{\partial z}{\partial h}\right] < 0$$

$$\frac{\partial z}{\partial h} = \int_0^{b^{\max}} xb\, db\, z_C + \int_0^{b^{\max}} (1 + qb)b\, db\, z_T > 0$$

(38) $$\frac{db^{\max}}{dE} = \frac{1}{\mu}\left[-(1 + qb^{\max})\frac{\partial z}{\partial E}\right] < 0$$

$$\frac{\partial z}{\partial E} = wz_C + z_T > 0$$

(39) $$\frac{db^{\max}}{dw} = \frac{1}{\mu}\left[-(1 + qb^{\max})\frac{\partial z}{\partial w}\right] < 0$$

$$\frac{\partial z}{\partial w} = Ez_C > 0$$

(40) $$\frac{db^{\max}}{dc^{\min}} = \frac{1}{\mu}\left[-(1 + qb^{\max})\frac{\partial z}{\partial c^{\min}}\right] > 0$$

$$\frac{\partial z}{\partial c^{\min}} = -\frac{\beta}{\alpha(T^{\max} - T)} < 0$$

(41) $$\frac{db^{\max}}{dT^{\max}} = \frac{1}{\mu}\left[-(1 + qb^{\max})\frac{\partial z}{\partial T^{\max}}\right] > 0$$

$$\frac{\partial z}{\partial T^{max}} = -\frac{\beta}{\alpha}\frac{\left(C - c^{min}\right)}{(T^{max} - T)^2} < 0$$

Model III

(42) $\frac{db^{max}}{dx} = \frac{1}{wq} = \frac{b^{max}}{x-w} > 0$

(43) $\frac{db^{max}}{dq} = -\frac{x-w}{wq^2} = -\frac{b^{max}}{q} < 0$

(44) $\frac{db^{max}}{dw} = -\frac{x}{qw^2} = -\frac{1+qb^{max}}{qw} < 0$

Model IV

(45) $\frac{db^{max}}{dx} = \frac{\theta}{wq} = \frac{\theta b^{max}}{\theta x-w} > 0$

(46) $\frac{db^{max}}{dq} = -\frac{\theta x-w}{wq^2} = -\frac{b^{max}}{q} < 0$

(47) $\frac{db^{max}}{dw} = -\frac{\theta x}{qw^2} = -\frac{1+qb^{max}}{qw} < 0$

(48) $\frac{db^{max}}{d(\delta+\lambda)} = -\frac{x}{qw}\frac{g}{(\delta+\lambda-g)^2} < 0$

(49) $\frac{db^{max}}{dg} = \frac{x}{qw}\frac{\delta+\lambda}{(\delta+\lambda-g)^2} > 0$

Appendix 3: The weakening of the subsistence effect as the labour market integration increases in model II

The subsistence effect when the value of yield (x) increases is given from (35) as $SE = \frac{X(1-\alpha)}{X+wE-c^{\min}}$, whereas the farm firm is equal to one, both divided by $\mu > 0$, which we ignore here as it is the strength of subsistence effect relative to the farm firm effect which is of interest. We want to prove that SE is reduced as E increases;

$$\frac{\partial SE}{\partial E} = \frac{(1-\alpha)\frac{\partial X}{\partial E}\left(X+wE-c^{\min}\right)-X(1-\alpha)\left(\frac{\partial X}{\partial E}+w\right)}{\left(X+wE-c^{\min}\right)^2} = \frac{(1-\alpha)}{\left(X+wE-c^{\min}\right)^2}\left[\frac{\partial X}{\partial E}(wE-c^{\min})-Xw\right]<0$$

$$\Leftrightarrow\ wE-c^{\min}-X\frac{w}{\frac{\partial X}{\partial E}}>0;\quad \frac{\partial X}{\partial E}<0 \text{ cf. (38)}$$

As the consumption cannot be lower than the subsistence level, $X+wE-c^{\min}\geq 0$, a sufficient condition for the inequality to hold is;

$$\left|\frac{w}{\frac{\partial X}{\partial E}}\right|>1 \Leftrightarrow -\frac{\frac{\partial X}{\partial E}}{w}<1$$

Using (1), (3) and (38) we get;

$$\Leftrightarrow\ \frac{xhb^{\max}(1+qb^{\max})(wz_C+z_T)}{wzq+w(1+qb^{\max})hb^{\max}[xz_C+(1+qb^{\max})z_T]}<1$$

$$\Leftrightarrow xhb^{\max}(1+qb^{\max})(wz_C+z_T)-wzq-w(1+qb^{\max})hb^{\max}[xz_C+(1+qb^{\max})z_T]<0$$

Using the FOC and manipulating the expression yields;

$$\Leftrightarrow xhb^{\max}(1+qb^{\max})(wz_C+z_T)-wzq-w(1+qb^{\max})xhb^{\max}(z_C+\tfrac{z_T}{z})<0$$

$$\Leftrightarrow xhb^{\max}(1+qb^{\max})[\tfrac{z_T}{w}-\tfrac{z_T}{z}]-zq<0$$

When the household is constrained in the labour market, $w\geq z$, thus the expression in [ ] is non-positive, and the inequality holds. This completes the proof.

Appendix 4: Parameter values in the numerical example

Variable	Symbol	Initial value
Population (households)	N	82
Land use intensity	m	10
Subsistence requirement	c^{min}	1200
Maximum labour input	L^{max}	5
Output per ha	x	500
Labour per ha	l	1
Distance costs	q	0.1
(parameter)	α	0.2 / 0.9
(parameter)	β	0.2 / 0.9
(parameter)	v	8 / 242
Wage	w	400
Off-farm employment available in model II	E	0
Discount rate	δ	0.2
Risk of loosing the land	λ	0.3
Expected growth in x	g	0.01
(parameter)	θ	1.026

The two sets of parameter values for α, β and v refer to two different situations in the Chayanovian model. In the first case the subsistence effect will dominate (low α); in the second the farm firm effect will dominate.

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Chapter 3

Shifting Cultivation Expansion and Intensity of Production: A Theoretical Model*

Abstract:

This paper studies decision making in shifting cultivation related to the intensity of production (fallow period and labour input) and the expansion of agricultural land into primary forest. The models combine forest rotation (Faustman) and spatial (von Thünen) approaches in resource economics. The small, open economy assumption is used, that is, all prices, including the wage rate, are exogenous in the models. Three different property rights regimes are discussed: social planner's solution with secure rights to all forest land, open access, and homesteading, where property rights are established through forest clearance. The main force towards both intensification in terms of shorter fallow periods and land expansion (deforestation) is lower effective real wage, which in turn is determined by five variables: agricultural output price, nominal wage, technological level, transport costs, and distance from the centre. Many governments aim to both intensify cultivation and limit expansion (deforestation) of traditional agriculture. The paper suggests a trade-off between these objectives; policies which stimulate intensification will also lead to an expansion of agricultural land.

* I would like to thank Rögnvaldur Hannesson, Stein Holden, Ottar Mæstad, Karl R. Pedersen, Øyvind Sandbukt, Ussif Rashid Sumaila, and Arne Wiig for comments on draft versions of this paper. Remaining errors and omissions are my responsibility. An early version of this paper is published as CMI Working Paper 1994: 3.

1 Introduction

Shifting cultivators as commonly seen as both obstacles to economic development and major agents of environmental degradation. The first concern relates to the shifting cultivation system's low productivity per unit of land, that is, the low *intensity* in terms of long fallow periods, little labour input, and almost no use of purchased inputs. The environmental concern relates in particular to the *expansion* of agricultural land into primary forest (deforestation).[1]

A policy issue has therefore been how to simultaneously intensify and limit expansion of shifting cultivation systems. This paper develops analytical models to address the following questions: Which factors determine the intensity of production in a shifting cultivation system, i.e., the length of the fallow period and labour inputs? Which factors determine the total agricultural area or expansion of the system? *Will policies which promote intensification also limit expansion, or do policy makers face a trade-off between different policy objectives?* And finally, how do the answers to the above questions depend on the *property regime*?

The outline of the paper is as follows. Section 2 gives a brief overview of some key aspects related to shifting cultivation modelling: the spatial dimension and forest rotation dimensions, and the market and property regime assumptions. In section 3 the main components of the model are developed. Section 4 discusses the simplest version of the social planner's solution or command optimum, that is, the single rotation (Fisher) model. Section 5 deals with the more complete multi-rotation (Faustman) problem, where the value of forest land after clearing are included. Section 6 very briefly compares the Faustman solution with the communal and private management outcomes, which under certain conditions is similar to the social planner case of section 5. The open access case is discussed in section 7. Section 8 deals with a special case of open access, namely when clearing of forest gives property rights to the farmers (homesteading). Section 9 compares the different models, and the effects of changes in exogenous variables. Section 10 gives some concluding remarks.

The present paper is complementary to Angelsen (1995; 1996a). The latter discusses the issue of extensification (deforestation) only, but under a wider set of market assumptions. Angelsen (1995) gives an empirical analysis of recent changes in the shifting cultivation system of the Seberida district, Sumatra.

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[1] Some of the assumptions underlying these concerns clearly could be questioned, but this would be beyond the scope of this paper (see Angelsen 1994; 1995).

2 Some key aspects of shifting cultivation modelling

2.1 The importance of shifting cultivation

Shifting cultivation is an agricultural practice at an early stage in the evolution of agricultural systems (Boserup, 1965; Ruthenberg, 1980). The system is characterized by abundant land, whereas labour is considered the constraining factor. A system with effortless self-fertilization of the soil through a long fallow period, and burning of the vegetation before one or a few years of cropping, therefore represents a rational response on the part of farmers to the relative scarcity of inputs. In this situation, the shifting cultivation system may yield higher output per unit of labour input than sedentary systems (Boserup, 1965; World Bank, 1990).

Most studies of shifting cultivation belong either to the sphere of anthropology, typically focusing on how the production system is integrated in a wider cultural and social structure, or to that of soil science, focusing on issues like erosion and nutrient cycling (see Robinson and McKean (1992) for an extensive bibliography). There are relatively few *economic* studies and models of shifting cultivators' behaviour and decision-making. Exceptions include Dvorak (1992), who develops a simple model with a subsistence requirement and no costs of expanding land use; Holden (1993), who uses a Chayanov (1966) approach and develops linear programming models to study of shifting cultivation in northern Zambia; Nghiep (1986), who similarly uses an LP model to study conditions for agricultural transformation in Brazil; and López and Niklitschek (1991), who develop a general equilibrium, dual (two sector) model. This paper presents an alternative economic approach to the study of shifting cultivation, which focuses on two major characteristics of the shifting cultivation system: its *spatial* dimension, and its *forest rotation* aspect. These issues are not treated satisfactorily in the above models.

There is a number of good reasons why shifting cultivation deserves further economic analysis and modelling. The deficiency of economic modelling in this area is one; the nature of economic decision-making and farmers' response to exogenous changes need to be better understood in order to design effective policy instruments. Policy makers may want to influence the development of shifting cultivation for both environmental, social, economic, and political reasons. The problems of deforestation and soil erosion related to expansion of shifting cultivation are well established. Shifting cultivation is commonly held responsible for about half of tropical deforestation; see, however, Angelsen (1995) for a critical discussion of this estimate, and of the different environmental effects of various forest land uses. Some governments focus on the extensive nature of the practice, considering it an inefficient use of forest land.

On political grounds governments may also want to "develop" shifting cultivation communities into more permanent settlements which may be easier to control, or due to the economics of scale in the supply of public services. Others argue that the "primitive" nature of shifting cultivation may not correspond to the image of progress that governments want to present (Dove, 1983).

The often low incomes among shifting cultivators make increasing agricultural income a key element in a policy aiming at reduced rural poverty. The key challenge in this respect is how to enhance the output from the system, while maintaining its long term productivity (e.g., avoid soil mining/erosion) and avoiding losses in other environmental functions (e.g., reduced biodiversity due to expansion into virgin forest); in other words, how to achieve a *sustainable intensification* of the system. There is no easy answer to this problem, which may entail important trade-offs in some situations: the concern for the system's long term productivity indicates longer fallow periods, whereas the goal of limiting its expansion may call for an intensification through shorter fallow periods. Thus, we may have conflicts between short and long term productivity, and between production and environmental conservation objectives.[2]

2.2 The spatial dimension: the von Thünen approach

The models in this paper make use of and integrate two different approaches in agricultural and resource economics: *spatial* models in the von Thünen (1826) tradition, and *forest rotation* models in the Faustman (1849) tradition.

In the von Thünen models transport costs and accessibility play a crucial role in determining the land rent and the location of the agricultural frontier, and thereby land area under cultivation. Land is assumed to be homogenous, and differs only by the location as measured by distance from a centre (village). This is contrasted with the Ricardian approach, where distance costs are neglected, but land differs in quality (soil fertility). Including differences in fertility would add another dimension to the problem, but would not change any of the main results presented in this paper (see Randall and Castle (1985) for a comparison).

In the von Thünen model land is assumed to be in infinite supply.[3] There is, however, scarcity of *good* land, that is, land close to the centre (low distance costs). The land frontier or the border between cultivation and virgin forest will be determined endogenously. A basic premise in the

[2] This is elaborated in Angelsen (1994).

[3] Or in the words of von Thünen himself: "Imagine a very large city in the midst of a fertile plain not traversed by any navigable river. The plain's soil is of uniform quality and capable of cultivation everywhere. At a great distance from the city the plain turns into an uncultivated wilderness separating this state from the rest of the world. The question is this: under these conditions what kind of agriculture will develop and how will the distance to the city affect the use of land if this is chosen with the utmost rationality?" (Quoted in Beckman, 1972: 1.)

model is that all forest land which yields a positive land rent will be converted to agricultural use. All land rent will be captured. The *frontier* is defined as where the *rent is zero*.

Many studies in the von Thünen tradition focus on how different activities are located in zones of different distance from the centre, depending on their transport costs, e.g., value/weight ratio for agricultural products (Randall and Castle, 1985). We ignore this aspect, and consider only the choice between one activity (shifting cultivation) and maintaining virgin forest. Further, we only deal with one homogenous agricultural crop, and do not discuss the choices between different crops, in particular, between annuals and perennials. These choices could be handled by using the usual "brute force" methods, i.e., comparing the maximum value of the objective function for different land uses or crops. Implicitly, we assume that these choices already have been made, and we consider the most profitable (mix of) agricultural product(s).

This paper belongs to the branch of spatial models which takes the centre as given, and assumes that a transport network already in place, i.e., it represents a *partial equilibrium approach* (Starret, 1974). This could be an acceptable simplification if the costs of establishing new centres are very high, and the transport system is a result of exogenous decisions. The latter is clearly the case in my study area in Seberida, Sumatra as well as many other areas in Southeast Asia, where road construction and other infrastructural developments have been closely connected to government sponsored projects such as large-scale logging, plantations, and transmigration.

2.3 The rotation dimension: the Faustman approach

In the Faustman (1849) forest rotation models the optimal age of the forest at the time of cutting is discussed under various assumptions about the variables included, such as the discount rate, relative prices, costs, technology, risk, environmental effects, etc. Most models developed in this tradition, like the one presented in this paper, assume all important parameters to be constant over time, and then discuss changes in the steady-state from one-time changes in exogenous variables. The models deal with different long-term bio-economic equilibria; there is, for example, no land degradation over time (the production function remains constant). Neither does the model deal with possible irreversibilities involved. These are crucial assumptions, which greatly simplify the analytics as a dynamic problem is reduced to one of static optimization.

The obvious similarity between timber production and shifting cultivation is the *rotation* aspect and the cyclical harvesting of a renewable resource. However, applying models of timber production to shifting cultivation requires several modifications. The benefits and costs involved are different, e.g., costs of planting trees are normally not present in shifting cultivation, whereas the clearing of forest is the start of a production cycle that involves labour inputs for planting, weeding, pest control, harvesting, etc. This paper explores how forest rotation models could be reformulated to the shifting cultivation setting.

More importantly, timber economics models normally assume private or government operated forests with well defined and secure property rights, and competitive input (including labour) and output markets. This may not always be the case in a shifting cultivation setting, where different property regimes are possible. An aim with this paper is to see how the outcome and effect of various policies depend on the assumptions made about the property regime (see below).

The application of the von Thünen and the Faustman approaches, separately or in combination with economic models of shifting cultivation, has been very limited so far. Barrett (1991) uses the Faustman model to discuss the effect of output prices on soil conservation (the length of the fallow period is used as a proxy). As we will return to in section 5.2, his main conclusion hinges on an insufficient specification of the cost structure of shifting cultivation.

Models which combine these two approaches in relation to timber production exist, for example, Ledyard and Moses (1976). By combining these two approaches, it is possible to make a more realistic description of shifting cultivation systems, and at the same time draw on the large literature that exists, particularly in the Faustman tradition. A contribution of this paper is to integrate these two approaches in general, and to apply them to a number of different settings for shifting cultivation in particular.

There is an alternative to the Faustman approach for the analysis of cyclical harvesting which uses optimal control theory, see particularly Lewis and Schmalensee (1979) and Krautkramer (1994). However, the analytical complexity and the lack of a general characterization of optimal policies have inhibited the further development of such techniques at the analytical level. Numerical models have been applied in particular to fishing; "pulse fishing" may be an optimal strategy if there are, for example, stock dependent costs or high fixed costs (Hannesson, 1975; Clark, 1990: 144 ff).

2.4 Market assumptions: small, open economy

Economic models for the study of agricultural decision-making can be categorized along a number of axes, in particular the behavioural and market assumptions (of which the labour, product, and credit markets are the most important). The implications of using different approaches when it comes to modelling of deforestation has been elaborated in Angelsen (1996a), thus we only include a brief discussion here.

The present model is within the *small, open economy* category. Markets exist, and all prices (including the wage rate) are taken as parametrically given. An intuitive interpretation is that the shifting cultivation sector is small compared to the rest of the economy. In addition to the simplification made by assuming exogenous prices, there is also a simplification inherent in the recursive property of such models: if labour can be sold or hired at a constant wage, the production decisions by a *utility* maximizing household can be studied as income or *profit* maximizing production behaviour (Singh *et al.*, 1986).[4]

We assume that output prices are exogenously given. The credit market only enters the discussion implicitly. The recursive property of open economy models allows us to neglect the consumption side when analyzing production decisions. Thus the use of credit to, for example, smoothen consumption is not included. Neither are there any capital investments in production as labour and land are the only inputs. Moreover, we confine the discussion mainly to long-run steady states, where consumption equals income. To the extent a credit market is needed, the implicit assumption is that it works perfectly; farmers can borrow and save as much as they want at a fixed interest rate (as in the Faustman model). Though this may be unrealistic, we consider it to be of minor importance for the main arguments of the paper.

2.5 Property rights regimes

It is widely recognized that the property rights regime is a crucial factor in determining resource allocation in tropical agriculture in general, and in frontier systems, such as shifting cultivation, in particular (see, for example, Bromley, 1991). The property regime is crucial in determining which costs and benefits that are to be included in the decision makers' optimization problem. We can identify at least five different regimes or solutions to the model:

1. *Global social planner:* All externalities are included in the optimization problem.
2. *Communal management (local social planner):* Local, but not national or global, externalities are included.
3. *Private property:* No externalities are included, but discounted future private benefits and costs are included in the optimization problem.
4. *Open access:* Neither externalities nor future benefits and costs are included.
5. *Homesteading:* This could be regarded as a special kind of open access, where forest clearing gives private property rights to the cleared land. Under this regime land is transferred from an open access resource (regime 4) to a private property resource (regime 3).

The global social planner's solution or command optimum is employed to define the socially optimal solution, and acts as a yardstick to measure the outcome under other regimes. Each of

[4] The wage rate in the small, open economy model could well be the *expected* wage rate in the urban sector in a Harris-Todaro (1970) model.

the four other property regimes have empirical relevance, and will be discussed. State property is sometimes referred to as a separate property regime (e.g., Bromley, 1991). We have not included this regime as it could be regarded as a special case of private property, where the owner is not a person, a household, or a firm, but the state.[5] Parts of economic theory have traditionally not distinguished between state property and the social planner's solution, but little knowledge about tropical resource management is needed to realize the lack of realism in this assumption. One could assume, or at least hope, that state management would contain *some* of the elements included in the social planner's problem. Generally, however, the state or powerful groups within the state may have strong financial interests in *certain* productive (as opposed to protective) uses of the forest, for example, in logging or plantations.

Much of the debate on tropical deforestation and shifting cultivation is focused on environmental externalities such as the carbon storage function of tropical forest, and the preservation of biodiversity. We shall *not* pay too much attention to these issues (except to some extent under the social planner's solution), not because they are unimportant, but because the model here will not add much to the standard approaches in environmental economics. Under all the four property regimes above (2.-5.), there will be no incentives to include (global) externalities, and the rate of deforestation will be too high. We do not make any attempt to answer the question of how much deforestation is optimal, that is, how different uses of the forest should be balanced. Instead, a major aim of the paper is to explore which factors determine the intensity and expansion of shifting cultivation, and thereby identify policy handles which can be used to influence shifting cultivators' decision-making.

3 Basic model

3.1 Fallow period and intensity of production

This section introduces the basic relationships and definitions to be used in the later sections. A crucial variable in a shifting cultivation system is the length of the fallow period, or to be more

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[5] Communal property could indeed also be considered a special case of private property, where the owner is a group of individuals, e.g., a community. The main distinction is between situations *with* property rights (where the agent with the rights is either the almighty, fully informed, and welfare maximizing social planner; the community; the state; or an individual/household) on the one hand, and situations where *no one* has property rights (open access) on the other. Real life situations will form a continuum along this axis, depending on how *secure* the rights (claims) are. Another complication of this categorization is the fact that the agent may not be well defined, for example, individual households may use land in a particular way after consultations with the leaders of the community. Property rights are a bundle of rights, which are always constrained to various degrees, for example, households may not be allowed to sell the land (to outsiders). Finally, a resource (land) may have different regimes governing different uses, for example, agricultural use resembles a private property regime, whereas collection of forest products from the same land is governed by communal management; see Angelsen (1996b) for a further discussion.

precise: the relationship between the fallow period and the cropping (tillage) period. Let H be cropping land, A total agricultural land (cropping and fallow land), C the length of the cropping cycle, and F the length of the fallow period. Then we have the following relationship;

$$(1) \qquad A = \frac{H}{\frac{C}{C+F}} = Hm \quad \Leftrightarrow \quad \frac{H}{A} = \frac{1}{m}$$

Here $\frac{C*100}{C+F} = R$ is Ruthenberg's (1980) R-value, i.e., the percentage of land that is under cultivation. $m = \frac{C+F}{C}$ is Boserup's (1965) land use intensity factor, which will be the key variable in our model. The inverse of m gives the share of land under cultivation, and can be used as a measure of intensity of production; lower m implies an intensification. Indeed, agricultural systems are commonly classified on the basis of these factors, as done by Boserup (1981: 19): forest fallow (R = 0 - 10); bush fallow (R = 10 - 40); short fallow (R = 40 - 80); annual cropping (R = 80 - 100); and multicropping (R = 200 - 300).[6] Ruthenberg (1980: 16) distinguishes between shifting systems ($R < 33$); fallow systems ($33 < R < 66$); and permanent cultivation systems ($R > 66$).

The fallow period is the most interesting variable in a shifting cultivation system, and shows much greater variation than the cropping period. To make the models more tractable, and to keep the focus on the fallow period, we assume instantaneous production and only one harvest before fallow. In this way we avoid some issues which are not particularly relevant for the overall theme of the paper, for example, discounting within the cultivation period and the different timing of costs and yield. Thus we shall refer to m as the fallow period, while keeping in mind this simplifying assumption.

3.2 Production function

The yield (output per ha of cleared land or land currently in production) - x - is dependent on the length of the fallow period (m), the labour inputs for weeding, pest control, etc. (l), and the technology level (a).[7] Labour for clearing is determined by the fallow period (see below), and is not a choice variable and has no yield effect in the model.

$$(2) \qquad x = af(m,l); \quad f_m \geq 0, f_{mm} \leq 0, f_l \geq 0, f_{ll} \leq 0, f_{ml} = f_{lm} \leq 0; a > 0$$

Yield is an increasing function of the length of the fallow period, as longer fallow increases the biomass and thereby the fertilization of the soil through burning. In addition, higher m implies less weed and pest problems. We assume $f(\ )$ to be concave in m and l.

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[6] A more general definition of R is to multiply in the above definition by the number of harvests per year, thus the R-value could exceeds 100 if there is more than one harvest per year.

[7] The formulation partly follows the function used by Dvorak (1992): $x = f(C,F,l)$, where F is the fallow period, and C the cropping period.

The cross derivatives are assumed to be negative, i.e., the marginal productivity of labour decreases as the fallow increases, as, for example, weeds become less of a problem. This is in line with Dvorak (1992), whereas López and Niklitschek (1991) assume a *positive* cross derivative. An argument for a positive sign is the fact that increased fallow period means more fertile land, and this *could* increase the marginal return to labour. A third possibility is that the sign depends on the level of m, for example in the way that the cross derivative is *positive* for small values of m, whereas it is *negative* for large values of m. The empirical evidence to determine the sign is weak. As the later analysis will show, none of the main conclusions on how m is affected by exogenous changes depend on this assumption, whereas they do for l.

Technical change is represented in this model by the parameter a in a manner implying Hicks neutral technical progress. The main argument of Boserup (1965) and others is that most of the technical change in a shifting cultivation system is *endogenous*, depending particularly on the fallow period, which in turn is determined by factors such as the population pressure. The models presented in this paper, like most models for agricultural decision-making, do *not* include endogenous technical change. Technical progress included in a in our model could be, for example, higher-yielding crop varieties.[8]

Finally, $X = Haf(m,l)$, where X is total production, and H is cropping area (land currently in production). Hence the model assumes that the elasticity for total production with respect to land is one (cf. the assumption of homogenous land).

3.3 Labour costs

We include three types of labour in the model.[9] The first type of labour input is weeding, pest control, etc. described above. Second, clearing and preparation of the field requires labour (g). The amount needed depends on the fallow period, $g = g(m)$; longer fallow requires more work to clear the field (larger trees to cut and burn). The function $g()$ reaches its maximum when the forest reaches its climax vegetation.

(3) $$g = g(m);\ g(0) > 0, g_m \geq 0, g_{mm} \leq 0$$

Third, there are costs related to the location of the field, as measured by the distance from the village (b). These may be thought of as time (c) spent on walking between the fields and the village. A number of alternative formulations of the distance cost function is possible. We have

[8] Even though the high-yielding varieties (HYV) associated with the Green Revolution in intensive, irrigated agriculture are not very relevant to shifting cultivators, some intermediates between traditional crop varieties and HYV may be.

[9] Ruthenberg (1980: 50-51) separates the labour operations in shifting cultivation as follows: (1) clearance of wild vegetation; (2) land preparation and planting; (3) weeding; and (4) harvest, transport of harvest, and processing. A slightly different categorization is used in this paper, which is more appropriate to the models developed.

chosen a specification which is both simple and has some intuitive appeal. It assumes c to be proportional to both distance and time working on the field per unit land $(l + g)$;[10]

$$c = qb[l + g(m)] \tag{4}$$

q is the time spent on walking per km for one day of work on a field of one hectare. Our formulation implies multiplicative distance costs, both in distance and in on-the-field labour inputs $(l + g)$. Thus, increased distance has exactly the same effect as a real wage increase in the model, which turns out to be a neat simplification. In reality there are both additive and multiplicative elements related to distance. If distance costs were only additive, fallow length and labour inputs would be independent of distance. This is clearly an unrealistic description which does not correspond to empirical observations. We have chosen to include only the multiplicative elements as these are the most important. Additive costs would only have implications for the determination of the agricultural frontier, whereas multiplicative costs are important for all three endogenous variables (labour, fallow, and agricultural frontier). Thus, adding an additive component does not give any new insight or change the main results.[11]

Summarizing the three types of labour inputs, we get;

$$l + g(m) + qb[l + g(m)] = (1 + qb)[l + g(m)] \tag{5}$$

3.4 Land rent

In a static model, the land rent (r) or profit from one single clearing of a plot at a given distance from the village, measured in units of the agricultural product (numéraire), is given by;[12]

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[10] One micro-justification for linear distance costs is the following. Assume the number of hours spent on the field per working day to be fixed (and equal one), and let the number of working days (N) be the choice variable. Then $N = l + g(m)$, and if we assume the farmer to walk at a constant speed per km, we get the formulation of (4). The linearity assumption is in line with the original von Thünen model and most later applications, for example, Jones and O'Neill (1994). Note, however, that if total hours of work per day, including walking, rather than on-the-field work is fixed, distance costs would be convex in distance. The implications on the agricultural frontier of assuming convex distance costs is discussed in Angelsen (1996a).

Further, the chosen formulation of distance costs implies that there is no optimization of transport costs, for example, in the way that farmers would work more per trip on the distant fields. This is an argument for the costs being concave in distance. On the other hand, one may argue that time spent on walking per km should be convex in distance, e.g., one may need to take a rest on longer trips. All in all, the linearity assumption may not be a perfect representation, but its simplicity and the lack of convincing arguments for a particular alternative make it acceptable.

[11] Additive costs would be a kind of sunk costs in the model: they would be important to the decision of whether or not to open a swidden at a given distance, but afterwards they would *not* influence the decisions regarding fallow period and labour input.

[12] This model gives the maximum land rent from one clearing. It does not take into account, *inter alia,* discounting or the value of land after clearing, which is considered later.

(6) $r[m,l;a,w(1+qb)] = af(m,l) - w(1+qb)[l+g(m)]$

w is the real wage rate, defined as nominal wage divided by the agricultural output price (i.e., the price of the agricultural output is the numéraire). Note that with our formulation of distance cost, (6) is equivalent to the more common formulation where the net output price declines with distance due to costs of transportation of output.

The maximum (undiscounted) profit from a single clearing for a plot at a given distance is found by setting $r_m = r_l = 0$;

(7) $\frac{f_m(m^*,l^*)}{g_m(m^*)} = \frac{w}{a}(1+qb) \equiv z; \quad m^* = m^*(z)$

(8) $f_l(m^*,l^*) = \frac{w}{a}(1+qb) \equiv z; \quad l^* = l^*(z)$

The fallow period is chosen in such a way that the production increase of longer fallow equals the increased clearing costs of extending the fallow period. Labour is similarly chosen such that marginal productivity equals effective real wage (z), that is, the real wage adjusted for the technological level and the time spent on travelling between the village and the field. We note that all the exogenous factors can be summarized into one variable, $z \equiv \frac{w}{a}(1+qb)$, which may be interpreted as the *effective real wage*, taking into account both the technological level and the distance costs. This implies that m^* and l^* on a particular field depends on its distance from the centre.

The highest possible land rent is given by;

(9) $r^* = r(m^*,l^*) = af(m^*,l^*) - w(1+qb)[l^* + g(m^*)]$

The optimal choice of m is illustrated in Figure 1. The second order condition, which ensures that (7) is a maximum point, is given by the assumption that $r(.)$ is concave in m and l: $r_{mm} < 0$, $r_{ll} < 0$, $r_{mm} r_{ll} - r_{ml} r_{lm} > 0$. In particular, the assumption of $r_{mm} < 0$ could be justified on the ground that there is a strictly concave relationship between yield and biomass whereas clearing costs are proportional to the biomass. The shape of $r(\,)$ is discussed in more detail in section 8.4.

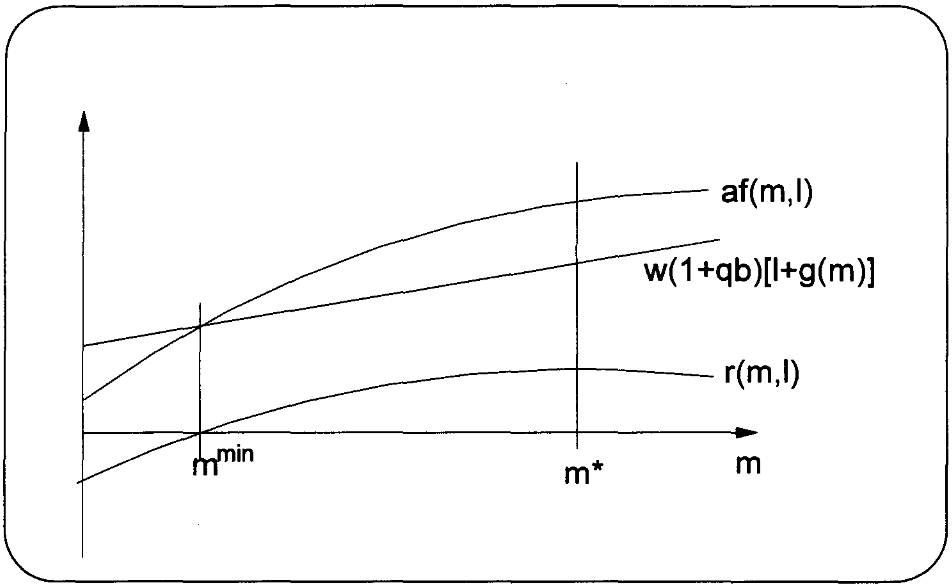

Figure 1. The fallow period (m) which maximizes (undiscounted) profit.[13]

3.5 Minimum fallow

We define m^{min} as the minimum fallow period which gives a non-negative profit, as illustrated in Figure 1.

(10) $r(m^{\min}, l^{**}) = 0 \Leftrightarrow f(m^{\min}, l^{**}) - z[l^{**} + g(m^{\min})] = 0$

(11) $\frac{\partial m^{\min}}{\partial z} = \frac{l^{**}+g(m^{\min})}{f_m(m^{\min})-zg_m(m^{\min})} > 0$

It follows from the definition of m^{min} that labour inputs must be chosen optimally according to $f_l(m^{min}, l^{**}) = z$. We assume $m^{min} > 0$, i.e., that we have a fallow system. If $r(0,l) > 0$ and $r()$ is concave, we would have permanent cultivation.

Note that the denominator in (11) is positive. Even though this resembles the first order condition in (7), here the expression is evaluated at $m = m^{min}$. (11) shows that the minimum fallow is an increasing function of z, that is, increasing in distance (b), real wage (w), and travel efficiency (q), and decreasing in the technology level (a). In particular, the minimum fallow will be higher for more distant fields, as we shall return to in section 7.

3.6 Agricultural frontier

Finally, we define the agricultural frontier (margin of cultivation) as the maximum distance (b^{max}) at which the land rent would still be non-negative, cf. Figure 2 below. Obviously, at the agricultural frontier the fallow period and labour inputs are chosen optimally according to (7)

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[13] l would in general vary with m; higher m implies lower l because $f_{ml} < 0$. In drawing the figure we have neglected this feature, which is of less importance to illustrate the basic relationship.

and (8). Note that the minimum fallow equals the optimal fallow for plots located at the margin of cultivation, i.e., $m^* = m^{min}$ at b^{max}.

(12) $r[m^*, l^*; a, w(1+qb^{\max})] = 0 \Leftrightarrow f(m^*, l^*) - \frac{w}{a}(1+qb^{\max})[l^* + g(m^*)] = 0$

Rearranging this yields;

(13) $b^{\max} = \frac{f(m^*, l^*)}{\frac{w}{a}q[l+g(m^*)]} - \frac{1}{q}$

The effect of parameter changes is given as;

(14) $\frac{\partial b^{\max}}{\partial \frac{w}{a}} = -\frac{1+qb^{\max}}{q\frac{w}{a}} < 0; \quad \frac{\partial b^{\max}}{\partial q} = -\frac{b^{\max}}{q} < 0$

The maximum distance at which shifting cultivation will take place is negatively related to the real wage (w), positively to the technical level (a), and negatively to the travel efficiency factor (q). Note that there is no effect on b^{max} from the effect a marginal change in z has on m and l (the envelope theorem).

Figure 2 illustrates the determination of the agricultural frontier. The variables m and l are in general functions of b, and the *af(m,l)* - curve will in general not be horizontal. We have neglected this when drawing the figure as the sign of the relationship between m and b may be different in the single and multi-rotation problem, as seen below.

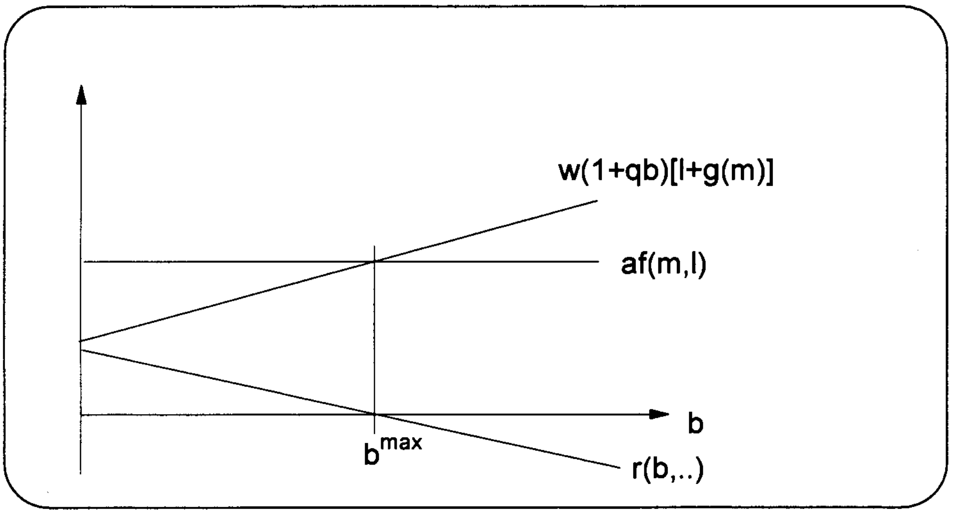

Figure 2. The determination of the agricultural frontier (b^{max}).

4 Social planner's solution I: the single rotation problem (Fisher)

4.1 The model

We first consider the simplest version of the social planner's solution, where the objective is to maximize the discounted net benefits from one rotation. Historically, this formulation goes back to Irving Fisher (1907) who used a single-rotation (SR) forestry management problem in his discussion of capital theory (see, for example, Hartwick (1993) for a discussion), and is still being applied in resource analysis.[14] Even though this is based on some unrealistic assumptions, it is illustrative as a first case, and serves to contrast the basic characteristics of the multi-rotation problem. It is customary to present both cases in the literature, see, for example, Hartman (1976), Heaps and Neher (1979), Hartwick (1993), and Reed and Clark (1990).

We assume starting from bare land, that is, when all forest is of age *0*.[15] As the time horizon is one rotation, we neglect the value of land after the clearing and cultivation is over. Because of our assumption about a village surrounded by homogenous land, which differs only in distance from the village, the area of cultivation will be a circle around the village. This assumption simplifies the analysis. The analysis is also valid in cases where the land available is a *fraction* of a circle.

Total discounted rent (*TDR*) from all plots is to be maximized with respect to labour inputs, fallow period, and by determining the agricultural frontier (b^{max});

$$(15) \quad \underset{m,l,b^{\max}}{Max}\ TDR = \int_0^{b^{\max}} e^{-m\delta} r[m, l; a, w(1+qb)] 2\pi b\, db$$

$$= \int_0^{b^{\max}} e^{-m\delta} \{af(m,l) - w(1+qb)[l + g(m)]\} 2\pi b\, db$$

$r()$ is the current value rent from one clearing and cultivation of forest land at a given distance. This rent is discounted, and integrated over total area, where $2\pi b$ is the circumference of a circle with radius b. The FOC are;

$$(16) \quad \frac{\partial TDR}{\partial m} = 0 \Leftrightarrow r_m - \delta r = 0 \quad for \quad b \in [0, b^{\max}]$$

$$(17) \quad \frac{\partial TDR}{\partial l} = 0 \Leftrightarrow r_l = 0 \quad for \quad b \in [0, b^{\max}]$$

$$(18) \quad \frac{\partial TDR}{\partial b^{\max}} = 0 \Leftrightarrow r = 0 \quad for \quad b = b^{\max}$$

(16) states that the optimal level of m is given by balancing the *capital costs* (δr) and the increase in rent as the forest grows older (r_m). Alternatively, it can be expressed as a requirement for the relative growth rate in the value of the resource to equal the discount rate: $\frac{r_m}{r} = \delta$, which is a well known formula in resource economics (and capital theory). Compared to the condition for maximum current value rent in (7), $r_m = 0$, the introduction of discounting implies a shorter fallow period. Discounting introduces impatience, and forest is cut and land cultivated earlier.

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[14] The solution to this problem is also called the Wicksell-Fisher method (Manz, 1986: 284).

[15] This is not an unreasonable assumption when we have private (or communal) property rights. An alternative would be to start with old-growth forest, which, in fact would be analytically simpler as m becomes exogenous. This case is discussed in section 8.

Note that because the fallow period and the labour input are functions of z, which again is a function of b, the optimal values of m and l will vary with distance, as shown under the comparative statics below.

(17) is the same as in a SR-model without discounting, as given in (8). Labour is added as long as the marginal productivity is greater than the effective real wage. Finally, cultivation is expanded from the village in such a way that the rent at the agricultural frontier is zero, cf. (18), which is the same condition as in (12).

The system (16) - (18) is partly recursive: (16) and (17) give the optimal values of m and l for given b, which, inserted in (18), give the optimal choice of b^{max}. Thus, the problem can be solved in two steps: first, maximizing the benefit from each plot (land at different distances), and then determining the total area (agricultural frontier). The reason for this recursive property is that there is no overall production target to be met (as in subsistence models, see Angelsen, 1996a), or any other connections between the different plots, for example, environmental effects. We utilize this property in the comparative statics below.

4.2 Comparative statics

Differentiation of (16) and (17), simplifying the notation by setting $a = 1$, and using that $z = w(1+qb)$ and $r_l = 0$, yields;

$$(19) \quad \begin{bmatrix} r_{mm} - \delta r_m & r_{ml} \\ r_{lm} & r_{ll} \end{bmatrix} \begin{bmatrix} dm \\ dl \end{bmatrix} = \begin{bmatrix} r & g_m - \delta(l+g) \\ 0 & 1 \end{bmatrix} \begin{bmatrix} d\delta \\ dz \end{bmatrix}$$

Given that $r(m,l)$ is concave, the second order conditions are satisfied, i.e., $r_{ll} < 0$ and;

$$(20) \quad D = \begin{vmatrix} r_{mm} - \delta r_m & r_{ml} \\ r_{lm} & r_{ll} \end{vmatrix} > 0$$

The effects on m and l of changes δ and z are presented below;

$$(21) \quad \frac{dm}{dz} = \frac{1}{D}[g_m r_{ll} - \delta(l+g) r_{ll} - r_{ml}] \gtrless 0$$

$$\Leftrightarrow \delta \gtrless \frac{g_m r_{ll} - r_{ml}}{r_{ll}(l+g)} \equiv \delta^c > 0$$

The sign of the effect on the fallow period of a change in the effective real wage is ambiguous, and depends on the level of the discount rate. For discount rates lower than a critical level, δ^c, higher z leads to shorter fallow period. The intuition behind the result is better understood by first considering the case when the discount rate is zero. As $\delta^c > 0$, higher z will in this case reduce m. The fallow length (m) in the single rotation model without discounting is handled in the same way as a standard factor of production in the theory of the firm. The marginal net benefits are declining with the fallow length ($r_{mm} < 0$), and an increase in the costs of clearing (real wage) will make a rational planner shorten the fallow period (use less of the input).

Discounting introduces *capital costs*, which makes delaying clearance and production costly; the higher the discount rate, the higher is the capital costs. Higher z means that rent is reduced, therefore the capital cost is also reduced. This effect pulls in the direction of longer fallow periods, and the magnitude of this effect is positively related to the level of the discount rate. If the discount rate is sufficiently high, this effect will dominate and higher z will induce higher m.

It would be of interest to characterize the critical value of the discount rate, as found in (21) above. Using that $\frac{g_m}{g} < \frac{1}{m}$, and assuming that the labour for clearing input is less than on-the-field labour input ($g < l$), and that the cross derivative is equal to zero ($r_{ml} = 0$), we get;

$$(22) \qquad \delta^c = \frac{g_m}{l+g} < \frac{1}{2m}$$

This implies that if, as an example, $m = 10$, then the critical value of the discount rate would be *below* 5 percent, i.e., a 5 percent discount rate would change the result of the analysis compared to the case without discounting. Similarly, with a fallow period of 5 years the critical discount rate would be below 10 percent. How much below would depend on the size of l (relative to g), and the particular form of the $g()$-function. One conclusion is, however, that the sign in (21) can be either positive or negative under realistic assumptions about the variables and functional form. Moreover, the critical discount rate is lower in more extensive systems (high m), i.e., a positive sign of (21) is more likely the higher m is. We also get that the smaller the clearing costs (g) are relative to other labour costs (l), the lower is the critical discount rate.

To sum up, we have identified three factors which make it more likely that higher z results in shorter fallow periods: a low discount rate, a short fallow period, and relatively high clearing costs compared to other labour costs (l).[16] This case has some counterintuitive implications: fallow period will *decrease* with distance from the village, i.e., the land use is more intensive on the distant fields. Further, an increase in the real wage will *reduce* the fallow period, whereas technological progress and improved transportation efficiency or accessibility will have the opposite effect. The single rotation model does *not* capture important aspects related to the opportunity costs of land, as will be seen in the multi-rotation model in the next section. This, of course, questions the applicability of the model. Indeed, Paul Samuelson labels the single rotation model "Fisher's false solution" (Samuelson, 1976: 470).

$$(23) \qquad \frac{dl}{dz} = \frac{r_{mm} - \delta r_m - r_{lm} g_m + r_{lm}\delta(l+g)}{D} < 0$$

[16] Note, however, that a short fallow period implies low clearing costs ($g_m > 0$), and also higher input of other types of on-the-field labour since $f_{ml} < 0$, *ceteris paribus*.

There are two effects on l of higher z. First, a direct effect of higher labour cost, which is always negative. Second, an indirect effect via changes in the fallow period, which may be either positive or negative, cf. discussion above. In (23) we make the plausible assumption that the direct effect dominates a *possible* opposite indirect effect via changes in m.

(24) $\frac{dm}{d\delta} = \frac{r_{ll}r}{D} < 0$

The result of (24) corresponds with intuition: a higher discount rate yields shorter fallow periods because the costs of delaying the clearing (capital costs) become higher.

(25) $\frac{dl}{d\delta} = \frac{-r_{lm}r}{D} > 0$

This result is linked with the previous one: shorter fallow means higher labour inputs because the marginal productivity of labour is assumed to increase ($r_{lm} < 0$).

What happens to the agricultural frontier when z increases? The frontier is defined in the same way in this model as in (12), i.e., the land rent at the frontier is zero, thus we can apply the result in (14) directly: a decrease in w or q, or a rise in a will increase b^{max}. The margin of cultivation is determined by the relative profitability of shifting cultivation, and any change in exogenous factors which increase the profitability will expand the area under shifting cultivation. As we have $r = 0$ at the frontier, it also follows that a change in the discount rate has no effect on the agricultural frontier and the extent of deforestation.

To conclude on the SR-case, a lower effective real wage rate (z) leads to agricultural land expansion, whereas the effect on the fallow period in general is ambiguous. A lower discount rate leads to longer fallow periods, but has no effect on the size of total agricultural land.

5 Social planner's solution II: the multi-rotation problem (Faustman)

5.1 The model

In the single rotation model the time horizon is one rotation; land is assumed to have no value after the (first) rotation is completed. It does not take into account the opportunity cost of land: when forest is cleared and the cropping period is over, a new cycle can start. Thus, there is an additional cost of delaying forest clearing and cultivation. The solution to the multi-rotation problem when it comes to timber production goes back to Faustman (1849), a remarkably early statement of what remains the basic formula for most analysis in forestry economics and capital theory one and a half century later.[17] The presentation here draws on Clark (1990), Hartman (1976) and others.

[17] The solution to the multi-rotation problem has different names in the literature; the Faustman-Ohlin theorem (Löfgren, 1983) and the Faustman-Hirshleifer-Samuelson optimization (Manz, 1986) being

We make three basic assumptions:

1. The problem is to maximize the net present value (*NPV*) of land rent from the total agricultural area, which is endogenously determined.
2. All parameters (prices, discount rate, technology, and functional forms) are known and remain constant over time. This is clearly the most critical assumption, and will be discussed later.
3. The time horizon is infinite, which -- together with the second assumption -- simplifies the analytics significantly as we may use the formula for an infinite geometric series to transform the problem into one where we can use static optimization.

From these assumptions it follows immediately that all fallow periods will be of the same length (for a given distance from the village). We shall mainly deal with long term equilibria, and do not discuss the path between different equilibria

The model will still be recursive, as under the single rotation problem; first optimal fallow and labour inputs are determined, then the agricultural frontier. The maximum *NPV* or discounted land rent (equal to the land price in a competitive economy) for a plot at a given distance ($b \leq b^{\max}$) can now be written as;[18]

$$(26) \quad \underset{m,l}{Max}\ NPV = \Sigma_{j=1}^{\infty} e^{-jm\delta} r(m,l) = \frac{1}{e^{m\delta}-1} r(m,l)$$

δ is the discount rate. The FOC are given by;

$$(27) \quad \frac{\partial NPV}{\partial m} = \frac{-e^{m\delta}\delta}{(e^{m\delta}-1)^2} r(m,l) + \frac{1}{e^{m\delta}-1} r_m = 0$$

$$\Leftrightarrow (1-e^{-m\delta}) r_m - \delta r = 0 \Leftrightarrow \frac{r_m}{r} = \frac{\delta}{1-e^{-m\delta}}$$

$$\Leftrightarrow r_m = \delta r + \frac{\delta r}{e^{m\delta}-1}$$

$$(28) \quad \frac{\partial NPV}{\partial l} = \frac{1}{e^{m\delta}-1} r_l = 0 \Leftrightarrow r_l = 0$$

(28) is identical to conditions (8) in the basic model and (17) in the single rotation problem. The new condition is the Faustman formula in (27). The last line in (27) is the one which gives the clearest economic interpretation of the Faustman result. The LHS gives the benefits in terms of increased net yield from one clearing by postponing forest clearing and cultivation for one year. At the optimum, this should equal the costs of one year delay: the first term on the RHS is a *capital cost*, i.e., the cost that is incurred by delaying the profit by one year. This equals the rent from one clearing times the discount rate. The second term is the new one in the MR problem, and gives the opportunity cost of land, or *site value*. $\frac{1}{e^{m\delta}-1} r$ is the present value of future net

two of them.

[18] This is only valid for positive discount rates, the case of a zero discount rate is discussed as a special case below.

benefits, which, when multiplied by the discount rate, gives the cost in delaying clearing by one year.

The agricultural frontier is determined in the same way as in the single rotation model, i.e., the rent at the margin should be zero. Formally, we have (where m^{MR} and l^{MR} indicate optimal values under the multi-rotation problem);

(29) $$\frac{\partial NPV}{\partial b^{\max}} = \frac{1}{e^{m^{MR}\delta}-1} r(m^{MR}, l^{MR}) = 0$$

$$\Leftrightarrow r = 0 \quad at \quad b = b^{\max}$$

The comparison of the two cases with respect to the agricultural frontier is straightforward. Remembering that the frontier is defined where the land rent is zero, the RHS in the last equation in (27) equals zero, thus it equals (16). At the frontier, the fallow period will be the same in both models (but shorter in the multi-rotation than in the single rotation model for land inside the frontier). With *m* and *l* the same and *r = 0* in both models, the frontier will be the same in the two models.

5.2 Comparative statics

We now want to explore how changes in the two exogenous variables, *z* and *δ*, affect the three endogenous variables, *m, l* and b^{max}. For example, which factors lead to an intensification of the system (higher *l* and lower *m*)? The recursive property simplifies the comparative statics, and we first explore the effect on *m* and *l*. As in the SR case *a = 1*. Differentiation of (27) - (28) yields;

(30) $$\begin{bmatrix} (1-e^{-\delta m})(r_{mm}-\delta r_m) & [(1-e^{-\delta m})r_{ml}-\delta r_l] \\ r_{lm} & r_{ll} \end{bmatrix} \begin{bmatrix} dm \\ dl \end{bmatrix}$$

$$= \begin{bmatrix} [r-me^{-\delta m}r_m] & [(1-e^{-\delta m})g_m-\delta(l+g)] \\ 0 & 1 \end{bmatrix} \begin{bmatrix} d\delta \\ dz \end{bmatrix}$$

(31) $$D = \begin{vmatrix} (1-e^{-\delta m})(r_{mm}-\delta r_m) & [(1-e^{-\delta m})r_{ml}-\delta r_l] \\ r_{lm} & r_{ll} \end{vmatrix} > 0$$

$$\Leftrightarrow r_{mm}r_{ll} - \delta r_m r_{ll} - r_{lm}r_{ml} + \frac{\delta}{1-e^{-\delta m}} r_l r_{lm} > 0$$

Here we have used that $0 < e^{-\delta m} < 1$. Further, given the assumption of *r(m,l)* being concave, i.e., $r_{mm}r_{ll} - r_{lm}r_{ml} > 0$, and that $r_l = 0$ in optimum, we can conclude that *D > 0*, corresponding to the second order condition for maximum.

(32) $$\frac{dm}{dz} = \frac{1}{D}\{r_{ll}[(1-e^{-\delta m})g_m - \delta(l+g)] - [(1-e^{-\delta m})r_{ml} - \delta r_l]\} > 0$$

The sign of the expression $[(1-e^{-\delta m})g_m - \delta(l+g)]$ is not readily seen. In Appendix 1 we show that it is always negative. In contrast to the SR case, we can therefore unambiguously conclude that higher effective real wage rate will increase the fallow period. Agriculture has become less profitable and the production will therefore be less intensive in terms of longer fallow periods.

Our specification of the model confirms some common results in forestry economics: a price increase leads to shorter rotation period, whereas an increase in the wage level has the opposite effect (Hyde and Newman, 1991:85). Longer rotation period when the (net) price increases is known as the *"Ricardo effect"* in capital theory (Ledyard and Moses, 1976: 151). As a corollary, (32) also implies that the fallow period will increase with distance from the village, a result corresponding to empirical observations in many tropical regions (e.g., Hiraoka, 1986; Angelsen, 1994) and other theoretical models (e.g., Heaps, 1981, proposition 5).

One of the very few applications of the Faustman model to tropical agriculture is Barrett (1991). Our result contrasts his proposition 3: "An unanticipated permanent increase in the output price will have no effect on the optimal fallow-cultivation cycle, and hence no effect on soil fertility and output". This result rests, however, on the omission of labour (or other inputs) costs in the model, which seems hard to justify. The paper fails to recognize that even in the case when "the shifting cultivator uses only traditional techniques" (page 184), an output price increase will change the relative price between labour and output and therefore the fallow period.[19] Contrary to Barrett we find that higher output prices will reduce the fallow period (increase soil erosion).[20]

(33) $\frac{dl}{dz} = \frac{1}{D}\{(1 - e^{-\delta m})(r_{mm} - \delta r_m) - r_{lm}[(1 - e^{-\delta m})g_m - \delta(l + g)]\} < 0$

Again using the result in Appendix 1, this effect on l of higher z is unambiguously negative. An increase in the effective real wage implies less labour efforts for two reasons. The first one is the standard effect of a higher real wage. Second, the marginal productivity of labour declines due to longer fallow periods, even though this effect is based on rather weak empirical foundations, as discussed above. This also implies that labour per ha declines with distance from the village, a result which is in line with Ledyard and Moses (1976) and others.

(34) $\frac{dm}{d\delta} = \frac{1}{D}[r_{ll}(r - me^{-\delta m} r_m)] < 0$

The expression in ( ) is positive, as shown in Appendix 2. A higher discount (interest) rate results in a shorter fallow period. The shortening of the fallow period follows intuitively from the logic behind the Faustman formula: a higher discount rate means that both the capital cost

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19 In fact, when costs are ignored, we are left with only one price in the model; there are no relative prices. A change in the price level then has no effect on the real variables; a well-known result in the forest economics literature is therefore that the rotation period is independent of the output price when no costs are included.

20 As noted earlier, the discussion of soil erosion becomes somewhat *ad hoc* in the Faustman model as all relevant parameters and functions, including the production function, are assumed to be constant over time.

and the opportunity cost of land (site value) increase, hence the fallow period will decline and forest land will be used more intensively for cultivation.

(35) $\frac{dl}{d\delta} = \frac{1}{D}[-r_{lm}(r - me^{-\delta m}r_m)] > 0$

Higher discount rate implies shorter fallow period, which means higher marginal productivity of labour, and therefore higher labour input.

We have earlier argued that the agricultural frontier will be the same in both the single- and multi-rotation models, thus the effects of a change in z on b^{max} would be the same in the two cases as given in (14). Moreover, a change in the discount rate does not affect the agricultural frontier in this model, as seen from (29) and (12). Land rent is zero at the margin, hence there is no rent to be discounted.

A major result deriving from this model is that policies which reduce z will lead to an intensification of the system. However, they will also result in more deforestation, and there is a conflict between intensification and forest conservation objectives. Policies such as higher agricultural prices, promoting technological progress, and improved accessibility will be appropriate in relation to intensification but not forest conservation objectives.

Credit policies which lower the relevant interest rate will lead to less intensive land use. This contradicts conventional wisdom which suggests that providing cheap credit to farmers will promote intensification. The argument is based on that farmers are credit constrained and cannot (afford to) buy non-labour inputs. These aspects are not included in the present model, which assumes perfectly competitive markets. Our results suggest, however, that there may be mechanisms in relation to, for example, credit programmes which leads to *less* intensive land uses.

5.3 Comparing the single- and multi-rotation solutions

The effect on the fallow period of an increase in the real wage or distance could be the opposite of that in the single rotation model. The difference between the two models is illustrated in Figure 3 below. For simplicity we ignore the effects of changes in l due to changes in z for the time being, and concentrate on how m is determined.

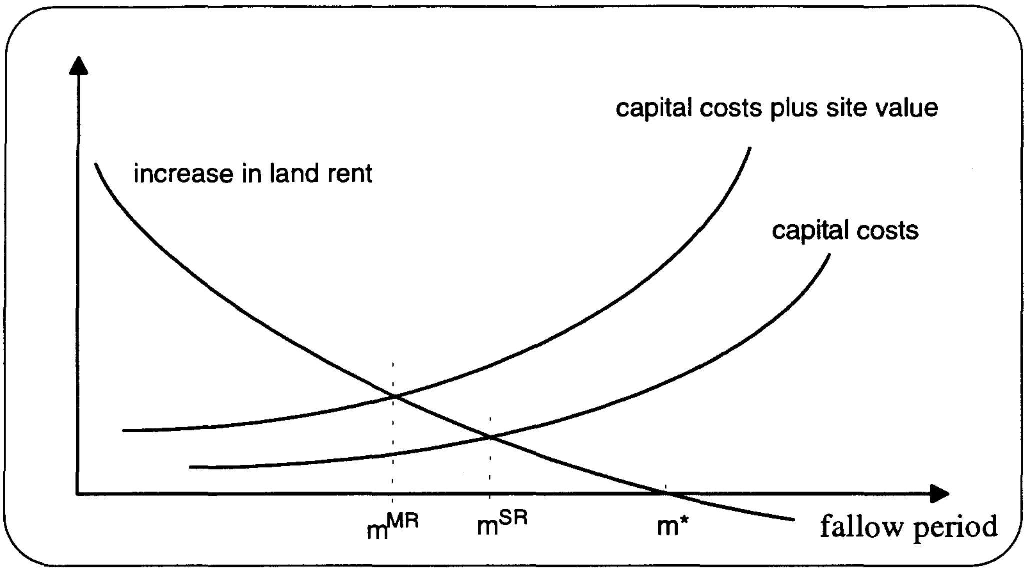

Figure 3. Comparison of the fallow period in the single rotation (SR) and the multi-rotation (MR) models.

In a single rotation model without discounting, that is, when the current value land rent is maximized, the FOC is $r_m = 0$, cf. (7). Graphically, this will be where the downward sloping curve intersects with the x-axis. The single rotation problem with discounting adds the *capital costs*, $r_m = \delta r$, cf. (16). The multi-rotation (MR) model includes yet another cost of delaying forest clearing, that is, the *site value*, cf. (27). We see that the optimal fallow period is shorter in the MR problem than in the SR model with discounting, which again is shorter than in the SR model without discounting.

What happens when z increases? All three curves shift downward. In the SR problem model without discounting, the fallow period will be shorter. In the SR model with discounting, the effect was found to be ambiguous. For high discount rates the shift in the capital cost curve will be sufficiently large to outweigh the shift in the r_m-curve, and the fallow period will increase. In the MR model, the shift in the curve representing the costs of delayed clearing will always dominate, i.e., the optimal fallow period increases.

5.4 Zero discount rate: MSR and MSY

A special case is obtained when the discount rate approaches zero. Besides its theoretical relevance, some argue that traditional agricultural societies are characterized by a strong concern for the future, which could be expressed as a low (or even zero) discount rate.

Consider the FOC in (27). The first term of the RHS is zero (no capital costs). For the second term, by applying l'Hôpitals rule, we get;

$$\lim_{\delta\to 0} \frac{\delta}{e^{m\delta}-1} = \lim_{\delta\to 0} \frac{1}{me^{m\delta}} = \frac{1}{m}$$

(27) then becomes;

(36) $r_m = \frac{r}{m}$

This is the condition of maximum annual profit or maximum sustainable rent - MSR, occurring when the marginal profit of increased fallow equals the annual land rent. Since the fallow period is increasing when the discount rate is lowered, cf. (34), the MSR solution gives a longer fallow period than the Faustman model with discounting.[21]

(36) clearly exposes the trade-off involved in the choice of fallow period in shifting cultivation. One the one hand, longer fallow period implies higher rent from the land when it is cropped. On the other, longer fallow implies that the land is cropped less frequently, which reduces the average annual rent. Equation (36) states the optimal balance between these two considerations.

Note that the MSR is different from the maximum sustainable yield (MSY) concept, because MSR includes costs. The optimality condition for MSY is $f_m = \frac{f()}{m}$.[22] The MSY principle, often advocated by foresters and environmentalists, is a special case when the discount rate is zero, *and* costs are ignored. Whereas the choice of discount rate is clearly debatable, ignoring costs could hardly be defended. If something is to be sustained over time, it should be rent, not output.

Interestingly, applying the MSR rather than the MSY approach leads to longer fallow periods. This can be seen by comparing the two optimality conditions. (36) can be rewritten as $f_m = \frac{f()}{m} - z\left(\frac{l+g}{m} - g_m\right)$. The expression in ( ) is positive, and given that the production function is concave, it follows that the MSR fallow period is longer than the MSY fallow period (see also Bowes and Krutilla, 1989: 103).

The expressions for the comparative statics in (30) are slightly different in the MSR case, but the results in (32) - (33) are still valid: higher z leads to longer fallow periods and less labour input.

5.5 Environmental benefits

The main concern about tropical deforestation, of which a significant proportion is caused by shifting cultivators, is related to the environmental benefits produced by standing forests. These range from local ecological functions in terms of flood control and soil protection to global benefits like maintenance of biodiversity and storage of carbon in the biomass. To what extent

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[21] The derivation of the condition for *MSR* can be done in an alternative and simpler way. The optimizing problem can be written as to maximize the average annual rent (AAR), given by: $AAR = r(m,l)/m$. The FOC are $r_m = r/m$ and $r_l = 0$, which are the same as found in the MR model when δ approaches zero.

[22] For this to be possible for $m > 0$ we must assume that $f()$ has a convex segment for low values of m.

such benefits are included in the decision problem depends on who the decision maker is: a farmer, a local community, or a fictional national or global social planner.

Environmental benefits (E) from standing forests can be included into the Faustman model, as first shown by Hartman (1976). E is assumed to be a non-decreasing and concave function of forest age: $E = E(m); E_m \geq 0; E_{mm} \leq 0$. The objective function for a plot with given distance then becomes;

$$(37) \quad \underset{m,l}{Max} \quad NPV = \frac{1}{e^{m\delta}-1}\left[r(m,l) + e^{m\delta}\int_0^m e^{-y\delta}E(y)dy\right]$$

The environmental benefits are discounted over the rotation period, and then multiplied by $e^{m\delta}$ to transform them to the same point in time as r, that is, the when the forest is cut and cultivation takes place. Necessary conditions for an interior solution are given in (28) and (38);

$$(38) \quad r_m + E(m) = \frac{\delta}{1-e^{-m\delta}}\left[r + \int_0^m e^{-y\delta}E(y)dy\right]$$

Compared to the standard Faustman equation in (27), the first terms on both sides are the same as before. The LHS gives the benefits of delaying clearing by one year, where the second term reflects the environmental benefits produced by a forest of age m. The RHS represents the costs related to delaying the cutting by one year, in terms of delayed future benefits. In addition to the production benefits (r), there are environmental benefits over the rotation cycle that should also be taken into account; this is reflected in the last term on the RHS.

Since we are adding a positive term on both sides of the Faustman equation, the impact on the rotation length of adding environmental benefits is not readily seen. In the single rotation problem, the RHS of (38) reduces to δr. In this case, the effect on the rotation period is clear: the optimal rotation is longer. Indeed, the optimal solution may be never to cut the forest, as elaborated by Strang (1983).

In the multi-rotation case, Bowes and Krutilla (1985: 539) show that when environmental benefits are rising with forest age (as we have assumed) the rotation will also be longer. However, if the *marginal* benefit of increasing stand age is zero in the relevant area, the Faustman solution will still be the correct one, even if the *total* environmental benefits are high. Bowes and Krutilla (1985) also show that if the environmental benefits are large compared to the production benefits, a higher discount rate may lead to *longer* rotations.

Given that the fallow period will increase when environmental benefits are taken into account, it will move closer to the fallow period which maximized average annual rent (AAR). Including environmental benefits will therefore increase annual agricultural income. There is no conflict between boosting agricultural income and environmental conservation, even without any direct link between environmental services and agricultural productivity, for example, in the way that reduced soil erosion increases productivity. The reason behind this result is that discounting makes one impatient, and the farmer cultivates the land too early compared to the solution that maximizes agricultural production over time. Including environmental benefits gives a reason to delay forest clearing and cultivation, and will therefore also boost AAR and agricultural production.[23]

Including environmental benefits of standing forest will also imply a contraction of the agricultural frontier. Consider the old frontier (before including environmental benefits), where $r = 0$, and $m = m^{MR} = m^*$, i.e., the fallow period is such that r has reached its maximum value. An increase in the fallow period, as would be the result of including E, will therefore *reduce r*. Furthermore, given that environmental benefits are non-decreasing with forest age, forest clearing implies a reduction in the stream of environmental services. These two arguments yield that b^{max} will be reduced. The result can more intuitively also be seen from Figure 2, where adding environmental costs of forest clearing reduces the optimal b^{max}.

5.6 Risk of losing the land

Shifting cultivators face several types of risk: yield, prices, biomass growth, and the risk of losing land to external claimants, etc. The risk of losing land through, for example, fire has been studied in the forest economics literature (e.g., Reed, 1984), and may be given an interesting application to shifting cultivation decision-making. Assume an average risk λ per unit time for losing the land before the forest is cultivated, which corresponds to a homogenous Poisson process at rate λ. The probability that the land has *not* been lost at time t is then given by $e^{-\lambda t}$. An empirically relevant modification would be that the probability of losing the land is dependent on the age of the forest, in the way that the claims are weaker the older the forest (the longer the time since last cultivation), i.e., $\lambda = \lambda(m)$, $\lambda_m > 0$ (nonhomogenous Poisson process).

The maximization problem, assuming a risk neutral agent, is then;

$$(39) \quad \underset{m,l}{Max}\ NPV = \frac{1}{\exp\left\{m\delta + \int_0^m \lambda(t)dt\right\} - 1} r(m,l)$$

The FOC are then given by (28) and (40);

$$(40) \quad r_m = \frac{r}{1 - \exp\{-\delta - \lambda(m)\}}[\delta + \lambda(m)] \Leftrightarrow r_m = [\delta + \lambda(m)]r + \frac{[\delta + \lambda(m)]r}{\exp\{\delta + \lambda(m)\} - 1}$$

[23] Obviously, if the environmental benefits are large the optimal fallow period can be extended beyond the period which maximizes average annual rent (AAR). In that case the unadjusted rent and agricultural output before and after inclusion of environmental benefits must be compared with the AAR solution.

Risk is included in the analysis by replacing the old discount rate with a risk adjusted discount rate: $(\delta + \lambda)$. The effect of including risk is therefore exactly the same as increasing the discount rate with a rate equal the probability of losing the land. This is an example of *risk discounting* (Clark, 1990: 351).[24] Making risk age dependent (nonhomogenous Poisson process) does not change the optimality condition, except that λ becomes a function of m.

The effect of introducing risk is therefore to shorten the fallow period, cf. (34), which corresponds to sound economic intuition: if there is a risk of losing the forest, one should cut it earlier to get the benefits, as waiting for one more year entails the risk of losing the land. In optimum the growth in stumpage value (taking into account the probability of losing the land) should equal the *expected* capital cost and site value.

The above formulation of risk assumes a specific structure of risk: forest land is lost for one cropping period, but not forever. The conventional forestry economics literature has focused on the risk of fire, which is not particularly relevant in a shifting cultivation system; in fact, forest is normally cleared by exactly fire! The above formulation would be a reasonable approximation for some other types of risk: forest land for shifting cultivation is often held by the household or lineage which cleared the forest initially. In the study area of Seberida, Sumatra, the household could not normally prevent other neighbouring households to cut the forest and cultivate the land for one season, provided they did not plan to do it themselves that year.[25]

For other types of risk where land is lost permanently, the inclusion of risk must be formulated in a different way. If land is appropriated by state or private, commercial projects, the forest land is likely to be lost permanently. Without resorting to formal analysis, the possibility for land to be lost forever provides an even stronger argument for more intensive cultivation (shorter fallow period).

In conclusion, insecure property rights or other types of risk lead to an intensification of the shifting cultivation system in terms of shorter fallow periods. This may contrast the general economic intuition, where risk would induce less input and investments in an activity, and more extensive resource use. Angelsen (1996b) arrives at a similar result, but from a very different modelling perspective.

As the model is formulated, the introduction of risk has no effect on the agricultural frontier. This follows from the previous result of the discount rate having no influence on the agricultural frontier, and that risk has the same effect as increasing the discount rate. Other types of risk than

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[24] See also Conrad and Clark (1987, chap. 5.3).

[25] Some restriction applied for the "renting" household, for example, no perennials were allowed to be planted as that would imply more permanent rights to the land (see Angelsen, 1996b for an elaboration of the tenure system).

the one included here could, however, be expected to influence the extent of deforestation. Given risk averse farmers which has an alternative and secure use of labour (w), price and yield risk would reduce b^{max}.

5.7 Changing technology or prices over time

The above discussion has assumed that technology (production function), prices, the discount rate and all other parameters are expected to remain constant over time, which all are quite heroic assumptions. Changing this assumption adds realism to the model, but complicates the analytics considerably.

One of the criticisms of the Faustman approach is that it may yield rotation periods that are shorter than the maximum sustainable yield (MSY) or maximum sustainable rent (MSR) rotation. Thus, the Faustman solution is less likely than the MSY or MSR solution to maintain the productivity of forest land. Walter (1980) applies a production function where the number of previous rotations, not only rotation length, is included in the production function. This would, in general, result in a solution with variable rotation length and a terminal date of exploitation of forest land. The optimality condition, however, resembles the Faustman equation.

Newman *et al.* (1985) discusses the case where the relative timber prices are increasing over time. If the rate of price change is less than the discount rate (which is a reasonable assumption), the optimality condition for the steady state is the Faustman equation, with the discount rate replaced by the interest rate *minus* the rate of price change (*real* interest rate). This is, however, based on some simplifying assumptions, in particular, no costs are included. If costs are included, as done in this paper, the direction of the result remain the same, but *net* prices must be used, and the analytics are more complex.

Questioning the usefulness of steady state results, the main message in Newman *et al.* (1985) is to distinguish between the effects of *rising* relative price and the change in the price *level.* The second (level) effect implies a shorter rotation, as shown in (32). However, the effect of the first one points in the opposite direction, as seen from (34), remembering that a change in the rate of price change has an effect similar to a change in the discount rate with the opposite sign.

> *"Increases in the rate of price change initially increases the optimal rotation. ... These two impacts eventually offset each other as the rotation lengths tend to a steady state. We would argue that the policy usefulness of the increase in the rate of price change is greater. That is, given discounting and the long production period in forestry, the positive impact on the initial rotation length is much more important than the steady-state rotation length or the elapsed time until the steady state" (Newman et al., 1985: 352).*

This illustrates how a more realistic description may change the results of the model. Note, however, that for shifting cultivation, where the rotation period is much shorter than in most natural forest timber production, their conclusion about the relative importance of the two impacts may not hold. The level effect, as we have focused on, may be dominating.

6 Communal or private property

In theory, the multi-rotation social planner's solution(s) discussed above could be obtained under both a private or a communal property regime. Some authors, following Samuelson (1976), use private property rights and a competitive market to derive the Faustman results above. Similarly, a communal management system, equivalent to a local social planner, would yield the outcome discussed above. The latter assumes that the local users can be treated as one decision-making unit, implying that internal co-ordination problems (such as free- or easy-riding) have been solved. If this is not the case, we may move in the direction of an open access solution, which is discussed in the next section.

Even though the formal modelling is the same, there may be some differences in the actual outcome. The first relates to the inclusion of public goods (or bads), like environmental benefits of standing forest. Generally, one could assume that public goods are included only if they occur at the same geographical level as the management takes place. Thus communal management may include local environmental effects, like flood prevention, whereas global effects such as the carbon storage in standing forests will not be included in local management decisions. Private property may not include either of these environmental effects, but may take into account, for example, *on site* soil erosion.

A second reason why the adaptation may be different is due to differences in the discount rate. It is commonly argued that traditional societies have a low discount rate, for example, based on a cyclical perspective of life and a strong concern for future generations of their own society. At the extreme, with no discounting, the solution approaches the MSR-rule. On the other hand, private managers may apply discount rates much higher than the "socially correct" (however defined) discount rate. As shown above in (34), the higher the discount rate, the shorter the rotation period. The agricultural frontier is independent of the discount rate in this model.

In other situations communal management may, for a variety of reasons, not be efficient in regulating individual farmers' resource use. Communal management may then be moving towards an open access solution, which, as shown below, can be studied as if the discount rate becomes higher.

7 Open access

7.1 The model

So far we have studied situations with well-defined and secure property rights. Now we move to the other extreme, that is, a situation where no property rights exist neither before nor after clearing. The farmers only have rights to the land during the period of cultivation. In the next section we modify this and look at a situation where no rights exist before forest clearing, but property claims are established through forest conversion to agriculture (homesteading).

Given that there is competition for land and that land is acquired at no costs (except for labour inputs), the profit (land rent) is driven to zero. All rent is dissipated under open access (Gordon, 1954). As in the previous models, all forest which can yield a non-negative rent, will be cleared. In equilibrium, farmers will be indifferent as to *where* they clear new land for swidden (as long as $b \leq b^{\max}$), and between farming and off-farm work (at wage *w).*

The model will then consist of the following equations;

(10) $r(m^{\min}, l^{**}) = af(m^{\min}, l^{**}) - w(1+qb)[l^{**} + g(m^{\min})] = 0;\ b \in [0, b^{\max}]$

(41) $r_l(m^{\min}, l^{**}) = 0;\ b \in [0, b^{\max}]$

The endogenous variables are *m* and *l*, whereas *z* is the only exogenous variable. (10) defines the minimum fallow which gives a non-negative rent; forest will be cleared as soon as it has reached an age which yields non-negative rent. Note that (10) also gives the agricultural frontier (b^{max}) when $m = m^*$ as given in (7).

Compared to the Faustman solution, open access implies shorter fallow periods (except at the frontier, where it is the same in both models). Thus, the labour inputs will also be higher inside the frontier in the open access model, the latter again being critically dependent on the assumption of $f_{ml} < 0$.

Neher (1990: 63) claims that the single rotation (SR) model "can apply on a 'frontier' where land is 'free' and the harvester intends to cut and then abandon the land and move on". Comparing the optimality condition in the SR problem, $r = r_m/\delta$, with the open access condition, $r = 0$, we see that a general statement about the SR model as a good description of the adaptation with 'free' land (or open access) is incorrect. However, the SR model solution approaches the open access solution as the discount rate goes towards infinity. As regards the multi-rotation (MR) case, (27) can be written as;

$$r = \frac{\frac{r_m}{\delta}}{1-e^{-m\delta}}$$

We find that also in the MR model the rent goes towards zero as the discount rate goes towards infinity. Thus, open access can be viewed as a special case in both social planner's models when the discount rate is infinite, and future values thereby neglected. In the open access case, the reason is that the farmers have no claims to future benefits. In the social planner's case, future benefits are discounted to zero (e.g., Clark, 1990: 43).

7.2 Comparative statics

To see how farmers in an open access situation respond to changes in z, including how fallow and labour inputs vary with distance, we differentiate the FOC to get (when $a=1$);

$$(42) \quad \begin{bmatrix} r_m & 0 \\ r_{lm} & r_{ll} \end{bmatrix} \begin{bmatrix} dm \\ dl \end{bmatrix} = \begin{bmatrix} l+g \\ 1 \end{bmatrix} dz$$

Given that $r_l = 0$ in optimum, we can solve the system recursively; first for m, and then use that result to solve for l. We then get;

$$(43) \quad \frac{dm}{dz} = \frac{l+g}{r_m} > 0$$

The fallow period is increasing in z, for example, higher real wages will increase the length of fallow for a given distance. Further, the more distant fields have a longer fallow period and higher yield per clearing, which is necessary to compensate for the distance costs.

$$(44) \quad \frac{dl}{dz} = \frac{1}{r_{ll}} - \frac{r_{lm}}{r_{ll}}\frac{dm}{dz} = \frac{1}{r_{ll}} - \frac{r_{lm}}{r_{ll}}\frac{(l+g)}{r_m} < 0$$

From (44) we see that an increase in z would lower the labour inputs for two reasons. The direct effect is that labour has become more expensive. As an indirect effect, the increased fallow length will, as we have assumed, lower the marginal productivity of labour.

As regards the agricultural frontier, it will be the same as under the social planner's solutions. The frontier is defined as the maximum distance where the rent is non-negative, and this would be the same in all cases. Consequently, the effect on b^{max} following an increase in z will also be the same as in the previous cases.

7.3 Adjustment is costly and takes time

The discussion above is based on a comparison between different long term equilibria. To see what happens in "real life" after an exogenous shock, consider the case when there is a sudden jump in the technological level (z down), and adjustment to a new equilibrium is costly and takes time (for example, due to limited mobility of labour). Immediately following the exogenous shock, there are opportunities to capture some rent because land is available with a fallow-distance combination that yields a positive profit. This is illustrated in Figure 4. In particular, the opportunities for rent capture are highest close to the village, where the distance costs are lowest. Thus, the short term effect will be a concentration of farming close to the village where the rent is highest, whereas the long term effect is an expansion of the agricultural frontier.

This phenomenon was observed in the shifting cultivation system of Seberida, Sumatra, Indonesia (Angelsen, 1995). After the mid-1980s, z was lowered due to lower transport costs (q), higher agricultural price (rubber), and lower opportunity cost of labour (lower w). Farmers' response in the period up to 1989 was to take land closer to the village, with a shortening of the fallow period. The share of households involved in shifting cultivation increased significantly and rubber planting increased. Since 1989, when land became less available close to the village, the swiddening has moved further away from the village, clearing older forest and increasingly primary forest as well.

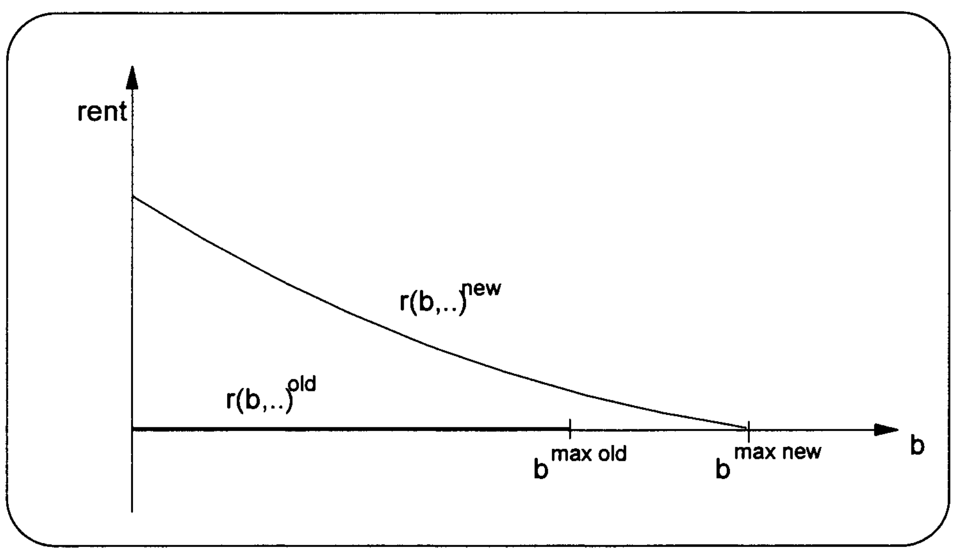

Figure 4. Land rent immediately after an exogenous shock that lowers the effective real wage (z).

8 Homesteading: private land rights established by forest clearing

8.1 The model

A common feature of shifting cultivation systems is that forest clearing gives the farmer some (usufructuary) rights to the land, particularly if perennials are planted or the land is 'improved' in some other ways. The protection of these rights in customary and national law varies considerably, and we shall later include unsecured property rights in the model. People involved in such agricultural practices are sometimes referred to as 'colonists' or 'squatters', but both farmers having lived in the area for a long period as well as newcomers may be involved. This is indeed the case in the Seberida district, Sumatra, where most of the expansion is due to local farmers, but transmigrants (migrants from Java) are increasingly taking up the shifting cultivation practice.

This regime has a parallel to homesteading in the United States, officially introduced with the Homestead Act of 1862 and ending in 1934 (Allen, 1991; Anderson and Hill, 1990). A large proportion of the literature on homesteading has focused on the negative aspects of such a regime because it causes farmers to rush to the land in order to gain property rights. In this process, all positive future rents and the potential gains from agricultural expansion are dissipated.

A homesteading regime implies that forest land is transferred from being an open access resource to private property. Compared to the previous open access model, such a regime for obtaining property rights makes it necessary to include some new elements in the model. Farmers will not only look at the immediate benefits from one cultivation, but also at the future gains (net present value - NPV). This makes it necessary to include another aspect, that is, farmers' expectations about the factors that determine future land rent. For simplicity, we assume risk neutral agents, i.e., *expected* NPV is maximized. We retain the zero-profit condition, except that the relevant profit now is the NPV of future land rent.[26] We assume further that the forest is managed optimally, in the way described by the Faustman rule after the initial clearing, when private property rights have been established. For simplicity we set $a = 1$. The model for the initial clearing consists of two equations, the zero-profit condition in (45), and the labour input equation in (46). Again we assume to start from bare land; the alternative when the initial situation is old-growth forest is discussed later.

$$(45) \quad NPV_k = r(m^1, l^1) + NPV^{MR}(z^e) = 0$$

$$(46) \quad r_l(m^1, l^1) = 0$$

The net present value at time k is the land rent from the first clearing, plus the NPV of future land rent after the initial clearing. The superscript MR refers to the multi-rotation (Faustman) solution, 1 refers to first clearing, whereas e indicates expected value of z.[27]

For land inside the boundary of cultivation, $NPV^{MR} > 0$. According to (45), the profit from the first clearing will then be negative. Farmers are willing to accept a loss as the NPV of subsequent clearings is positive, and getting rights to this benefit stream (that is property rights) outweighs their initial loss. Forest cleared to establish property rights will be younger than for the subsequent rotations. Thus compared to the situation of open access where clearing does not

[26] One may argue that the NPV will always form the basis for the decision, but that in the 'pure' open access situation the NPV is equal to the current land rent, as the farmers have no rights to future land rent.

[27] Note that NPV^{MR} is not discounted as it is assessed at the time of the first clearing.

give property rights, the initial rotation will be shorter, whereas later rotations will be longer inside the boundary.

As regards the agricultural frontier, we must distinguish between two cases. In the first one $z^e = z^{p(resent)}$, i.e., farmers expect the present effective real wage to remain the same in the future. In this case the agricultural frontier will be the same in both open access regimes. At the frontier, NPV^{MR} is zero, thus the profit from the first clearing must also be zero. And we have argued earlier that we get the same frontier in the Faustman and the 'pure' open access case; thus the agricultural frontier remains the same also in this case.

As a second case we look at the situation when $z^e < z^p$, i.e., farmers expect the effective real wage to decline due to, say, technological progress or lower transport costs. As the Faustman solution assumes all parameters to be constant, we have to think of this as a one-time drop in z after the first clearing. Consider a situation at the agricultural frontier as given in the first case above, where $z^e = z^p$. If now z^e drops, the NPV of future land rent at the frontier becomes positive. Therefore, it will be profitable to expand the frontier, even if this gives a loss at the first clearing. In this case the frontier under homesteading will be moved further away from the village compared to the pure open access case. This is shown formally below.

The two open access regimes are compared in Figure 5: the agricultural frontier will be moved further away when we have a regime that allocates property rights to the settlers, and $z^e < z^p$ (case 2). The figure is further discussed in Angelsen (1996a).

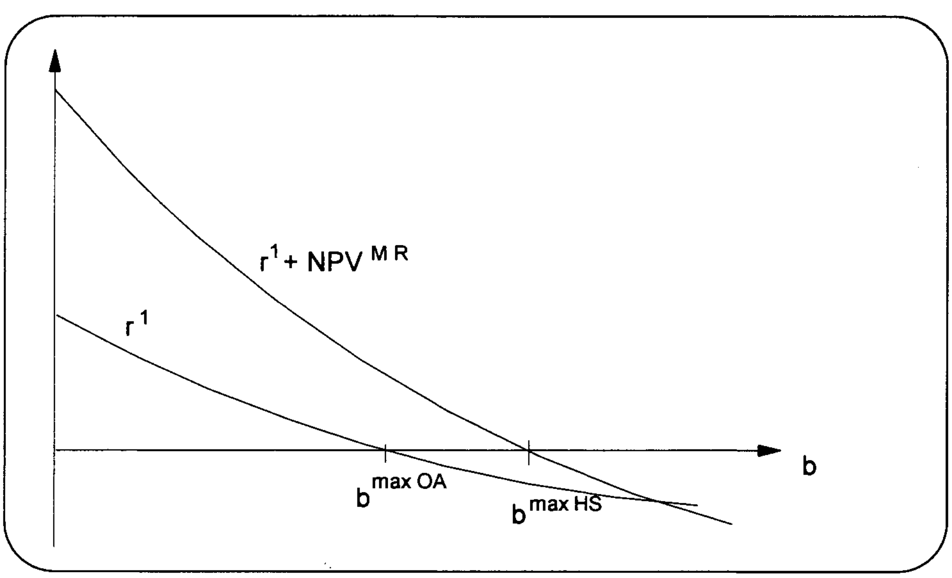

Figure 5. Agricultural frontier under two types of open access regimes.

8.2 Comparative statics

What happens if z^e declines (z^p remains constant)? We focus on the effect on fallow length and labour input for the first clearing, and the agricultural frontier. The effect on m and l *after* property rights have been secured, has been discussed under the multi-rotation model.

$$(47)\quad \begin{bmatrix} r_m & 0 \\ r_{lm} & r_{ll} \end{bmatrix} \begin{bmatrix} dm^1 \\ dl^1 \end{bmatrix} = \begin{bmatrix} -\frac{dNPV^{MR}}{dz^e} \\ 0 \end{bmatrix} dz^e$$

The term $\frac{dNPV^{MR}}{dz^e}$ is obviously negative. The solution is still recursive, i.e., we can first determine the changes in m^1 and then use this to determine l^1.

$$(48)\quad \frac{dm^1}{dz^e} = -\frac{\frac{dNPV^{MR}}{dz^e}}{r_m} > 0$$

$$(49)\quad \frac{dl^1}{dz^e} = -\frac{r_{lm}}{r_{ll}}\frac{dm^1}{dz^e} < 0$$

The interpretation of these results is straightforward. Consider a decline in z^e. Lower expected effective real wage means higher expected land rent in the future. Thus, farmers will clear younger forest, with larger loss from the initial clearing, in order to get rights to the land and the higher future land rent. Labour inputs will increase with lower z^e because shorter fallow means higher marginal productivity of labour, but this conclusion again rests on thin empirical evidence.

What is the effect on the agricultural frontier? Assuming again that we are starting in a situation where $z^e = z^p$, and remembering that both for the initial and the following clearings the fallow period at the frontier will be $m*$, cf. (7), differentiation of (45) gives;[28]

$$(50)\quad \frac{db^{\max}}{dz^e} = \frac{\frac{dNPV^{MR}}{dz^e}}{w^1q^1[l^1+g(m^1)]+\frac{1}{e^{m^{MR}\delta}-1}[l^{MR}+g(m^{MR})]w^eq^e} < 0$$

The result of (50) has a similar interpretation as the one above: lower expected effective real wage will lead to an expansion of the agricultural frontier. An increase in the expected NPV means that farmers would be willing to move further away and accept higher losses to get the higher future land rent.

The effect of a change in the discount rate can be analyzed in a similar way;

$$(51)\quad \frac{db^{\max}}{d\delta} = \frac{\frac{dNPV^{MR}}{d\delta}}{w^1q^1[l^1+g(m^1)]+\frac{1}{e^{m^{MR}\delta}-1}[l^{MR}+g(m^{MR})]w^eq^e} < 0$$

The intuition is similar to that of (50). A higher discount rate would lower the NPV of future land rent. Thus, the initial age of the forest cleared will be higher, and the agricultural frontier

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[28] Note that the effect of a marginal change in m or l is zero.

closer to the centre. Thus, somewhat surprisingly, a higher discount rate implies less deforestation because the positive future land rent is given less weight in farmers' decisions. This contradicts conventional wisdom which holds that lower discount rates would help preserve the environment. This is not true in our model under the homesteading property rights regime. Forest clearing is an investment as the farmer obtains land rights, and a lower discount rate implies more investments (i.e., more forest clearing).

8.3 Uncertainty about future rights

Most 'real life' situations will be in-between the two extreme cases discussed above: pure open access and homesteading with secure property rights. Generally, uncertainty about future rights would give a solution between the two extremes.

This can be discussed analytically in at least two ways. One possibility is just to add a parameter, β, before NPV^{MR} in (45), with $0 \le \beta \le 1$. $\beta = 1$ represents the homesteading case just discussed, whereas $\beta = 0$ is the open access case where clearing gives no property rights.

Another possibility will be to integrate tenure insecurity into the Reed (1984) approach, as discussed under the multi-rotation social planner's problem. The risk of losing land has the same effect as a higher discount rate, which is also argued by Mendelsohn (1994). And, as shown in (51), the effect of a higher discount rate is a contraction of the agricultural frontier.

The introduction of insecure future rights will therefore *reduce* the agricultural expansion compared to the case of secure property rights. We are moving from a homesteading solution with secure rights towards an open access solution which, as shown, implies less forest clearing. As further elaborated in Angelsen (1996a), land reforms which increase tenure security could in a context where forest clearing gives some land rights therefore boost deforestation.

This result should be contrasted with the conventional wisdom in this area as illustrated by Deacon (1994). His main argument is that tenure insecurity promotes more short-sighted and intensive strategies and therefore more deforestation. As the present paper has highlighted it is critical to distinguish between the *intensity* of agricultural production (fallow period) and the *total area* of agricultural production (deforestation). Pooling these issues may lead to unjustified policy conclusions; our model supports Deacon (1994) with respect to intensification, but yields that higher insecurity will reduce deforestation. The importance of clearly distinguishing between the issue of intensification and expansion is also highlighted by von Amsberg (1994) in the case of logging.

8.4 Alternative assumption: Initial situation is old-growth forest

The discussion of homesteading has so far, in line with the tradition of the Faustman literature, been based on the assumption that one starts from a situation with bare land, i.e., all forest is initially of age *0*. An alternative, and possibly also more realistic formulation for the discussion of land expansion in the homesteading case, would be that the initial situation is one with old-growth (climax or primary) forest. This would actually simplify the analysis. The homesteading model would then be;

(52) $NPV_k = r(m^{OG}, l^{OG}) + NPV^{MR}(z^e) = 0$

(53) $r_l(m^{OG}, l^{OG}) = 0$

The choice variables for the initial clearing and cultivation are the labour input in old growth (*OG*) forest, and the agricultural frontier. The initial age of the forest (m^{OG}) is given and is not a choice variable. As before, the farmer is assumed to follow a Faustman optimization after the initial clearing.

We define the rent from cultivation of old-growth forest: $r^{OG} = r(m^{OG}, l^{OG})$. It may well be that $r^{OG} < r^*$, as given in (9). Boserup (1965: 31), Dvorak (1992) and others report that swidden farmers in general have a preference for secondary forest due to the high costs of clearing old-growth forests. This is in line with the assumptions made for the *f(m,l)* and *g(m)* functions, and is illustrated in Figure 6. Rent as a function of forest age reaches its maximum, r^*, at m^*, and then declines until the forest reaches its climax at m^{OG}. After this age the forest is in a steady state, and the rent does not change.[29]

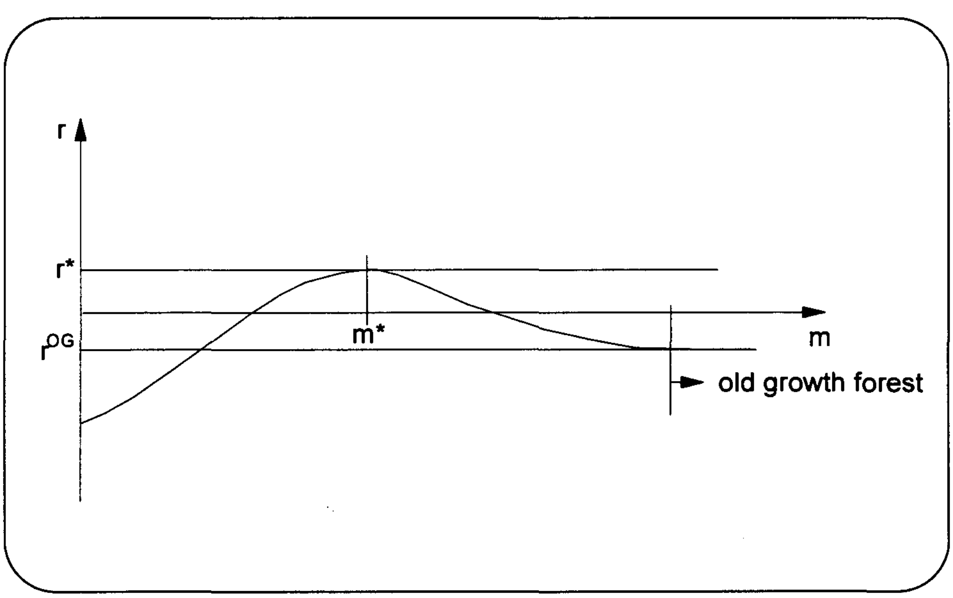

Figure 6. Rent in old-growth forest (r^{OG}) and maximum rent (r^*).

[29] Note that *r()* is not globally concave in *m* any longer. However, in the relevant region when *m* is a choice variable, i.e., between m^{min} and m^*, we still assume that *r()* is concave.

In contrast to the result when we assume starting from bare land, the homesteading regime will give more deforestation than the open access solution even in the case where the effective real wage is expected to remain the same in the future ($z^p = z^e$). Farmers clearing old-growth forest at the frontier accept a loss for the first clearing and cultivation; this is compensated for by a positive NPV^{MR} after the initial clearing.

If the expected effective real wage (z^e) declines, farmers would expand the frontier further, and be willing to take an even larger loss during the initial clearing to get the property rights. Hence the conclusions and the comparative statics results in this version of the homesteading model remain the same as when assuming to start from bare land.

8.5 Two possible scenarios

Thus far the discussion has compared different long term equilibria. Adjustment will take time, both due to the long rotation periods involved and because there are adjustment costs. Consider a situation where $z^e = z^p$, that is farmers plan as if the effective real wage will remain the same in the future. Property rights have been established for all land up to the agricultural frontier. Then there is an exogenous decrease in z^e. This implies that the expected NPV for some land outside the old cultivation boundary is "up for grabs". Farmers will compete among themselves for the rights to the land, and we have a "race for property rights" or uncaptured land rent.

Another related scenario would be where there exists some form of communal management of the forest. z^e is expected to decrease in the future. However, since communal rights to all forest land are already established, there is no need to clear land to secure property rights. New land is not cleared before it yields a positive (or non-negative) rent from the first clearing. Consider now the effect of the forest being opened to outsiders for competition, i.e., we move from a regime of communal management to one of open access where clearing gives property rights. In this scenario, even the expectation alone of such a change, could cause an expansion of the agricultural frontier.

The homesteading case and both scenarios draw the attention to the importance of *expectations*, and how these are formed. Angelsen (1995) argues that in the study area in Sumatra, state sponsored land claims (primarily transmigration, logging, and plantation projects) have been important in initiating a land race. Eventually, however, the main driving force is internal mechanisms in terms of increased competition among the farmers, expressed by increased forest clearing and rubber planting. Such land races may therefore be self-reinforcing through their impact on farmers' expectations.

9 Comparison of the different property right regimes

This paper has combined the Faustman rotation approach and the von Thünen spatial approach in a model for a small, open economy, i.e., a model with a perfect labour market and exogenous real wage. We have looked at four different solutions to this model, corresponding to different assumptions about the property rights regime. A comparison of the variables and the effects of exogenous changes is given in Tables 1 - 3 below.

	Social planner: Single rotation (SR)	Social planner: Multi-rotation (MR)	Open access (OA)	Homesteading (HS) (1. rotation)
Fallow period	m^{SR}	$> m^{MR}$	$> m^{OA}$	$> m^{HS}$
Labour input	l^{SR}	$< l^{MR}$	$< l^{OA}$	$< l^{HS}$
Agr.frontier	$b^{max\ SR}$	$= b^{max\ MR}$	$= b^{max\ OA}$	$< b^{max\ HS}$

Table 1. Comparison of the level of endogenous variables under different regimes. Under the HS case, the values refer to the initial clearing (for the subsequent clearings the MR-solution is followed), and we assume that the expected z is lower than the present one.

The fallow period for a particular z will be longest in the single rotation problem, where the discounted profit from one clearing is maximized. The shortest fallow is obtained in the homesteading regime, as farmers are willing to accept a negative land rent during the first clearing(s) in order to get property rights to future positive land rents.

The margin of cultivation will be the same in all cases, except the last one (HS) when z is expected to decline in the future, or the initial situation is old-growth forest. This result is somewhat surprising, but the reason is straightforward. The agricultural frontier is the maximum distance possible without getting a negative rent. In the first three models this means that the rent from one clearing must be maximized and set equal to zero at the frontier.

In the last model (homesteading), a negative rent is accepted for the first clearing, given that the rent is expected to increase in the future. Thus, the frontier is moved further away. This case is probably the most realistic description of large areas of tropical forest. It illustrates the importance of property rights, and how an ill-designed regime may produce perverse environmental outcomes.

The conclusion above that the agricultural frontier is the same in the first three models is modified if we include environmental benefits in the model. Obviously, an open access solution -- even if it does not give the farmer property rights -- will lead to more deforestation than the social planner's solution. The same is true for a private property regime.

	Social planner: Single rotation (SR)	Social planner: Multi-rotation (MR)	Open access (OA)	Homesteading (HS)
Fallow period (*m*)	decrease/ increase	increase	increase	increase
Labour input (*l*)	decrease	decrease	decrease	decrease
Agr.frontier (b^{max})	decrease	decrease	decrease	decrease
Profit (*NPV* or *r*)	decrease	decrease	no effect (= 0 by assumption)	no effect (= 0 by assumption)

Table 2. The effects of an increase in the effective real wage (z) on endogenous variables.

The effects of an increase in the effective real wage (z) is shown in Table 2. In all cases, except for the ambiguity in the single rotation model, the fallow period will increase. In the multi-rotation model, higher z implies lower opportunity costs of delaying clearing, and therefore longer fallow. The reason for the effect of z on m is somewhat different in the two open access models: higher z reduces the relative profitability, and an increase in fallow period is necessary to retain non-negative profit. Labour inputs decrease in all cases, as is to be expected.

An increase in z will in all models cause a contraction of the agricultural frontier. Any policy that increases the relative profitability of shifting cultivation will lead to an expansion and increased deforestation. This seems to be a robust conclusion, not dependent on the actual property rights regime.

	Social planner: Single rotation (SR)	Social planner: Multi-rotation (MR)	Open access (OA)	Homesteading (HS)
Fallow period (*m*)	na	decrease	na	1. clearing: Increase Later clearings: Decrease
Labour input (*l*)	na	increase	na	1. clearing: Decrease Later clearings: Increase
Agr.frontier (b^{max})	na	no effect	na	decrease
Profit (*NPV* or *r*)	na	decrease	na	no effect (= 0 by assumption)

Table 3. The effects of an increase in the discount rate on endogenous variables.

Finally, the effects of an increase in the discount rate are summarized in Table 3. In the multi-rotation model, the fallow period declines because the opportunity costs of delaying the clearing and harvest is increased. The labour input increases, whereas the discount rate has no effect on the agricultural frontier. In the homesteading regime, the effect of an increase in the discount rate is to put less emphasis on the positive land rent in the future. Thus, the age of the forest cleared initially will increase, whereas later fallows will follow the MR-model, i.e., decrease. The reduced weight given to future positive rents also implies that the agricultural frontier will decrease. Because of the perverse incentives under homesteading a lower discount rate will augment deforestation.

10 Concluding remarks

The main line of argument throughout this paper is that the intensity of cultivation (inverse of fallow period and labour input) as well as the agricultural frontier is determined by the relative profitability of shifting cultivation, as captured in a single variable -- the effective real wage (z). The main force towards *intensification* in terms of shorter fallow periods and an *expansion* of the system is lower z, which in turn is determined by five variables: agricultural output price, nominal wage, technological level, transport costs, and distance. Policies affecting these factors can be used to influence intensity of production and agricultural expansion (deforestation).

Given that governments may want to both intensify and limit expansion of shifting cultivation, there is a trade-off between these objectives under all property regimes. Policies which affect the effective real wage rate will either support the intensification or the forest conservation objective.

Policies related to land tenure has more mixed effects. A homesteading regime gives more deforestation than the other property regimes. Introducing alternative ways of allocating property rights to forests than through forest clearing will reduce the incentive for this kind of rent-seeking behaviour. More secure land rights, which is equivalent to a lower discount rate, will in the homesteading case promote deforestation, whereas it has no effect in the other cases.

Interestingly, in the multi-rotation model improved tenure security will also lead to longer fallow periods. Land reforms can therefore reduce the intensity of production.[30] There are, of course, a number of other effects related to improved tenure security which are not included in the models. The effects discussed in the present paper should, nevertheless, be considered in the design of tenure policies.

Besides their policy relevance, the models can also be used to explain some other observed phenomena. The Boserup (1965) hypothesis suggests that population growth induces agricultural intensification. Whereas population is not directly included in the model, it could be interpreted as lower real wage rate (z), as is the effect in model II in Angelsen (1996a). The effect of lower z

[30] See Angelsen (1996b) for a similar result in a very different model.

is to increase the output per unit total agricultural land for two reasons: the fallow length will be reduced, and the labour input will increase. The present model therefore provides an analytical explanation of the Boserup hypothesis.

Another application of the model is to explain dual economic growth in poor countries, cf. López and Niklitschek (1991). Economic growth is associated with improved possibilities for off-farm employment and higher opportunity costs of labour (w). The effect of higher z is longer fallow periods and less labour input, which is the opposite of the Boserup story. The model can explain a dual economic development with the emergence of a modern sector (higher w) while the extensive farming practices in the traditional agricultural sector are maintained. The Riau province, Sumatra is an example of a region characterized by such a dualism (e.g., Hill, 1989). This dualism will be particularly apparent if the technological development in agriculture is slow or agricultural prices kept low.

Appendix 1

In this appendix we prove that the following expression in (30) is negative: $(1-e^{-\delta m})g_m - \delta(l+g) < 0$. The condition is equivalent to;

$$\theta \equiv \frac{(l+g)}{g_m}\frac{\delta}{(1-e^{-\delta m})} = \mu\tau > 1;\ \mu \equiv \frac{l+g}{g_m};\ \tau \equiv \frac{\delta}{1-e^{-\delta m}}$$

We always have that $\mu \equiv \frac{l+g}{g_m} > m$, which follows directly from the assumptions made about *g()*. Then we must show that $\tau \equiv \frac{\delta}{(1-e^{-\delta m})} > \frac{1}{m}$, which consists of two steps. First, we explore what happens when the discount rate goes to zero, using l'Hôpitals rule;

$$\lim_{\delta\to 0}\tau = \lim_{\delta\to 0}\frac{\delta}{1-e^{-\delta m}} = \lim_{\delta\to 0}\frac{1}{me^{-\delta m}} = \frac{1}{m}$$

Next, we take the derivative of τ with respect to the discount rate, and show that this is positive;

$$\frac{\partial\tau}{\partial\delta} = \frac{1-e^{-\delta m}-\delta me^{-\delta m}}{(1-e^{-\delta m})^2}$$

This expression is positive iff;

$$\frac{1-e^{-\delta m}}{\delta me^{-\delta m}} = \frac{e^{\delta m}-1}{\delta m} > 1$$

This is true iff $\phi(\delta) \equiv e^{\delta m} - \delta m > 1$, which holds for any $\delta > 0$, as we have;

$$\phi(0) = 1;\ \frac{\partial\phi}{\partial\delta} = m(e^{\delta m} - 1) > 0 \quad \textit{if} \quad \delta > 0$$

We have then shown that τ approaches $\frac{1}{m}$ as the discount rate approaches zero, and that τ increases as the discount rate increases. Thus, we always have $\tau > \frac{1}{m}$, which combined with $\mu > m$ gives that $\theta = \mu\tau > 1$, i.e., the expression $(1-e^{-\delta m})g_m - \delta(l+g)$ will always be negative.

Appendix 2

We want to prove that the effect of a higher discount rate on the fallow period is negative, cf. (33): $(r - me^{-\delta m}r_m) > 0$. Using the FOC in (27), $r = (1-e^{-\delta m})\frac{r_m}{\delta}$, we obtain;

$$1 - e^{-\delta m} - me^{-\delta m}\delta > 0$$

$$\Leftrightarrow\ \phi(\delta) \equiv e^{\delta m} - m\delta > 1$$

$\phi(\delta)$ is identical to the expression in Appendix 1, which was proven to be greater than one.

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Chapter 4

Shifting Cultivation and "Deforestation": A study from Indonesia*

Abstract:

About half of tropical deforestation is commonly explained by the expansion of traditional agriculture (shifting cultivation). This paper first questions the share of responsibility assigned to traditional agriculture -- it may well be overestimated because of unclear definitions, uncertain estimates, and potential political biases. Second, a simple framework based on a theory of land rent capture is developed to explain agricultural expansion. The framework is applied in the study of recent changes in shifting cultivators' adaptations in a lowland rainforest area in Sumatra, Indonesia. Increased rubber planting and expansion into primary forest are seen as a response to increased rubber profitability and (expected) land scarcity, and as a race for property rights. Government land claims have had significant multiplier effects on forest clearing through changes in farmers' expectations and in initiating a self-reinforcing land race.

** This is a slightly revised version of an article with the same title published in World Development, 25 (10), 1995. Part 3 to some extent overlaps with chapters 2 and 3, but I have chosen to maintain the structure of the paper since it has already been published, and because each essay of the thesis should be self contained and therefore may be read independently. I would like to thank Stein Holden, Bustanul Arifin, Ian Coxhead, Odd-Helge Fjeldstad, Johan Helland, Richard Moorsom, Jerry Shively, Ussif Rashid Sumaila and two referees for constructive comments on draft versions of the paper. I claim exclusive property rights to remaining errors. The fieldwork benefited from being part of a larger interdisciplinary project -- Norwegian-Indonesian Rain Forest and Resource Management (NORINDRA). Funding for the project was provided by the Norwegian Research Council (NFR) and the Norwegian Ministries of Foreign Affairs and Environment.*

1 Introduction

Agricultural encroachment by shifting cultivation occupies a central position in the debate on tropical deforestation.[1] Shifting cultivators are often seen as the primary agents of deforestation in developing countries; estimates of their share range as high as 45 % (UNEP, 1992) to 60 % (Myers, 1992). Attempts have been made to control and integrate them into national development schemes, and to replace the system with more intensive sedentary systems. The British in Malaya in 1937 described the practice as a "destructive and out-of-date system of cultivation, a tragedy to those who practice it and a menace to their future prosperity". In the case of Indonesia, government policy is to "devote concentrated attention to rationalizing and controlling shifting cultivation completely within a span of 10 - 15 years." (Indonesian Tropical Forestry Action Plan, vol. 2, 1991: 35). Generally, such efforts have not been very successful (Atal, 1984). The reasons for this failure include an inadequate understanding of the logic of shifting cultivation and factors influencing farmers' decision making.

The main objective of this paper is to analyze some basic factors and mechanisms behind the expansion of shifting cultivation into primary or old-growth forest, with the subsequent loss of ecological functions such as biodiversity maintenance and carbon storage. Before entering into a discussion of the causes and dynamics of deforestation, some comments on the definitions, estimates and consequences of deforestation are in order, as documented in section 2. There is no clear definition of "deforestation", neither are there reliable estimates of its extent nor its primary causes, and -- partly as a reflection of these -- there is no consensus on the underlying causes. We argue that even though the contribution made by traditional agriculture (mainly shifting cultivation) to the overall tropical deforestation is clearly an issue of concern, its magnitude in relation to other causes is sometimes put out of proportion. This is illustrated by recent data on deforestation in Indonesia, as well as field data from Riau, Sumatra. Moreover, the environmental consequences of traditional shifting cultivation, such as global climate change, biodiversity, and soil erosion, are smaller compared to many other uses of forestland.

Section 3 develops a theoretical framework for the discussion, based on a theory of land rent capture. The open economy approach taken here is contrasted with a conventional subsistence or

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[1] Shifting cultivation could be considered as an early stage in the evolution of agricultural systems. The system is based on cutting and burning the vegetation in the dry season, and planting crops in the ashes early in the wet season. Declining soil productivity and increasing weed problems lead farmers to abandon fields after a few, often only one or two, years of cropping. Other types of vegetation take over, and the field eventually grows into secondary forest, before the cycle is repeated. The length of this fallow period varies considerably -- 5-20 years is common. Shifting cultivation has low productivity in terms of output per hectare of total agricultural land (i.e., both cropping and fallow land) compared to most other ("modern") systems, but relatively high return to labour. As the population depending on shifting cultivation increases, "the system increasingly fails to satisfy the requirements for higher production per unit area" (FAO, 1974: 3). This may result in shorter fallow and longer cropping periods, initiating an accelerating and self-reinforcing process of land degradation.

closed economy approach, which yields quite different results when it comes to the effects of population growth, technological progress, and risk. The framework is illustrated with some examples of the deforestation history in Southeast Asia.

In section 4 we use this framework to analyze forest encroachment by shifting cultivators in a lowland rainforest area in the Seberida district, Riau province, Sumatra, Indonesia, based on data collected during fieldwork in 1991-92. Increased rubber planting and agricultural expansion into primary forests are seen as the result of a number of factors which have increased the profitability of frontier farming relative to alternative employment opportunities. Increased tension between customary and national law has made it more important for local farmers to secure their land claims. Expectations about increased future land scarcity pull in the same direction. Section 5 provides some conclusions and policy implications.

2 The role of shifting cultivation in "deforestation"

2.1 *Estimates of "deforestation"*

Estimates of tropical deforestation entail great uncertainty. An authoritative source on changes in the resource base is the biannual report by the World Resources Institute (WRI). The following figures illustrate the uncertainty involved and how estimates can change with new information. The *World Resources 1990-91* report (WRI, 1990) estimated the annual tropical deforestation in the 1980s at 0.9 %. The figures for the three main rainforest countries, Brazil, Zaire, and Indonesia, were 1.8, 0.2 and 0.8 %, respectively. Four years later in WRI (1994), based on a comprehensive study by FAO (1993), the estimate for overall tropical deforestation in the 1980s is more or less unchanged (0.8 %). Looking at the individual countries, however, the estimate for Zaire is tripled to 0.6 %, whereas it is reduced to one third in the case of Brazil (0.6 %)!

Part of the reason behind the wide range in estimates is variations in the use of the term. *Deforestation* is often taken to mean *destruction or removal of tree cover*, but the range of uses is great, from a complete and permanent removal of the tree cover to small alterations in the ecological composition. WRI (1992: 118) provides the following definition:

> *"The term deforestation describes a complete change in land use from forest to agriculture - including shifting cultivation and pasture - or urban use. It does not include forest that has been logged and left to regrow, even if it was clear-cut".*

This definition entails a contradiction since forest opened by shifting (swidden) cultivation often would be secondary forest previously used for swidden agriculture, and then left for fallow. Thus, temporary clearing by logging is not classified as deforestation, whereas temporary clearing by shifting cultivators is included. Myers (1992) similarly assumes that shifting cultivation was largely replaced by permanently cleared land (Houghton, 1993: 26).

More precise definitions and a clarification of what is meant by the term deforestation would definitely advance the debate on causes, consequences, and solutions.[2] Much confusion arises because no distinction is made between permanent and temporary conversions, or between conversion and alterations (cf. the distinction between deforestation and forest degradation).

Unfortunately, the availability of data rarely allows for the use of very precise definitions of deforestation. Commonly cited estimates of deforestation in Indonesia during the 1980s include 1.3 million ha/year (FAO, 1991), 1.2 million ha/year (FAO, 1993) and 0.9 million ha/year (World Bank, 1990), compared to a forest stock of some 110 million ha in 1990 (FAO, 1993). These estimates may well be too high, according to a more critical study (Dick, 1991), which estimates deforestation to 0.6 million ha/year. According to Dick, earlier estimates have not made the distinction between temporary and permanent clearing, and they have assumed that all causes of deforestation are additive. No account has been made for the fact that smallholders usually occupy disturbed forest, or that shifting cultivators also may occupy land that has not been forested for decades. Moreover, some of the previous figures were "based more on wishful thinking by development agencies than on actual accomplishments" (Dick, 1991: 30), thus overestimating forest conversion.

One of the most interesting findings in Dick (1991) is that programmes sponsored or explicitly encouraged by the Government of Indonesia account for 67 % of all deforestation, whereas the share of traditional agriculture is only 22 %.[3] Furthermore, a large share of the latter would be in forest that has been in a rotation cycle for a long period. These findings have important policy implications. According to the latest World Bank (1994) country study on environment and development in Indonesia, "this challenge the conventional wisdom, which holds that traditional shifting agriculture is the main agent of deforestation" (page 51). This forms the background for a significant change in the policy focus of the World Bank when it comes to the main challenges for forest management, away from traditional agriculture, to logging and government policies that encourage deforestation.

Data from the fieldwork in the Seberida district, Sumatra, further illustrate these points, not to claim that these are representative for Indonesia, but to show the importance of how the contribution of shifting cultivation to deforestation is measured. Forest clearing by shifting cultivators in 1991 is estimated at 2 400 ha, about 0.85 % of the total land area of these villages.

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[2] The debate between foresters and environmentalists on logging and deforestation is a case in point, where foresters claim that selective logging is not deforestation, whereas many environmentalists would include it.

[3] Spontaneous migration (*swakarsa* transmigrants), which is explicitly encouraged by the Ministry of Transmigration, is the single largest agent of land use change, accounting for 178 500 ha (29 %) of the total deforestation (623 300 ha). FAO (1991) and World Bank (1990) have included these migrants under "traditional agriculture", whose annual clearance was estimated to be 461 000 ha (35 %) and 500 000 ha (56 %), respectively. This compares to 134 500 ha (22 %) in Dick (1991).

To account for net forest clearing, however, one should primarily look at the *expansion* of shifting cultivation into forest previously not used for agriculture. For 1985-91 only about 10 % of the annual forest clearing represented an expansion of the system. Moreover, even for this share it is questionable whether it should be grouped as deforestation because the fields are left to recover into secondary forest, probably economically enriched with rubber.

Identification of the primary agents of deforestation is not politically neutral. Governments (and others) may have an interest in putting the blame on primitive, tradition-bound, and ignorant farmers, beyond the control of the state (Bromley, 1991; Dauvergne, 1994). Unclear definitions and uncertain estimates widen the scope for political biases. Nonetheless, the role of shifting cultivators remains important, although it should be seen in perspective and compared with other sources of deforestation and government policies that influence farmers' decision-making.

2.2 Environmental effects of different types of "deforestation"

A distinction between different types of forest conversions or alterations under the deforestation umbrella is important because the environmental effects and social costs may be very different. We consider three of the most important potential environmental effects of deforestation: climate change due to the release of carbon, loss of biodiversity, and increased soil erosion. At the global level, tropical deforestation accounts for about 25 % of heat-trapping emissions. But the net carbon flux from "deforestation" will be small if, as is the case in Seberida, most of the cleared forest is secondary/fallow forest which also regenerates into secondary forest. As Table 1 shows, conversions of old growth forest to shifting cultivation or plantations will typically lose 30-60 % of the initial carbon stock in the vegetation, whereas conversion to permanently cultivated land or pasture loses more than 90 % (Houghton, 1993).

The biodiversity consequences will also be very different depending on the type of land use change. Estimates of biodiversity loss are often based on species-area curves, with an elasticity of the number of species with respect to area typically in the range of 0.15 to 0.35 (Connor and McCoy, 1979). Such crude measures are inaccurate for at least two reasons. First, overall figures of deforestation do not account for the *fragmentation* of forestland, which magnifies the impact on biodiversity (WRI, 1994: 133). Second, there are significant differences in biodiversity between different land uses. Work by zoologists in the lowland rainforest of the Seberida district shows that the fauna diversity of long-fallow forest (with or without rubber) is only slightly lower than for logged or unlogged primary forest, and well above that of plantations (Danielsen and Heegaard, 1995). Finally, some disturbance may actually enhance species diversity as the habitat becomes more heterogeneous.

A third area of environmental concern is related to soil erosion, but deforestation figures are poor indicators of the magnitude of the problem. Surface erosion is mainly determined by the density of the ground cover. "The ground cover rather than the tall tree canopy must command our attention, even though popular myth dwells on the importance of tree crowns in reducing raindrop impact and hence particle detachment through splash erosion" (Hamilton, 1995: 5). Comparing surface erosion from different land uses with tree cover, Wiersum (1984) finds the median value for shifting cultivation to be 0.15 (fallow period) and 2.78 (cropping period) ton/ha/year, compared to 0.30 for natural forest. Tree crops or forest plantations where the ground cover is removed have average soil losses of about 50 ton/ha/year. Forest cover, due to its root system, is more important for mass erosion, e.g., landslip.

Type of land use	**Carbon release**	**Biodiversity**	**Soil erosion**
	Pct. of initial carbon stock from vegetation lost	*Pct. of bird diversity lost*	*Ton/ha/year (average values)*
Natural forest	-		0,30
Shifting cultivation - cropping period	60 %	15-20 %	2,78
Shifting cultivation - fallow period			0,15
Permanent cultivation	90 - 100 %	> 90 %	
Pasture	90 - 100 %		
Tree crops, with cover crop			0,75
Tree crops, clean weeded			47,60
Forest plantations, undisturbed	30 - 50 %	50-70 %	0,58
Forest plantations, burned/litter removed			53,40
Logging	10 - 50 %	No significant effect	

Table 1. Environmental effects of different land uses.
Sources: Houghton (1993) (carbon release); Danielsen and Heegaard (1995 and personal communication) (biodiversity); Wiersum (1984) (soil erosion).

Overall figures of deforestation are therefore at best very crude measures of the actual environmental changes. The concern for global climate change indicates a focus on biomass; biodiversity should guide our attention to forest composition and fragmentation, in addition to overall size; whereas the problem of soil erosion is mainly due to changes in ground vegetation and root structures. Hamilton (1988) has even suggested that the term "deforestation" should be abandoned, or if used carefully defined and qualified by a description of the real nature of the change. A fruitful approach -- in line with economic theory -- would be to first describe and, to the extent possible, quantify the variety of ecological functions provided, including the three discussed above. Second, the social desirability of different land uses should be evaluated based on a valuation of the changes in these functions or environmental services (see, for example, Winpenny, 1991). For analytical purposes, and to get a handle on the causes of the problem and its solutions, the term "deforestation" is of limited value.

3 Land rent capture and agricultural expansion

3.1 Subsistence v. open economy models[4]

Economic models of decision-making in tropical agriculture differ with respect to their behavioural and market assumptions, of which the labour, product, and credit markets are the most important. Two important, somewhat stylized and extreme categories, which especially relate to the labour market assumptions, are the subsistence and the open economy models.

The *subsistence models* assume in the extreme case that no markets exist. Farmers produce only for their own consumption, with family labour as the only input in addition to land. The area of cultivation would in such models be determined by factors such as population size, soil fertility, and technology. A common version of the subsistence model is the *"full belly"* case[5] (e.g., Dvorak, 1992); the households' objective is to meet a basic subsistence requirement, and they do so by minimizing their labour efforts (maximizing leisure).[6]

In *open economy models,* markets exist, and all prices (including the wage rate) are taken as parametrically given. An intuitive interpretation is that the shifting cultivation sector is small compared to the rest of the economy. In addition to the simplification made by exogenous prices, a further simplification is due to the recursive property of such models: if labour can be sold or hired at a constant wage, the production decisions by a utility maximizing household can be studied as income or profit maximizing production behaviour (Singh *et al., 1986*). The area of cultivation will in the open economy case be determined by the relative profitability of frontier farming.

These extreme cases give the range of possible adaptations and farmers' responses. The effect on deforestation of changes in exogenous economic variables and policies may be very different in the two models, as illustrated by the following examples:

(i) Population growth: Increased population has no effect in the open economy model, as the size of the agricultural sector and its expansion into virgin forest are determined by its relative profitability. In a subsistence model population growth is a critical variable in determining

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[4] The issues raised in this section is elaborated in Angelsen (1996b).

[5] The term "full belly" is attributable to Fisk (1962).

[6] The Chayanov (1966) model is a more general formulation. The household acts as if maximizing a utility function, with consumption and leisure as the arguments. They reach a subjective equilibrium with a shadow wage rate reflecting the rate of substitution between consumption and leisure, cf. model II in Angelsen (1996b). Holden (1993) compares the "full belly" and Chayanov formulation in a study of shifting cultivation in Zambia.

variables like forest clearing. Whereas population is endogenous in the first, it is exogenous in the second model.

(ii) Technological progress: In an open economy model technological progress will increase the profitability and therefore expand the agricultural sector. In a "full belly" model technological progress implies that the subsistence requirement can be met by cultivating less land.

(iii) Increased risk: In the open economy case increased risk makes risk-averse farmers reduce the scale of the risky activity (farming). This hypothesis is supported by, among others, Elnagheeb and Bromley (1994) in a study from Sudan. In the subsistence case increased risk implies a larger area under cultivation as risk-averse farmers would aim to be on the safe side of the subsistence requirement.[7]

The underlying assumptions are often not clearly spelled out, and they turn out to be more significant than might appear at first sight. Many policy recommendations and arguments in the popular and partly also the academic debates are grounded on the subsistence (or even "full belly") assumption, and policies based on this may produce unintended results.

It is commonly argued that the subsistence model may be the most appropriate for "traditional" economy, whereas the open economy model gives a better description of a "modernized" or "commercial" economy (Holden, 1993; Stryker, 1976). Definite tests of the subsistence versus the open economy hypothesis are difficult to formulate, and are rarely undertaken in empirical work (López, 1992).

These models are stylized descriptions, and it is often necessary to draw on elements from several approaches. We would, nevertheless, argue that *in our case* the open economy approach gives the best explanation and has more predictive power; therefore we use this as the *main* framework in the discussion. One could further argue that the open economy approach is becoming increasingly applicable also for other areas of frontier agriculture for two reasons in particular: traditional agrarian societies are increasingly being integrated in the larger market economy, and commercialization of village life creates increased cash income "needs".

If one also considers *migration*, the open economy assumption would clearly give a more realistic description of frontier agricultural systems. A key variable in migration decisions is the difference in expected income between the old and new locations. Related to this, the difference between the subsistence and the open economy approaches is also a reflection of the time

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7 One possible behavioural assumption for subsistence farming under risk is that farmers minimize the probability of yield below a subsistence requirement, or that they minimize labour input, given a predetermined acceptable probability for output falling below subsistence (safety first models). See for example Roumasset (1976) for a more detailed discussion.

horizon for the analysis: the open economy model is more relevant for the study of long-term effects.

3.2 A simple framework for land rent capture

To organize some of the arguments in the deforestation debate and the discussion of our case, we develop a simple framework for land rent capture to explain agricultural expansion and deforestation.[8] *Land rent* is defined as the surplus or profit to the owner of the land, that is the gross value of production minus all costs of production, except for land.[9] In particular we want to include costs related to the location of the land, for example, transport of output, and walking back and forth to the fields. Naturally, the location or distance costs are directly correlated with the distance from, say, the village centre, thereby causing land rent to increase with accessibility. More formally, we can define land rent as:[10]

$$r = pX - wL - qD$$

r	land rent per hectare (ha);
p	price per unit of output;
X	output per ha (reflecting the technological level, soil fertility, etc.);
w	opportunity cost per unit of labour (wage in alternative employment);
L	labour input per ha;
q	costs per ha and km related to distance or location of field;
D	distance in km from the village center to the field.

The relationship between land rent and distance is illustrated by the left curve in Figure 1. Keeping the other factors constant, land rent declines as distance increases, and eventually reaches zero. This is the *rent gradient* or *bid-rent curve*[11]. Given that people are free to move and

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8 A comprehensive and formal treatment of different models based on the open economy assumptions is found in Angelsen (1994; 1996b).

9 The discussion of land rent has a long history in economics, and goes back to the work of Ricardo and von Thünen during the first part of the 19th century. The presentation here is based on the von Thünen approach, where *location* is the key variable for differences in land rent. Ricardo focused on the *quality* of land.

10 Some of the simplifications behind this definition are: (a) We only include two types of costs: labour and location costs, which are the most important in frontier agriculture. (b) X and L are assumed to be fixed per ha. Thus, we do not discuss the decision of optimal labour input, nor decisions on cropping and fallow periods. The rotation aspect of shifting cultivation is ignored here to keep the presentation simple. These assumptions are relaxed in Angelsen (1994). (c) We consider one homogenous agricultural product, which may be thought of as a single crop or a fixed combination of crops. (d) Land has the same quality. Differences in fertility would add another dimension to land, in addition to location. The x-axis in the figure below would then be an index of fertility and distance. (e) Finally, it is a partial equilibrium approach in the way that we take the centres or villages as given. The analysis does not include the formation of new villages.

11 The bid-rent function (or curve) refers to the maximum rent someone would be willing to pay (or bid) for land at a given distance in a competitive market.

open new land, the basic premise is that *all forest land with a positive land rent will be cleared and transformed to agricultural production.*[12] The distance at which land rent is zero defines the *agricultural frontier* or *margin of cultivation* (point *A*).

The figure can be given both a micro (village) and a macro (regional) level interpretation. At the micro level, one may think of a village surrounded by forest. The main distance costs would be to walk back and forth to the field, and locations more than, say, 3-4 km may have too high distance costs to make cultivation worthwhile. A macro level, and more abstract, interpretation would be to let the *x*-axis in the figure represent all forest land within a larger area, ranked according to accessibility.

The policy lesson from this model is straightforward. Any changes in the variables which increase the profitability of frontier agriculture (i.e., move the curve to the right) will augment deforestation: higher output price (*p*); technological progress (*X* up and/or *L* down); lower opportunity cost of labour (*w*); and lower transport costs (*q*), which would particularly be influenced by the availability of roads and other infrastructure. The opportunity costs of labour (*w*) should be thought of in a broad sense, and would include other types of self-employment, wage labour, or -- in the case of potential migrants -- the income from farming or other occupations at their present place of residence.

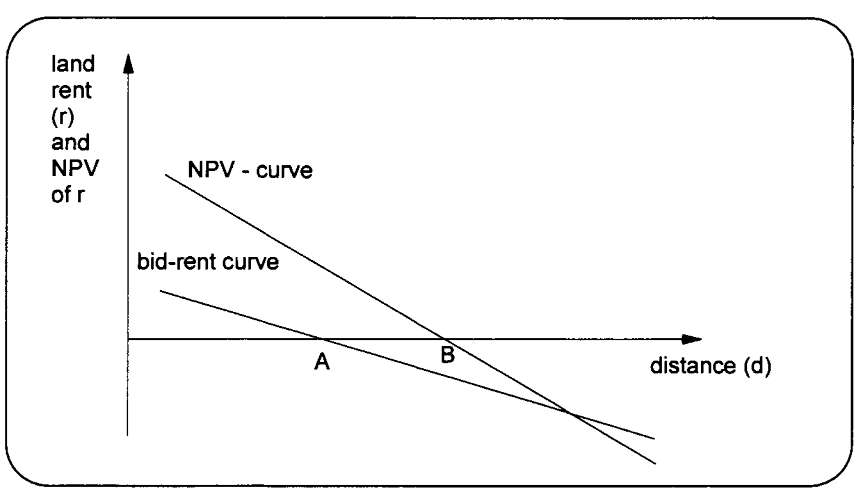

Figure 1. Agricultural frontier under two different property rights regimes.

So far we have neglected the issue of *property rights*, which has a prominent position in the debate on resource degradation in developing countries. The above description corresponds to a situation of open access, that is with free entry and no restrictions on land use. This applies *de facto* to most frontier areas, even though about 80 % of the closed forest in developing countries is formally owned by the state. Moreover, a common feature in many areas is that forest clearing gives the farmer claims to the cleared land, particularly if perennials are planted or the land

[12] There are land rent functions for other activities (logging, plantations, etc.), but we consider only the choice between agricultural production and virgin forest here.

"improved" in some other way. The protection of these rights in customary or national law varies considerably, but to make the argument simpler we assume that forest clearing gives *secure* private property rights to the land. How would this modify the discussion above?

Consider the following situation: the land rent at any distance is expected to increase over time (the bid-rent curve moves to the right in the figure), for example, due to technological progress or lower transport costs.[13] As clearing gives property rights, farmers not only look at the immediate benefits, but also at the future surplus from production, as summarized in the net present value (*NPV*). The expected *NPV*, at a particular time *k*, of an infinite stream of expected rents r_t^e, discounted at a rate *i*, is given by:

$$NPV_k^e = \Sigma_{t=k}^{\infty} \ (1+i)^{-t} \ r_t^e$$

This is illustrated by the right curve in figure 1, which gives a snapshot of the situation at time *k*. The *NPV*-curve intersects the x-axis to the right of the bid-rent curve. The reason for this is straightforward: consider point *A*, where $r_k = 0$. Because rent is expected to increase over time, the *NPV* at distance *A* must be positive, i.e., the *NPV*-curve lies above (to the right) of the bid-rent curve.

Competition among farmers for new land will ensure that all forest with a positive *NPV* is cleared. The agricultural frontier will now be where the *NPV* is zero (point *B*). Forest is cleared even if it has a negative rent the first years (i.e., forest between *A* and *B* in the figure). This loss will be outweighed through a positive land rent some time in the future. Early clearing is necessary to establish property rights; otherwise the land would be taken by others. We can therefore conclude that a system where clearing gives property rights will move the agricultural frontier beyond a pure open access regime (point *A*), and therefore stimulate deforestation.

This situation has been described as "the race for property rights" (Anderson and Hill, 1990), and has an historical parallel in homesteading in the United States.[14] Such a land race is unproductive from a social viewpoint because it gives a negative contribution to overall production (as land rent will be negative for the first years), and is a kind of rent-seeking. The principle reason for the inefficiency is the link between resource use (forest clearing) and allocation of property rights.

In addition to the factors included in the equation for land rent above, we have now added two others: the property rights regime, and farmers' expectations about the variables that determine

[13] This may not necessarily always be the case. Land degradation may reduce land rent over time.

[14] Homesteading was officially introduced with the Homestead Act of 1862 and ended in 1934 (Anderson and Hill, 1990).

future land rent.[15] The factors influencing the *NPV* and thereby the extent of forest clearing for agriculture are summarized in table 2.

Variable	*Effect on land rent, agricultural frontier and deforestation*
1. Higher agricultural price (p)	Increase
2. Technological progress (X up or L down)	Increase
3. Higher opportunity cost of labour (w)	Decrease
4. Higher transport (access) costs (q)	Decrease
5. Property rights regime - clearing gives property rights	Increase
6. Expectations about higher land rent	Increase

Table 2. Factors affecting the net present value (NPV) of future land rent.

3.3 Deforestation in Southeast Asia

How does this framework compare with the deforestation history of Southeast Asia? We discuss briefly two of the above factors: the opportunity cost of labour and distance costs (accessibility). Other factors will be dealt with in relation to the case study from Sumatra.

Agricultural expansion in the uplands is often caused by *push-migration* from the lowlands. In the Philippines, about one third of the population is located in the uplands, of which about 50 % farm on forestland (World Bank, 1989). The basic push-factor is the limited sources of income (low w) for a large proportion of the people in the lowlands, caused by such factors as high population growth, inequitable land distribution, and landlessness.

Population growth may therefore be included in our framework as far as it lowers the opportunity cost of labour, thus making more forest conversion profitable. The root of the problem is that frontier agriculture may act as an employment residual. Thus, the solution to the problem of deforestation is to be found as much outside the upland agricultural sector in providing attractive alternative employment opportunities for potential migrants. This is the 25 year old wisdom of the Harris-Todaro (1970) migration model: the solution to the migration problem is not as much in the immigration sector, where the most pressing problems are located, as in the emigration sector.

Poverty is often cited as the main cause of environmental degradation in developing countries. The most typical characteristic and cause of poverty is a low value of the most important -- and often only -- asset of the poor: labour. The lower the opportunity cost of labour, the further away people would be willing to clear forest. In this context, the poverty of people cultivating on

15 Another factor which is important in determining the *NPV* is the discount rate. In our model a higher discount rate would actually *reduce* forest clearing, as relatively more weight is put on the present (and negative) land rent. We have not included this in the further discussion as it is hard to find empirical evidence on the role of different discount rates in determining forest clearing.

marginal forest land is a reflection of their limited alternative income opportunities rather than the conditions on site.

Variations in accessibility (q) are a very significant factor in a cross-section analysis of deforestation in Southeast Asia. Thailand has halved its forest cover over the last three decades (53 % in 1961 to 26 % in 1991), one of the most rapid deforestation rates of any country for any period of history. A large share of this loss can be assigned to state-promoted agricultural expansion facilitated by large scale road construction (Hirsch, 1995). Laos, at least until recently, provides an instructive contrast to Thailand. Large areas of the country remain inaccessible, and the country has a relatively good forest cover (slightly less than 50 %). The situation over the past decades could be described as lack of "development", in the conventional sense. Economic reforms since 1986, however, include stimuli of smallholder commercial agriculture and an extensive program of road construction. Thus it may only be a matter of time before Laos repeats the Thai experience.

Finally, the *logging-shifting cultivation tandem* is frequently used to explain deforestation. Selective logging is a very extensive activity, providing access to previously inaccessible areas by its network of roads. Grainger (1993) and others argue that agricultural expansion following the logging frontier has been one of the main vehicles of deforestation in Asia. Norman Myers has even estimated, somewhat speculatively, that for every cubic meter of harvested timber 0.2 ha of forest is destroyed by migrating farmers (Colchester, 1993: 7). This contrasts with the situation in Amazonia, where logging follows the farming frontier.

4 A case study from Seberida, Riau, Sumatra

4.1 The study area

This part of the paper is based on data collected during one year's fieldwork in 1991-92 in the district (*kecamatan*) of Seberida in the regency (*kabupaten*) Indragiri Hulu in Riau province, Sumatra, Indonesia, cf. figure 2.[16] Seberida is 2 800 km^2 in extent. In the south, a hill massif, the Tigapuluh Hills, runs across the border of Jambi and Riau, and takes up approximately 1 000 km^2 of the district. The elevation of this hill massif is mostly below 300 m, but the terrain is rugged, and some of the hills reach 7-800 m. This area was designated as a Priority 1 Nature Reserve in the National Conservation Plan of 1982, but this has not yet been implemented. The north and east parts are covered by flat, swampy land, whereas the western part is dominated by the low undulating country of the Cinaku valley. The two main rivers in the district are the Cinaku, draining into the Indragiri, and the Gangsal, a tributary of the Reteh river. The climate is

[16] The fieldwork was part of a larger interdisciplinary project -- the Norwegian-Indonesian Rain Forest and Resource Management Project (NORINDRA). This section draws on NORINDRA (1992); see also Sandbukt and Wiriadinata (1994).

characterized by abundant rainfall (about 2 800 mm annually), high humidity, and high temperatures.

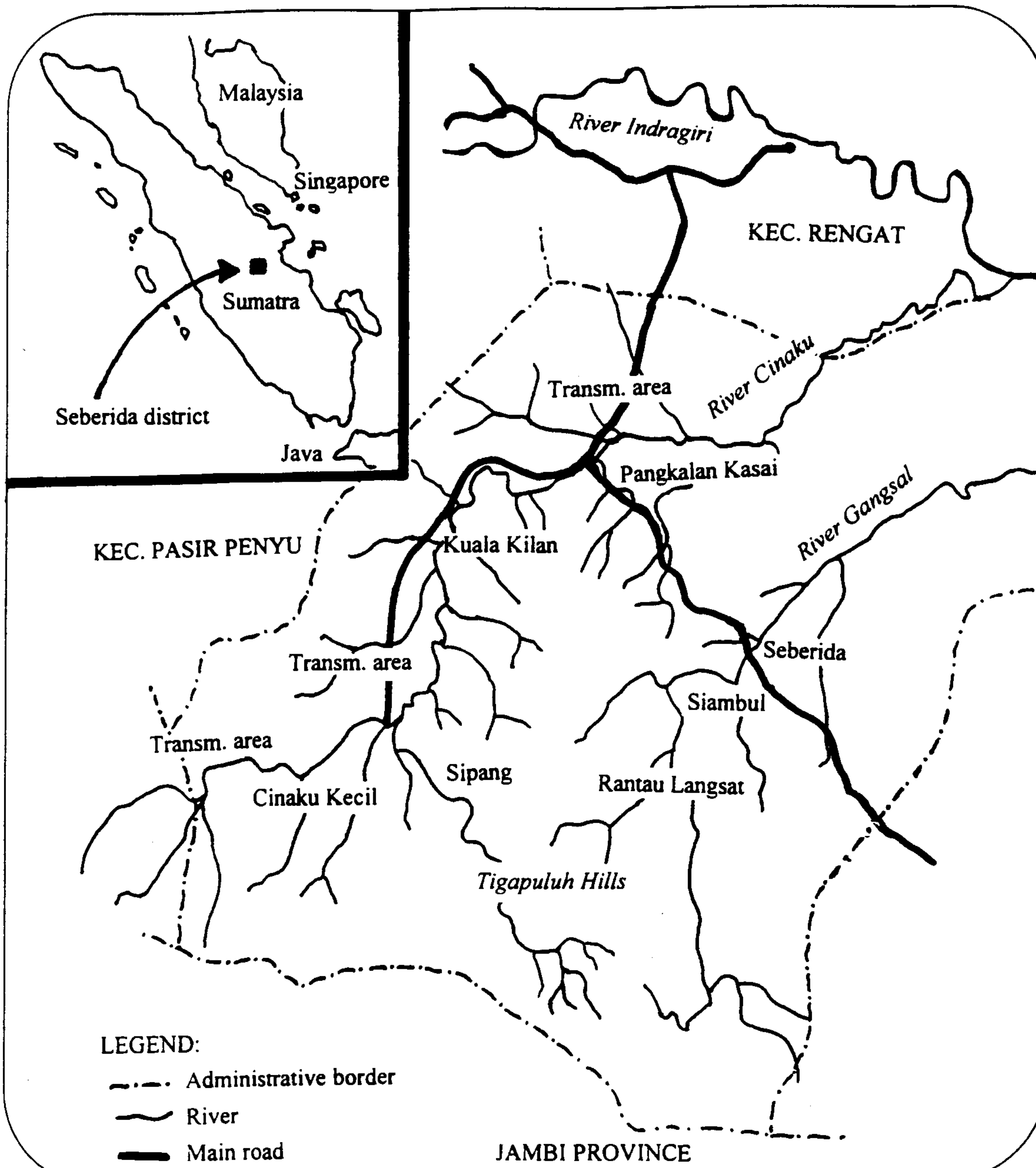

Figure 2. Map of the district (kecamatan) of Seberida.

The natural vegetation consists of lowland rain forest and swamp forest. Along the roads and rivers, the vegetation is a mosaic of secondary forest, swiddens, and traditional rubber forests. Traditional subsistence has been based on shifting cultivation and collection of forest products, but during this century forest collecting has increasingly been replaced by swidden-based rubber planting. Traditional shifting cultivation allows farmers to put land from the common forest into individual use, and obtain usufructuary rights according to customary (*adat*) law. These rights are strengthened by the planting of perennials.

Permanent cultivation is found in the transmigration settlements (Government-sponsored migrants from Java and Bali) along the Cinaku valley. These are partly covered by *Imperata* grassland (*alang-alang*), a fire climax vegetation, because permanent rice cultivation has faced severe problems. The majority of transmigrants in many settlements depends on off-farm work outside Seberida for their survival, and a large proportion have returned to Java.

The population density has been relatively stable throughout most of this century. The censuses of 1930 and 1961 show a density of slightly above 3 persons/km^2, the ratio increasing to 4 in 1980, and 5.5 in 1991, which is still not very high (14.3 including the transmigration settlements).[17] There are at present more than 41 500 inhabitants in Seberida. During the 1980s, the population in Seberida increased by 13.1 % per year, which is extremely high compared to other districts. The growth was mainly due to the establishment of 15 transmigration villages in the drainage area of the Cinaku river. The transmigrants now comprise more than 60 % of the total population.

4.2 The household survey

The focus of the present study is on the non-transmigrant part of the population. An extensive survey of 196 randomly selected households in eight (out of 20) villages provides most of the data used. The survey was done by two interviews, the first after the planting of rice (September - November 1991), and the second just after harvesting (January - February 1992). It concentrated on swidden cultivation, rubber tapping, collection of forest produce, and off-farm economic activities. The emphasis was on the situation in 1991, supplemented with basic data on shifting cultivation for the period 1985-1991, and farmers' plans for 1992. A longer time series would have been desirable. Informal interviews and secondary data reveal, however, a relatively high stability in the "tree crop swidden cultivation" (Barlow, 1991) system until the mid-1980s, as reflected in the population density figures above. This allows us to focus the analysis on changes since the mid-1980s.[18]

The villages were selected to obtain a representative picture of the variation in socio-economic and cultural adaptations within Seberida. Two criteria commonly used for the classification are

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[17] See Østergaard (1994) for a discussion of the history of the district.

[18] The uncertainty of quantitative data collected from interviews should be acknowledged. Our experience was that we got fairly accurate information on concrete questions on, for example, opening of swidden in a particular year, rubber planting, and rice yield. Thus retrospective interviews for the survey period of seven years is not expected to be a significant problem, since swidden cultivation is a, or *the*, major event that year. The answers were more unreliable for some of the more hypothetical or abstract questions included in the survey, for example, why farmers did not switch to wetland rice, or how they would respond to a price change. Most of these are not included in this paper. An additional statistical problem arises when using time series. The households in the survey are those living in the village at the time of the survey. Figures for the years before 1991 have been multiplied by a factor reflecting the population growth, thus they should give an unbiased estimate of the percentage of households in that particular year that opened swiddens.

land scarcity (or population density) and remoteness (or market access).[19] In addition, we have in the analysis distinguished between the ethnic groups of Malay and Talang Mamak (TM), the latter constituting about 8.5 % of the traditional (nontransmigrant) population.

Population density and central location are not perfectly correlated; some villages in upper Cinaku are unfortunate to have both a remote location and relatively high land scarcity (e.g., Cinaku Kecil). Village level data for population density are not included because they are poor indicators of land scarcity.[20] The division into land-abundant and land-scarce villages is therefore based on both population density and on other indicators and informal information.[21]

In table 3 we distinguish between three main zones of villages, according to remoteness and ethnicity. This categorization reveals some significant differences in the income profile between the zones, where the order of listing roughly indicates a general development over time. The Talang Mamak group, mainly living in remote areas, have a tradition of hunting and gathering forest products. These include wild growing rubber (*jelutung* or *Dyera costulata*), various species of rattan, dye from dragon's blood rattan (*jernang* or *Daemonorops spp.*), and a number of animals (wild boar, deer, etc.). Forest products are still the main income source (35 % of total income), but rubber (*Hevea brasiliensis*) is becoming increasingly important (29 %). The Siambul village was established under a resettlement program for the group, and the villagers have adapted the more widespread rice-rubber cultivation, while maintaining a substantial income from forest products. A similar development has also taken place among the TM population in the lower Rantau Langsat, whereas the settlements upstream (Datai area) still have their traditional hunting and gathering practice as the main source of livelihood. Rubber planting has, however, started also in this area in recent years.

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19 See, for example, Pingali *et al.* (1987).

20 Official data follow administrative borders, which are not respected by shifting cultivators. Nor is all land within the village necessarily suitable for shifting cultivation because of the slope, distance from settlements, swamps, logging operations, protection forest, plantations, etc.

21 Three of the eight villages in the survey are categorized as land scarce (Cinkau Kecil, Kuala Kilan, Pangkalan Kasai), with an average population density of 9.3 persons/km^2, whereas five are land abundant (Sipang, Seberida, Siambul, Rantau Langsat - Malay, Rantau Langsat - TM) has an average of 4.3 persons/km^2.

Zone[1]/ Variable	*Talang Mamak (TM)*	*Remote Malay*	*Central Malay*	*Total Seberida district*
Villages in survey	Rantau Langsat (TM), Siambul	Rantau Langsat (Malay), Sipang, Cinaku Kecil	Seberida, Pangkalan Kasai, Kuala Kilan	
Population in the zone	1,311	5,794	8,301	15,406
Annual pop. growth 1980-1991	-0.5	2.5	3.6	2.8
Pct. clearing swidden	91	74	49	61
Pct. tapping rubber	62	73	40	53
Average household income (Mill. Rp)	1.4	1.4	2.2	1.9
Income from major activities (pct. of total):[2]				
- rice & other annual crops from swiddens	22	20	14	16
- rubber tapping	29	42	16	23
- fishing	10	10	5	7
- forest products	35	5	4	7
- off-farm income	4	23	61	48

[1] The main criteria for remote-central classification are whether the village can be reached by car/trucks throughout the year, and distance from the district centre (Pangkalan Kasai).

[2] The exchange rate Rp/USD was about 2 000 at the time of the survey. The income figures include both production for sale and for direct consumption (local market prices). The value of (non-timber) forest products and fishing is the most difficult to get data for, and there may be an underestimation, at least for some products for some villages. We have included the five main sources of income, excluding income from minor sources, like animal husbandry and homegardens.

Table 3. Key variables for different zones of villages in the Seberida district (1991). Sources: Household survey and Seberida district office (Kantor Camat).

The second zone is the remote Malay villages, where rubber is the dominating income source (42 % of total income), and is likely to become even more so in the future. The central Malay villages comprise the third zone, where off-farm income accounts for 60 % of total income. The income from rice and other annual crops planted on the swidden fields counts for 16 % of the income on average in the Seberida district, ranging from 6 % in Pangkalan Kasai to 25 % in Sipang. Rubber has increasingly become the main agricultural crop, now accounting for 23 % of total income.

We found large variations in average income between villages, particularly between the remote areas (Rp 1.4 million/year) and the central ones (Rp 2.2 million/year). The entire gap is explained by differences in off-farm income, which counts for almost half of total income on average. The highest household income is observed in the Seberida village (almost Rp 3 million/year), fortunate to have both land abundance and a central location with relatively good off-farm income opportunities. Two major off-farm income sources in this village are trading -- mainly owners of small shops (*warung*) or rubber dealers -- and employment with the logging company which operates in the area.

4.3 Swidden-rubber cultivation

Most of the shifting cultivation practice (*padi ladang*) in Seberida can be defined as a *bush-fallow system* (fallow period from 5 to 10 years), but also with a significant share of *forest-fallow* (fallow length of more than 10 years, see Rutenberg, 1980). This demonstrates that the shifting cultivation system in Seberida is at a relatively early stage in its evolution, implying that the "degradation syndrome" has not (yet) occurred.

The output from tree crops swidden cultivation can be divided in three groups: dryland rice, other annual food crops, and rubber. Rice is the main short-term output, and is considered the main reason to open swidden. Several other food crops are also planted during the first year. Cassava is cultivated by a large proportion (particularly the TM population), and has advantages over rice in terms of pest and drought resistance. Other plants include maize, sweet potatoes, and a variety of vegetables for consumption. When rubber is planted on the swiddens, this is done during the first year as there is little competition between rubber seedlings and annual crops.

7 out of 10 households cleared forest for swidden cultivation at least one of the last two years (1990-1991), the share being close to 100 % in some remote villages. This reflects the better availability of other income and employment opportunities in central areas, whereas land is generally more abundant in the remote areas. The average rice output per swidden is very low, only around 480 kg per swidden or 400 kg per ha in 1991 (average swidden size is 1.2 ha), and with huge variations (high yield risk).[22] This is sufficient for only 4-5 months consumption on average. The average local market value of rice and other annual crops from one ha is about Rp 250 000 (USD 125). The low yield is a reflection of the poor soil quality (acidity) in the area, as well as problems related to pests, particularly wild boar (forest pig).

If rice cultivation is both highly risky as well as low-yielding, why do people continue? First, it is a reflection of the limited availability of alternative income sources, implying a low opportunity cost of labour. Second, opening of swiddens is necessary to plant new rubber, which has much higher profitability. Third, whereas a large majority of the farmers in the survey agreed that growing rice was the most risky activity, with low income compared to the work involved, they also like the work. 75 % said this was the type of work they preferred. Rubber showed the opposite picture: the risk is low, 69 % consider this the most profitable activity, but only 20 %

[22] This compares to 1 926 kg/ha for Riau and 2 110 kg/ha for Indonesia for dryland rice in 1990 (Central Bureau of Statistics, 1991: 179).

rank this as the work they preferred. Finally, farmers also have preferences for producing their own food.

8 out of 10 households have rubber gardens, more than 97 % being planted with traditional, low yielding trees (*karet rakyat*). The number having mature rubber gardens that can be tapped is much lower, reflecting a sharp increase in rubber planting from the mid-1980s. The average size of rubber holdings per household for those who have rubber gardens is 2.5 ha for mature rubber (46 % of the households), and 3.4 ha for immature traditional rubber (64 %). In addition 11 % had immature, high yielding rubber planted through the World Bank and Government funded Smallholder Rubber Development Program (SRDP), with an average of slightly more than 1 ha per household. The area of rubber holdings by the non-transmigrant population is about 12 000 ha, which is about a quarter of the secondary forest and 4.3 % of the total area of these villages.

An average of about 600 rubber trees are planted per ha. The mortality rate is, however, very high: two thirds of the original trees have died for mature gardens, and one third for immature gardens. Thus, the present rubber production system is quite extensive, and has considerable potential for intensification. The reported average yield is 366 kg/ha dry rubber, close to the average for Indonesia (364 kg[23]), with a farm gate value of about Rp 340 000 (USD 170). The yield is significantly higher in land-scarce areas than it is in land-abundant areas -- 445 and 286 kg/ha, respectively. The average annual income from one ha of tappable rubber garden (Rp 340 000) exceeds the income from the annual crops (mainly rice) planted on the first year on the swidden (Rp 250 000). Moreover, traditional rubber can be tapped for 30-40 years after an initial maturation period of 10-12 years, whereas rice presently is harvested in only one out of about every nine years.

4.4 Recent changes in the exogenous environment

Whereas some of the basic features of the swidden-rubber system have been more or less constant over several decades, the last decade has brought a number of significant changes in the exogenous environment of the shifting cultivators, as summarized below:

(i) Increased land claims from external users, i.e., government sponsored projects. Land claims have come from mainly three sources: First, *logging* operations started in the area in the 1970s. Generally, the effect of logging on land scarcity for swidden cultivation has been limited, partly because logging is targeted on primary forest, whereas most swiddening reopen secondary (fallow) forest. Moreover, logging roads provide access to new areas, and may actually increase land availability. Some farmers have in recent years opened swiddens along logging roads.

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[23] Central Bureau of Statistics (1991: 212-214). This figure includes all types of smallholdings, whether planted with traditional or higher yielding rubber varieties. The latter type covers about 15 % of the total rubber area of smallholders.

Second, 15 *transmigration* settlements have been established since 1980, occupying about 26 000 ha. The transmigration establishment had several impacts on the traditional economy: (a) increased land scarcity where fallow forest and rubber gardens were appropriated to the transmigration development; (b) improved infrastructure, particularly roads; (c) competition for forest based resources, particularly rattan; and (d) increased availability of consumer goods.[24]

Third, the establishment of *plantations* (oil palm) is of more recent date, but may become the most important external land claim in the future. The majority of workers on the plantations are likely to be drawn from the transmigration settlements.

(ii) Improved infrastructure and market access, and changes in relative prices. There was a substantial improvement in roads during the 1980s, primarily due to the logging and transmigration projects. Several weeks of transport by river has been replaced by a few hours transport by road. Local market prices of rubber still vary by 25-30 % between the central and remote areas of Seberida. Better market access means higher prices for cash crops, whereas consumption commodities become cheaper. Thus, it will be more profitable, *ceteris paribus*, to move from production based on self-consumption toward cash-crops and more specialized production. Moreover, world market rubber prices increased steadily from 1985 to mid 1988, after which they leveled off and stabilized at the 1985-86 level. The increase, even if temporary, may at the time have given a strong incentive for rubber planting and expectations about high rubber prices in the future.

(iii) Declining profitability of non-timber forest products. Collection of forest produce has traditionally been a significant income source. Rattan collection was a major source of cash income 5-10 years ago, particularly in the more remote areas where as much as half of the households were engaged in rattan collection. Today very few find it attractive: there has been an over-exploitation of the resource, not by the local Malay (and Talang Mamak) population alone, but by the combined effect of the collection by these people, the transmigrants in the area, and people from outside Seberida. Furthermore, the export ban on raw rattan, introduced in July 1988, caused the farm gate price to drop by around 50 %.

(iv) Population growth. The population in the 20 traditional (non-transmigrant) villages grew from 11 413 in 1980 to 15 406 in 1991, that is an annual growth rate of 2.8 %. Whereas the household survey shows a substantial male immigration, we do not have data to determine the *net* immigration. However, a growth rate of 2.8 % is comparable to the natural population growth rate in rural Indonesia, indicating that the net migration was low.

(v) Centralized, legal land rights system replacing customary (adat) law. The tension between the customary (*adat*) system of usufruct land rights and a centralized, legal system, uniform to all

[24] See papers in Sandbukt and Wiriadinata (1994) for a further discussion of the transmigration in Seberida.

Indonesia, has increased. All forest in Indonesia is *de jure* state property according to the Basic Act on Forestry of 1967, but lack of management and enforcement makes large parts of forests *de facto* open access, unless some forms of communal management exist.[25] The *adat* law gives usufruct rights to forested land planted with perennials after clearance. Even in the case where no perennials are planted, those who cleared the forest initially have a priority for later clearance. Indonesian law states that any plot cleared and overrun by secondary forest through lack of tending for more than two years becomes communal property and can be handed over to a third party on request, given the agreement of the village head (Mary and Michon, 1987: 46). More important, customary rights have *not* been respected by logging, transmigration, and plantation projects.[26] The result is a movement towards an open-access-like situation.

Related to our definition and discussion of land rent in section 3, the recent development clearly provides an example where land rent has risen: the rubber price has increased, and transportation or travel costs have decreased. The opportunity cost of labour has also decreased, because of the declining profitability of forest produce, and population growth not absorbed in the off-farm economy.

4.5 Shifting cultivators' response and changes in adaptation[27]

The changes above have resulted in significant modifications in the shifting cultivators' adaptations. We employ a number of indicators to illustrate these changes, which -- when added up -- have resulted in a transition from a relatively stable rice based shifting cultivation system to a smallholder rubber system increasingly encroaching on previously unused old-growth forest. The trends for 1985-91 are summarized in Figure 3.

1. Increasing share of households opening swidden. About 42 % of the households opened swidden in 1985; this share increased to 61 % in 1991. The rise has been sharper in the land abundant villages. The increase essentially took place during 1987-89, whereas the proportion opening swidden was stable during 1985-87 and 1989-91.

2. Increased rubber planting. The other apparent trend is a sharp increase in rubber planting on swiddens after rice and other annual crops have been harvested for one year. During 1985-86 about one third of the swiddens were planted with rubber. This has increased steadily to more than 90 % in 1991. Most of the swiddens are therefore now transformed into smallholder rubber gardens.

[25] See Angelsen (1996a) for a discussion of different land right regimes.

[26] Indonesian law distinguishes between *hak milik* (rights of ownership) and *hak ulayat* (rights of avail). Whereas the Basic Agrarian Laws of 1960 explicitly acknowledge the *hak ulayat*, it also states that this recognition must be in accord with national interests and unity. Swidden fallow land is normally classified as *hak ulayat*, and this right has routinely been overridden when in conflict with any government supported project (see Dove, 1987).

[27] See Angelsen (1994; 1995) for a more detailed discussion.

3. Fallow period. The increased proportion of households opening swiddens and the increased rubber planting have an impact on land availability and therefore other characteristics of the swidden system. A slight downward trend can be observed up to 1989 in the fallow period (8 years), after which it increases to about 12 years. Data about the farmers' plans for 1992 show a further increase in average fallow period to 18-20 years, a reflection of an increasing share to be opened in old secondary forest of more than 35-40 years (*belukar tua* or *kerimbaan*).

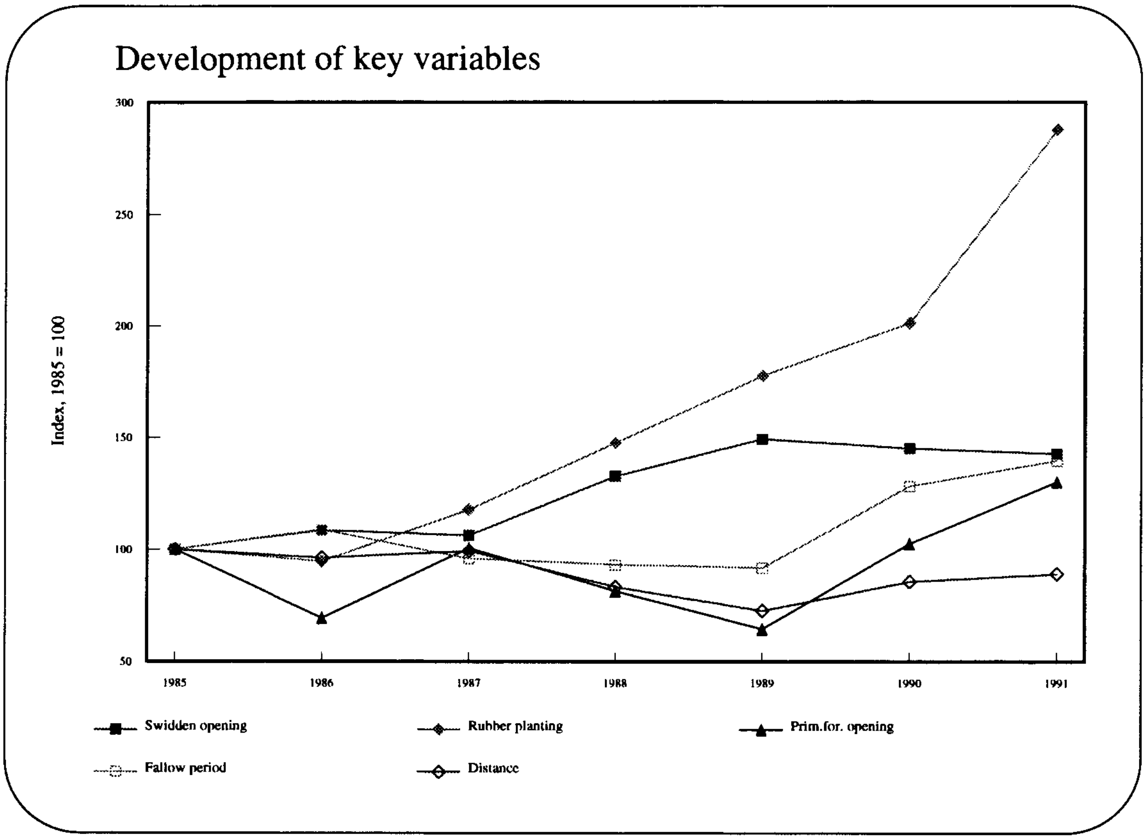

Figure 3. Development in key variables of the shifting cultivation system in Seberida.

4. Type of forest cleared. Primary forest clearing decreased from 1987 to 1989, whereas it increased substantially from 7 % in 1989 to 13 % in 1991. Data about the farmers plans for 1992 confirm the trend of increased clearing of primary forest. As there is, almost by definition, much less primary forest left in the surroundings of the land scarce villages, the increase mainly takes place in the land abundant (and remote) areas. On average, almost 19 % of the swiddens here were opened in primary forest, the share in one village (Sipang) being 44 %.

5. Distance from village to swidden. Distance from village to swidden is positively linked to the fallow length and proportion of primary forest cleared. Thus, from the two previous figures we should expect to find a decrease in the distance up to 1989, and increase thereafter, which is exactly what the data show. Data for 1992 indicate a further increase from 1.9 km in 1991 to 2.4 km in 1992. We would have expected a sharper increase after 1989. The desire to plant rubber on the swiddens means, however, that land located far away from the village (more than 3-5 km) will be less valuable, given that the tapper has to go back and forth every tapping day and carry the rubber to the village.

6. *Size of swiddens.* The average size of the swiddens has not changed much during 1985-91. It varied between 1.1 and 1.2 ha. Generally, the size of the swiddens is higher in land abundant areas (1.3 ha in 1991) than in land scarce areas (1.1 ha). We also find a significant difference in size between swiddens opened according to type of forest opened: in 1991 the average size of swiddens opened in primary forest was 1.65 ha.

The above factors increased the total forest cleared by shifting cultivators from about 1 400 ha in 1985 to 2 400 ha in 1991. A decomposition of this change can shed some light on the factors behind the increase in forest clearing (first order explanation).[28] Annual forest clearing can (by definition) be written as the product of three factors:

Total area cleared
≡Average size of swidden (7 %)
** proportion of households opening swidden (70 %)*
** total population (households) (23 %)*

The relative importance of these factors in explaining the increase in total forest clearing during 1985-91 is given in parentheses. The main factor is the increasing share of households that open swiddens. Population growth, often supposed to be the main factor behind (increased) forest clearing, accounts for "only" 23 %.

The primary forest clearing increased from 160 ha to 420 ha in 1985-91. In a similar way as for the total area cleared, the direct factors behind the increase can be decomposed into four factors:

Primary forest cleared
≡ Average size of swidden (19 %)
** proportion of households opening swidden (30 %)*
** proportion of swiddens opened in primary forest (39 %)*
** total population (households) (13 %)*

Here we find the main factors to be the higher share of swiddens opened in primary forest combined with the general increase in the share of population opening swiddens. We also note that the size of the swiddens opened in primary forest has increased substantially, contributing to 19 % of the increase. Again, population growth cannot explain much, only 13 %.

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[28] The decomposition can be done in two ways. One, the situation in 1985 can be used as a starting point. Inserting, one at the time, the 1991 values for the four variables into the identity give their relative contribution to the growth in forest clearing. The absolute contributions of each factors do not add up to the actual increase in forest clearing because of multiplicative effects. Two, the 1991 situation can be used as the starting point. The 1985 values for each of the variables are inserted, and their relative contribution calculated. Adding up using this method will overestimate the actual increase. The reported figures are averages of the two methods.

Population growth may obviously have indirect effects, i.e., it affects farmers decisions on whether to open swiddens, and the size and location of swiddens. Nevertheless, the implication of these figures is that the direct effect of population growth is relatively small, and the increased (primary) forest clearing should be explained by changes in other factors. The subsistence approach therefore seems less appropriate to explain the development in Seberida. Deforestation models like the one used by FAO (1993), where population density is the only explanatory variable, may produce very inaccurate predictions.

The farmers' response in our case is consistent with the open economy hypothesis, *but not necessarily inconsistent* with the subsistence hypothesis. One may argue that the response is due to a decline in other food or income sources in the period. The average income level among the local Malay and TM population, however, is substantially (about 50 %) higher than for the transmigrants, and for most households above the poverty line. There are also substantial income differences between households. This indicates that their objectives go beyond a pure subsistence requirement.

4.6 Discussion

The exogenous changes can be summarized as an increase in land rent, complemented by a weakening of customary land rights. The main responses of farmers have been increased (primary) forest clearing and increased rubber planting over the period 1985-1991. Figure 3 shows two phases in the swidden cultivators' response since the mid-1980s. During the period 1987-1989, swiddens closer to the village with shorter fallow period were opened. Returning to our framework in section 3, land rent in Seberida increased due to higher rubber price, lower opportunity costs of labour, and lower transport costs. The boost in land rent would be highest for land close to the village, making it the most profitable and important land to secure rights to. The increase in the relative profitability of rubber to rice made a location close to the village more important, as rubber will be tapped from these plots almost daily for decades and therefore have higher distance costs. Thus a closer location was traded for a shorter fallow and lower rice yield (rice yield is positively correlated with fallow length).

Land close to the village is limited, and a large part has now been occupied with rubber. The development after 1989 shows that farmers had to start going further away from the village to find forest that could be cleared, hence the increase in distance, fallow period, and primary forest clearing observed.

The sharp increase in rubber planting could be viewed from at least three perspectives found in the literature. These are complementary and, in fact, all fit into the framework discussed in section 3. First, it can be viewed as a rational response to increased profitability of rubber compared to other crops because of relative price changes and declining rice yield due to pest problems. There is abundant evidence throughout the developing world of peasants' responsiveness to changes in relative prices (e.g., Godoy, 1992).

Second, increased land scarcity is generally seen as a major driving force for agricultural intensification (Boserup, 1965; Rutenberg, 1980). The two most common evolutionary paths of land-use intensification for the humid tropics are (i) shortening of the fallow period and/or increasing the cropping period, and (ii) introduction of perennial crops. The first option will eventually lead to a permanent cultivation system, which "is technically possible and ... balanced systems can be achieved, but only at a high cost, and the question is whether these systems are economic from the point of view of the farmer" (Rutenberg, 1980: 67). The recent experience with permanent rice cultivation in the transmigration areas in Seberida illustrates the difficulties with this option. The transition from a shifting system with largely annual crops to perennial crops is relatively simpler and cheaper, and has in our case both environmental and financial advantages. The sharp increase in rubber planting, combined with the fact that the fallow period is increasing, indicate that the major development in the system is not toward intensification by shortening of the fallow period, but rather by introduction of perennials.

A third perspective is to view the switch to rubber and increased land clearance as a way to obtain and secure land rights, both according to customary and national law, as further discussed in Angelsen (1996a). The importance of this factor has increased due to the increased land rent. This approach is in line with the demand-induced models for development of more secure and individualized property rights (Hayami and Ruttan, 1985) or the evolutionary theory of land rights (Platteau, 1995). Such a development is a function of the value of land and how well this value can be captured under existing property rights arrangements. The situation described above is one of simultaneous intensification and development of individual property rights. This is a widely observed phenomenon when land increases in value (Feder and Feeny, 1993: 243). Furthermore, the security provided by customary rights is to a large extent determined by government policy. The lack of respect for *adat* law by the state drives farmers to establish claims that are more likely to be protected. Besides planting of rubber, farmers now increasingly obtain written titles to their rubber holdings, but this is a rather expensive option for the average farmer.

As noted in section 3, *expectations* about future land rent may be even more important than actual land rent. Expectations about increased future land scarcity, and therefore higher land values, seem to play an important role in our case. More than three quarters of the households expected increasing difficulties in finding suitable land for swiddens. The most common reasons as to why the households in the survey expected this development was increased rubber planting (89 %), population growth (72 %), the establishment of transmigration areas (32 %), establishment of plantations (14 %), and logging activities (7 %). We note the dominance of internal factors, i.e., the increased demand for land from the local population.

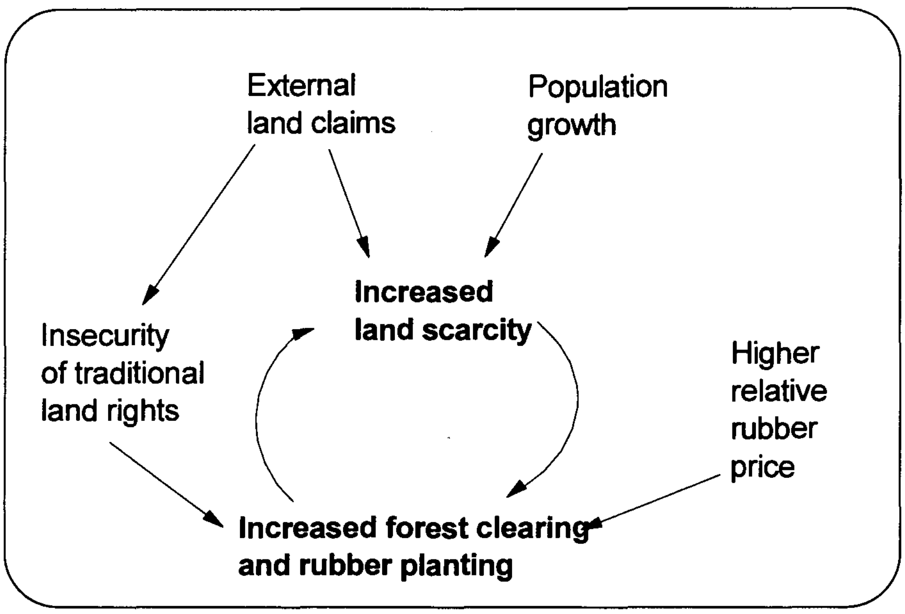

Figure 4. Dynamics of increased forest clearing and rubber planting.

The interrelations between the various explanations of recent developments are summarized in figure 4. Population growth and external land claims have been important factors leading to increased (expectations about) land scarcity. The scarcity has led to an intensification and securing of land rights through increased forest clearing and rubber planting. This development is spurred by the boosted profitability of rubber, and the decreasing respect for customary law by outside user groups and the state. Moreover, increased rubber planting in itself has a snowball effect on land scarcity, at least in the short run. Planting of rubber implies that farmers cannot practice a normal fallow cycle of 5-10 years, as the plots have been occupied by rubber trees. Thus, the land race or race for property rights is self-reinforcing. Land is becoming scarce now because people expect it to become scarce. The answers by farmers regarding factors behind land scarcity indicate that the internal dynamics now play the most important role in increasing scarcity of forest for agriculture, whereas external factors have been relatively more important in initiating the land race.

A crucial question is what will happen when farmers start receiving income from the presently immature rubber gardens? Will the proportion of farmers opening swidden decline and the expansion into primary forest area stop, or will the present trends continue? This will depend on a number of factors: the availability of land for expansion (influenced by, *inter alia,* the establishment of new plantations, conservation areas, etc.); the availability of off-farm employment; the rubber price; and immigration to the area. The recent completion of the East

Sumatran Highway through the Seberida district is likely to fuel immigration and increase the pressure on the largest remaining lowland rainforest area on Sumatra.

5 Conclusions

We have argued that the change in land rent is the single most important factor to understand and explain agricultural expansion. The land rent capture approach outlined in section 3 provides an alternative to the subsistence approach, and yields conclusions for policy design which differ from generally held views in the popular debate:

(a) Technical progress (e.g., intensification programmes) in frontier areas may increase forest clearing. Intensification programmes in a subsistence model have the potential for reducing forest clearing, as people can get their subsistence income from a smaller land area. However, the increased profitability of farming will attract more people, both through a shift from alternative income generating activities among those already living in the area, and through immigration.

(b) The development of off-farm jobs is crucial in limiting future forest clearing. The profitability of agricultural expansion is to a large extent determined by the availability and conditions of alternative employment.

(c) Improved infrastructure and roads reduce transport costs, thereby increasing land rent and forest clearing. This has been a significant pattern of deforestation in several countries throughout Southeast Asia, most commonly as a side-effect of logging or other large-scale projects.

The case study from Seberida, Sumatra basically shows a development in accordance with the land rent capture approach. In addition to the points mentioned above, which are all valid to the study area, some additional lessons can be learned from our case study:

(d) The transition from a rice based shifting cultivation system to a smallholder rubber system has several positive features. Smallholder rubber gardens provide an annual income per ha which is several times higher than the traditional rice based shifting cultivation system. The experience from Malaysia and elsewhere shows that even very intensive rubber production can be sustainable, in the sense that yields are maintained over time. The traditional smallholder rubber gardens preserve most of the ecological functions of natural forest. The development in Seberida should be seen in light of the accelerating land degradation occurring elsewhere as a result of non-sustainable attempts at intensification of shifting cultivation systems. If the present expansion into primary forest could also be limited, the transition from rice to rubber would clearly be a step toward more sustainable resource use. Indeed, introduction of tree crops in farming systems is often seen as an essential part in the development of more sustainable

agricultural systems in the humid tropics. We should note that in our case, the transition is not a result of any deliberate government policy. The development of a local economy heavily dependent on a single crop and its price fluctuations on the world market remains a concern, and some diversification of the tree crops would be desirable.[29]

(e) A large potential for sustainable intensification exists, but the incentives for intensification are limited. Rice output could be increased by growing rice (and other crops) twice on the same plot before fallow, and to some extent also by shortening of the fallow period.[30] The largest intensification potential is in rubber production. The yield could be augmented by increasing the number of trees per ha, and by planting higher yielding rubber varieties. As long as land is relatively abundant, however, the incentives for intensification are limited.[31] The situation in Seberida could be described as one where the *expected* land scarcity is clearly higher than *actual* land scarcity. This provides incentives for securing future land rights by forest clearing and rubber planting, whereas the incentives for intensification of rice and rubber production, mainly determined by actual land scarcity, are more limited. The incentives at this stage are to secure rights to new land rather than to intensify production on already cleared forestland.

(f) Government-sponsored land claims have a multiplier effect on forest clearing. Government projects (transmigration, plantation, logging, and mining) have several effects on the land use in the area. The direct effect on forest clearing is obviously the amount of forest being cleared by the project. A commonly observed indirect effect is increased forest clearing by shifting cultivators as a result of road construction. This has been of some importance in our study area, but less so than the weight given to this phenomenon in the general debate on tropical deforestation in the region. The main multiplier effect of external land claims has been in changing the expectations about future land scarcity, thereby increasing present forest clearing and rubber planting. The land race initiated is self-reinforcing, and is spurred on by the decreasing respect of customary land rights by the state.

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[29] Two other potentially negative aspects of this development is the likely reduced food self-sufficiency, and the reduced *on site* biodiversity if large areas are planted with more intensively driven rubber gardens. Again, this development must be compared to the realistic alternatives.

[30] There are limits to how short the fallow period could be before the "degradation syndrome" occurs. Although area specific data on this are not available, we believe there still is some room for a sustainable intensification through particularly planting rice twice on the plots before fallow or planting of rubber.

[31] Given the mixed experience with rubber intensification programmes (Barlow and Tomich, 1991), one should have realistic expectations about the possibilities of successfully introducing high-yielding varieties. Indonesia has in the past relied exclusively upon block planting projects. A low-cost dispersal approach, as advocated by Barlow, Shearing and Dereinda (1991), lowers the ambitions, but may provide better incentives to farmers to increase the productivity.

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Chapter 5

The Evolution of Private Property Rights in Traditional Agriculture: Theories and a Study from Indonesia*

Abstract:

The starting point of this paper is a universally observed tendency of common property to be replaced by private property in traditional agriculture. The paper seeks to explore the forces behind such a development. Four different theoretical approaches are discussed: neo-institutional economics, which focuses on increasing land value; Marxian, class-based explanations; a state-local perspective, focusing on predatory state intervention and lack of respect for customary law; and a cultural explanation based on a "commoditization of land" hypothesis. These approaches are discussed in relation to the development in the study area in Sumatra. A framework which integrates elements of all approaches is outlined, using a "demand and supply for institutional change" metaphor. In particular, the neo-institutional and the state-local approaches are found to be relevant to explain the evolution of private property rights. The paper also develops a formal analytical model which endogenizes farmers' decisions about tenure security.

* An early version of this paper was presented at the *Fifth Common Property Conference: Reinventing the Commons,* the International Association for the Study of Common Property, 24-28 May 1995, Bodø, Norway. I am grateful for discussions with and/or comments to the paper made by Turid Bøe, Rögnvaldur Hannesson, Lars Gule, Are Knudsen, Ottar Mæstad, Karl R. Pedersen, Ussif Rashid Sumaila, and Arne Tostensen.

1 Introduction: The Evolution of Private Property Rights (EPPR) hypothesis

"In the long course of historical development, economic societies can be viewed as moving in a general way from C [common property] to P [private property]" (Cohen and Weitzman, 1975: 310).

The starting point for this paper is a general observation of the replacement of common property by private property rights to natural resources. This seems to be valid both as a generalisation throughout history, as well as a description of processes taking place in many developing countries today. There exists a number of examples of successful management of resources held in common (e.g., Ostrom, 1990). My purpose is not to question these studies, indeed this paper should be complementary as it explores the forces that could lead to the weakening or disappearance of common property regimes.

A general proposition on the evolution of private property rights (EPPR) raises a number of relevant research questions:

1. To what extent is this proposition universally valid?
2. What are the forces behind such a development?
3. What are the effects on particularly economic efficiency (economic growth) and equity?
4. How can governments influence this development, either to limit, redirect, or promote and facilitate it depending on the governments' objectives?

This paper will mainly address the second question, but touch upon the three others, particularly the forth one in relation to the case study. The first question relates to a more fundamental one: is common property just a temporary stage in a more or less natural and optimizing evolution towards private property rights over natural resources? If yes, trying to preserve common property regimes may have negative consequences on both the productivity and the environment, as argued by Ault and Rutman (1979) in the context of land rights in Africa.[1] While this paper does not pursue the question on the universal validity of the EPPR hypothesis, our tentative answer would be a conditional "yes" for resources where exclusion is possible (i.e., has relative low costs). For resources with high exclusion costs, it may *not* be the case.

The discussion of the EPPR will focus on traditional agricultural societies, where typically some form of communal management of common property land is gradually moving towards a system of more individualized and well defined property rights. Compared to many natural resources, land is generally *not* a public good (non-rivalry in consumption), and the exclusion costs may be manageable (unlike for resources like fish, air, etc.). There is rivalry in land use, and exclusion is possible at reasonable costs.

How can the EPPR hypothesis be formulated more precisely? In this paper we argue that the EPPR implies a development characterized first and foremost by *individualization:* more rights are moved from the community to individuals (or households). Related to this are three other

[1] This view will be discussed further in section 3.3.

phenomena: there is a *specification* of the rights in the way that they become more explicit and detailed; there is a *formalization* in the way that the rights are increasingly embedded in the statutory law, not (only) customary law; and there is a *securing* of the rights for the rightholder. The latter could be made operational in the way that the risk (probability) of losing the land is reduced, but this would not always be the case as increased scarcity is associated with increased competition and claims from others. Rather it is the rightholder's *efforts* to protect the land that increase.

The evolution of private property rights is a central theme in the classical work on agricultural evolution by Boserup (1965). Her focus was on the role of population growth in inducing agricultural intensification and the accompanying changes in the property regime. However, "there has been little systematic empirical research on the development of property rights arrangement" (Alston *et al.,* 1995: 90).

The structure of the paper is as follows. Section two provides a discussion of the meaning of property rights, and of different property rights regimes. In section three I present four different views or positions on the EPPR: the neo-institutional economics (NIE) approach, where land value is a key explanatory factor; a Marxian, class-based explanation; a state - local perspective, including the tension between customary and statutory land law; and a cultural (ideological) explanation. These are not separate analytical approaches, nor are they mutually exclusive. The classification, however, relates to different positions and approaches in the debate on EPPR, and may be a useful clarification as such.

Section four provides a case study from a shifting cultivation (rice and rubber) based economy in a lowland rainforest area in Seberida district, Sumatra, Indonesia. First, we discuss Indonesian customary and statutory law, with a particular focus on the conflict between these two types of law. Next we describe the changes towards individualization and more secure land rights in the study area, and discuss various secular factors which may explain this development. More external land claims, population growth, and higher profitability of rubber have resulted in increased forest clearing and encroachment in primary forest, and securing of rights through rubber planting.

Section five tries to integrate the discussion of the previous sections, that is to see how the various elements from the four approaches in section three can be drawn together in a framework which can the be used to explain the development described in section four. This framework is mainly rooted within the NIE approach, but also includes the customary law - statutory law dichotomy in the model. It is argued that increased land value provides the main driving force towards individualization of the rights, and this force combined with the increase in external claims make farmers increasingly secure their claims in statutory law.

Section six summarizes the main conclusions of an agricultural household model with endogenous tenure security. The formal model is presented in the appendix. Tenure security is determined by the number of external claims, as well as decision made by the farmer about intensity of production and enforcement of property rights. An increase in external claims, which makes the rights more insecure, could result in a strategy of rubber planting, *increased* intensification, and increased efforts on enforcement (e.g., land certificates). Section seven concludes.

2 Property rights and property rights regimes

> "Property rights of individual assets consists of the rights, or the powers, to consume, obtain income from, and alienate these assets" (Barzel, 1989: 2).[2]

The property rights regime is a key institution in an economy. Property rights shape the incentives of individual resource users, and are therefore critical for economic efficiency (growth) and environmental conservation. The term "institutions" are in the literature used both in the meaning of "the rules of the game" as well as for "the teams playing the game". Following North (1990) we shall use it in the first sense, that is, to use institutions in the meaning of *rules, not organizations.* North (1981, chap. 15) distinguish between institutions at three levels:

1. *Constitutional rules*, or "the rules for making rules".[3]
2. *Operating rules*, or *institutional arrangements* created within the constitutional rules. The property rights arrangements are key rules here.
3. *Moral behavioural codes*, alternatively labelled ideology, culture, or cultural endowments.

Most analyses of property rights change (e.g., Feeny, 1993) take 1 and 3 as exogenously given, and study changes in the institutional arrangements. This may be justified by the much higher stability of the constitutional and cultural rules, something which also contributes to the stability of the operating rules. Another justification is simply that in order to build a theory, some variables must be kept exogenous.

The right to an asset should be understood as a bundle of rights. Three types of property rights are generally distinguished between in the literature (Barzel, 1989; Eggertsson, 1990: 34):[4]

1. *Use rights:* the rights which define the potential uses of land that are legitimate for an individual, including the right to transform it physically, e.g., through different agricultural crops and growing techniques.
2. *Income rights:* the rights to the income, and contract over the terms with other individuals.
3. *Transfer rights:* the rights to transfer the asset to another party.

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[2] Looking at the Chinese symbols for the content of a concept may sometimes be enlightening. The term "rights" or *quanli*, introduced into the Chinese language in the mid 19th century, was made up of two symbols; power (*quan*) and benefit or profit (*li*). Thus the term rights was taken to mean the power to enjoy the benefits from something. Note, however, that the Chinese word for land rights is to be translated to ownership, where the possibility to sell and buy land is central.

[3] Feeny (1993: 172)

[4] Bromley (1989: 187-190), based on earlier work by Honoré, distinguishes between eleven different categories of rights.

A property institution consists of a set of *rights* and a set of *duties* or *obligations*. Statutory rights are never unlimited, for example, the kind of uses permitted by the law is often restricted (e.g., not growing marihuana, or taxation of income). Restrictions of the rights that shrink the set of permissible uses will lower the economic value of the land.

Property rights will never be fully delineated because of *transaction costs*. Transaction costs can be defined as "the costs associated with the transfer, capture, and protection of rights" (Barzel, 1989: 2), or "the costs that arise when individuals exchange ownership rights to economic assets and enforce their exclusive rights" (Eggertsson, 1990: 14). One may distinguish between transaction costs related to three different activities (cf. Eggertsson, 1990: 15):

1. *Information:* costs associated with the search for information about the price, quality, and sometimes also quantity of economic goods.
2. *Contracts*: costs related to bargaining, making, monitoring and enforcement of contracts.
3. *Enforcement of property rights:* costs incurred by the rightholders efforts to protect the rights.

Unlike conventional economic analysis which regards such rights as absolute, the inclusion of *transaction costs* in the analysis of property rights gives that "rights are never complete, because people will never find it worthwhile to gain the entire potential of "their" assets" (Barzel 1989: 2). According to Barzel, the (security of) rights people have over an asset is a function of three factors: the rightholder's protection efforts (costs), other people's capture attempts, and the government protection.

Property arrangements are *social relationships* among individuals, "they link not merely a person to an object, but rather a person to an object against other persons" (Bromley, 1989: 202). The key element of this triadic relationship is the right of the owner to exclude others from the benefits related to the asset (use, income, and transfer rights). In short, property rights give a person the legal right to exclude others within the limits set by the law; to what extent these rights are protected is, *inter alia,* determined by the person's own enforcement of the rights. The latter will, as discussed later, be based on a calculus of the benefits and costs of better protection through his/her own enforcement.

The above is related to another key aspect of property rights, that is, the *residual right of control*, or the owner being the *residual claimant* (Grossman and Hart, 1986). The residual right of control refers to the right to make any decisions within the restrictions set by law and contracts with others. The residual claim or return is the net income from the asset, for example, the land rent (profit) from owning a piece of land. "Tying together residual returns and residual control is the key to the incentive effect of ownership" (Milgrom and Roberts, 1992: 291), because the decision maker (owner) bears the full consequences of the choices made.

Property rights exist along a number of dimensions, thus any classification represents a simplification of a complex reality. The most common distinction is according to the economic agent holding the rights. Based on this, one may distinguish between four different property rights regimes.[5]

1. *Private property*; an individual, a household or a *de jure* person (e.g., a company) hold the rights.
2. *Common (or communal) property*; a group of individuals, for example, a community, holds the rights. This can be further subdivided into:
   2a. *Unregulated* common property, which only limits the access to the resource; and
   2b: *Regulated* common property, which both limits the access, and impose and enforce rules for resource use.
3. *State property*; the state holds the property rights, which in some respects could be regarded as an extended form of 2.
4. *Open access*; no property rights exist (either *de facto* or *de jure*).[6]

The main distinction here is between situations *with* property rights (where the agent with the rights is either the state, the community, or an individual), and situations where *no one* has property rights, i.e., open access.

Whereas these four categories may help clarify the discussion on property rights regimes, real life regimes are likely to be a combination of these four. In describing actual property regimes a number of dimensions should be added:

- Which rights are included? The agent may not have all the three types of rights listed above, and within each of the three types of right the agent may only have some of all possible rights (for example, only certain uses are allowed). This is the case under customary land law throughout Indonesia (section four). Related to this is the fact that the agent may not be well defined; for example, individual households may use land in a particular way after consultations with the leaders of the community.
- Land may have different regimes governing different uses; for example, agricultural use may resemble a private property regime, whereas collection of forest products from the same land is governed by a communal management regime. Certain rights rest with the individual, whereas others rest with the community and therefore implies certain duties or obligations for the individuals.
- Property rights to land are normally based on either written, statutory law, or unwritten, customary (traditional) law. It is generally more difficult (costly) to enforce informal than formal rights through the legal system. Customary rights may also receive less respect from potential users outside the community, where the customary law has evolved and can be enforced, e.g., through social sanctions. Thus, the *enforcement* costs may be higher for customary rights, whereas the *contract* costs are lower.
- The security of the rights will also differ. In the most stylized form (as often has been the practice in conventional economic texts), the three first categories assume 100 percent security for the agent against third party intervention, whereas the open access case assumes no security. As noted above the security of the rights depends on a number of

[5] See, for example, Libecap (1986) and Bromley (1991).

[6] *Homesteading* could also be considered a separate regime, which is particularly relevant in frontier areas: land clearing/preparation gives private property rights to cleared land. Under this regime land is transferred from an open access resource (regime 4) to a private property resource (regime 1). See Angelsen (1994; 1996).

factors, including the owners enforcement efforts, and the protection given to these rights by the state, and its enforcement ability.

Classification of property regimes is complex because of the number of rights (and duties) in question, and the fact that different rights are held by different agents. Typically for some traditional societies (cf. section four), a farmer may have some use and income rights, but not the right to sell the land to outsiders. The formal ownership may rest with the village, whereas the most valuable rights, that is the use and income rights, are held by individuals or households. Should such a system be grouped as communal management or as private property? Too often in the literature it is grouped as the former, which means that the classification is based on just the third type of right (the transfer right). One could argue that it would be more logical to base the classification on the most important rights, which in this case rest with the individual.[7]

3 Theoretical approaches for explaining the EPPR

> "The common reason for the establishment of private property in land are deduced from the necessity of offering to individuals sufficient motives for cultivating the ground, and of preventing the wasteful destruction of immature products of the earth" (William Foster Lloyd, 1833).[8]

The purpose of this section is to provide a critical review of four different approaches to institutional change in general, and the EPPR hypothesis in particular. The approaches and the key element in each of them are:

1. Neo-institutional economics (NIE): Increased land value.
2. Marxian theories: Class struggle .
3. State v. local community approaches: Predatory state intervention.
4. Cultural changes: Commoditization of land.

These four approaches are not mutually exclusive. On the contrary, the purpose of section five is to integrate the elements of the different approaches that are relevant to explain the recent development in the study area. The approaches represent, however, four distinct views on what is the main driving force behind the EPPR, and the distinction is useful as such.[9]

3.1 Neo-institutional economics (NIE): Increased land value

Neo-institutional economics (NIE) represents an extension of the neo-classical economic research programme to include institutions in the analysis. Neo-classical economics here refers to the methodology of individual rational choice, that is, individuals act as if the maximize certain objectives subject to certain constraints. The approach implies methodological

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7 One common observation is that when transfer rights are given to farmers, they are very rarely used, that is land markets do frequently *not* develop when private property rights are introduced (e.g., Platteau, 1995). This indicates that the most important rights to the farmers are the use and income rights.

8 Quoted in Hardin and Baden (1977).

9 The division into four categories is to some extent based on subjective judgements. Bardhan (1989), for example, distinguish between the Marxist school, the property rights, transaction costs or Coase-Demsetz-Alchian- Williamson-North (CDAWN) school, and the imperfect information school. Further, the neo-institutional economics (NIE) school can be divided in several categories, as will be discussed below.

individualism, and rational behaviour in the sense of consistency between actions/behaviour and goals/preferences (ends-means consistency). The preferences are assumed to be exogenous (and normally also constant) in the model. The emphasis is on how changes in the constraints (choice set) affect behaviour and equilibrium outcomes. When we in this paper refer to "conventional neo-classical economics", it is the *practice* rather than the methodology we have in mind.

NIE is both concerned with how institutions influence behaviour by modifying the choice set, and how institutions change over time (North, 1986; Eggertsson, 1990: 29-30). In the first set of analysis institutions are exogenous, in the second they are made endogenous. The more difficult research question, which is also the topic of this paper, is the latter one. Modelling the evolution of property rights, or institutional change more generally, is still among the least developed areas within NIE (Eggertsson, 1990: 248).

Conventional neo-classical economic theory has assumed costless exchange and perfect information. NIE adds the concept of *transaction costs* in order to understand and explain institutions and their change. Or in the words of North (1990: 27): "My theory of institutions is constructed from a theory of human behaviour combined with a theory of the costs of transacting." The rational choice framework for the study of human behaviour is maintained from neo-classical economics. As such, NIE is but another extension of a more than a century long neo-classical research programme.

NIE is an umbrella for several quite different schools of thought. Bromley (1989, chap. 1) distinguishes between three distinct approaches: (1) The property rights school, represented by, among others, Coase (1960) and Demsetz (1967); (2) the induced institutional innovation theory (Ruttan and Hayami, 1984; Hayami and Ruttan, 1985); (3) the North (1981; 1990) approach, which has inspired much of the present paper. Eggertsson (1990, chap. 8) divides NIE into "the naive model" and "the interest group theory of property rights", which partly corresponds with Bromley's first and third category, respectively.

"The naive theory of property rights" refers to some of the earlier attempts in the 1960s to model and explain the emergency of property rights without including social and political institutions in the analysis (Eggertsson, 1990: 250). Demsetz (1967) is the classical paper on this theory: "Property rights develop to internalize externalities when the gains of internalization become larger than the costs of internalization. ... the emergence of new private or state-owned property rights will be in response to changes in technology and relative prices". Institutions are formed and modified in order to minimize transaction costs. Demsetz and others members of the property rights school only looked at the individual demand for property rights, and did not include coordination (free rider) problems, the role of conflicting interest between groups, or the role of the state in supplying institutions. In the tradition following Coase (1960), the analysis in these early writings was an harmonious and optimistic one with regard to the free market's ability to develop efficient institutions, in the sense that social welfare (often equated with economic growth) is maximized. It also provided an input to a theoretical justification for the free market economy.

Later work in the NIE tradition, particularly by Douglass North, has broadened and extended the analysis to include these initially overlooked factors. The importance of the individual demand for institutional change is maintained in the model, but there may be a large gap between individual demand for change on the one hand, and the actual outcome on the other. *First*, because institutions have important collective good characteristics, well known problems of free (easy) riding, collective rationality and group behaviour and become critical. *Second*, the state, which has a potential role in solving this dilemma, has its own interests. Socially inefficient institutions may be created or maintained by the rulers because the existing institutions serve their interests. *Third*, existing institutions, which are critical in determining both the individual demand for institutional change as well as in solving collective action problems, may prevent socially desirable changes. Thus, a society may be caught in a *low efficiency institutional trap*. Indeed, very few would still hold the view that a free or unrestricted evolution of institutions would ensure economic efficiency. "It is absurd to argue that processes of institutional evolution 'optimize'" (Nelson, 1995: 83).

Ruttan and Hayami (1984) represent a noteworthy application of the NIE approach to developing countries, mainly within the property rights school. Their "induced institutional innovation" approach focuses on changes in resource endowments, technical change, and growth in product demand. These factors shape the demand for institutional innovation. While they are certainly aware of the importance of supply of institutional arrangements, these are not well integrated in their analysis. Feeny (1993) represents a further extension of this work, and focus more explicitly on the supply factors within a demand and supply framework of institutional change. We will return to this in more details in section five.

The engine of change in NIE is new economic opportunities. "It is the possibility of profits that cannot be captured within the existing arrangemental structure that leads to the formation of new (or the mutation of old) institutional arrangements" (Davis and North, 1971: 39). The sources of this creation of uncaptured profit under existing arrangements can be due to changes in several parameters (Ruttan and Hayami; 1984; Libecap, 1989: 16; North 1981, 1986; Eggertsson, 1990; Feder and Feeny, 1993: 243). Changes in relative prices is the most common explanation, for example, as a result of changes in relative resource endowments (including population growth). Technologies, both for production and enforcement, are also referred to as a source of change, even though technological change itself should be endogenous. Some writers also note that changes in preferences (sometimes included in the term "ideology") can initiate institutional changes (see further discussion below).

Related to the EPPR hypothesis, the main proposition by the NIE is that (private) property rights evolve when an asset becomes more scarce and therefore more valuable, as reflected in relative prices. When the value increase, competition for the resource will make it worthwhile to spend more resources to create and protect the property rights to that asset. Problems related to free or easy riding (moral hazard) will also direct this specification and securing of rights towards increased privatization.

3.2 Marxian theories: Class struggle

It is difficult to pin down *the* Marxian model since the interpretations of Marx' work seem innumerable, partly a reflection of the ambiguity or richness -- depending on your personal faith -- in Marx' own writings. In discussing Marxism in the context of our paper, one should remember that Marx wrote about the evolution of private property rights in feudal Europe, particularly England, and not in the much less class-divided agrarian societies which are our point of reference. Nevertheless, Marxists have an established theory of endogenous institutional change, which is worth examining.

> At a certain stage of their development, the material productive forces of society enter into contradiction with the existing relations of production, or - what is but a legal expression for the same thing - with the property relations within which they have been at work hitherto. From forms of development of the productive forces these relations turn into their fetter. Then begins an epoch of social revolution" (Marx, 1859).[10]

In other words, changes in the productive forces (means of production and technology) leads to a tension between the existing structure (including property rights arrangements) and the productive potential. This tension is solved through class struggle, and the result is new institutions.

Except for the notion of class struggle, we see the obvious similarities between the NIE and the Marxian approaches to institutional change. The idea of class struggle is, however, a key one in Marxian theories, and cannot simply be skipped. Further, Marxists' emphasis is on *technology* as the primary engine of change (technological determinism), whereas the NIE's main focus has been on population growth, but also other factors, including technology. This preoccupation with technology as a dominating force of change, and the subsequent neglect of other factors, is indeed one of the main points of critique by writers within the NIE, e.g., North (1981: 60-63) and Ruttan and Hayami (1984: 216-217).

Parts of the Marx inspired analysis on the evolution of private property rights during the enclosure movement in Western Europe from the late Middle Age and onwards focus on the importance of class structure and class power for the different outcomes in different countries. Brenner (1976: 31) holds that "class structures tend to be highly resilient in relation to the impact of economic forces; as a rule, they are not shaped by, or alterable in terms of, changes in demographic or commercial trends".

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[10] Preface to *A Contribution to the Critique of the Political Economy*, quoted in Bardhan (1989: 4)

Others would tend to view class structure as the outcome rather than the driving force of the process. Enclosures were a precondition for a capitalistic development. First, it gave rise to landlessness, and then a proletariat in the form of a landless labour force (Lazonick, 1974). Second, the profit of landowners served as "a primary source of primitive capital accumulation and formed a basis for the capitalist mode of production" (Cohen and Weitzman, 1975: 289). Cohen and Weitzman, which basically is a formalization of the Marxian arguments on the consequences in terms of increased inequality of the enclosure movement, do not ascribe the class relations any major role in initiating the change. Instead their explanation can more appropriately be grouped under the cultural view as discussed below.

Private property rights seem to emerge in traditional agrarian societies even in cases where there is no distinct class structure initially. In traditional agrarian societies land is normally relatively abundant, which means that one of the preconditions for the conventional landlord-landless or bourgeoisie-proletariat class formation is not in place. Marx and most of his followers recognized this fact, even though they pointed out the possibility of other types of class division. We find it, however, difficult to assign any central position to class analysis in *explaining* EPPR in our context.

The usefulness in Marxian analysis in relation to EPPR seems to be in particularly two areas: First, it gives important contributions to the analysis of the consequences of such a development, not at least on the question of efficiency *v.* equity (question 3 asked in the introduction of the paper).[11] Second, as pointed to by North (1981: 61), the Marxian framework "includes all of the elements left out of the neo-classical framework: institutions, property rights, the state, and ideology". It draws our attention to commonly overlooked factors in conventional economic analysis. Furthermore, both the state-local and the cultural approaches presented below have been inspired by Marxian analysis.[12]

We would, however, argue that the methodology and theoretical framework for studying these elements are better provided by other approaches than the Marxian. In particular the NIE seems able to capture several elements of the Marxian analysis, while differing on certain key aspects: (1) methodological individualism *v.* the more questionable class as a the primary unit of analysis and action, and (2) the focus on supply and demand, and relative prices *v.* the labour theory of value, which does not seem to have much explanatory power. Thus, our views are in line with the conclusion of one of the leading neo-Marxian economists (Roemer, 1986: 191):

> "With respect to method, I think Marxian economics has much to learn form neo-classical economics. With respect to substantive research, I think it is the other way around, in many instances."

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[11] The Cohen and Weitzman (1975) paper is an example of this, which also shows how Marxian analysis and neo-classical methodology can be merged.

[12] The generous acknowledgement of Marxian theory by Douglass North (1981: chap. 6) should be noted. Indeed, Bardhan (1989: 13) holds that "North (1981) significantly differs from other members of the latter group of economists [neo-classical institutional economists], and is nearer the position of Marxists, in assigning a theory of ideology and the state a central place in his theory of history and institutional change".

3.3 State v. local community approaches: Predatory state intervention

At the core of this approach are several related conflicts: the centre *v.* the periphery, the state *v.* the local community, and statutory *v.* customary law. Compared with the two previous positions, this approach is to a much lesser extent a coherent theoretical framework. This political economy approach is, however, a common explanation of why a regime of private property is replacing regimes involving some form of communal management.

The behaviour of the state should be understood in light of its dual role: the state is both a social planner (welfare maximizer), and an instrument for powerful groups, or in Marx' terms "the executive committee of the bourgeoisie". This corresponds to what is known as the *contract* origin *v.* the *predatory* origin of the state. Decisions by the state should be understood in the intersection between these two roles. Conventional neo-classical economics, often implicitly, assumes the former, whereas Marxists and writers applying the state-local community perspective emphasize the predatory role of the state.[13]

The dichotomy between the developmental and the predatory state can be illustrated by a simple model and typology. Let X be total output in the society, and t the proportion of the output extracted by the state (an indicator of the degree of state intervention). X is a function of t in an inverted U-shaped relationship; some intervention will increase X, but beyond a certain point it lowers X (cf. the Laffer curve). The objective of the state can generally be formulated as:

$$\underset{t}{Max} \quad T = \alpha X(t) + (1-\alpha)tX(t); \quad \alpha, t \in [0, 1]$$

$\alpha = 0$: the predatory state (maximizing own revenue).

$\alpha = 1$: the developmental state (maximizing overall output).

In the first case the objective of the state is to extract as much as possible out of the economy, in the second the aim of state intervention is to maximize the overall output of the economy. Most states would have values of α between zero and one, that is, the state both tries to serve its own interest and the overall social interests. Obviously, the greater α is the larger the optimal t. In the social planner case the optimal t will be when $X' = 0$, whereas the predatory state solution is given by $X' + X/t = 0$.

The conflict about the distribution of resources is often expressed in tensions between statutory and customary law. National (statutory) law can be used to extract resources traditionally held by local communities. We believe this can be a useful approach, for example, as applied in the case of Indonesia by SKEPHI and Kiddell-Monroe (1993). The same authors also portray this as a conflict between a Western ideology and a local one, an approach which in many cases would be incorrect. In parts of Africa the customary tenure system was actually "invented" and institutionalized by the colonial rulers (Berry, 1993). Customary rules are ambiguous and subject

[13] Public choice theory, which is neo-classical economics applied to politics and as such is within the neo-classical economic theory, does certainly not assume the state to be a perfect social planner. On the contrary, it comes close to viewing the state as a predator.

to ongoing reinterpretation. Customary claims can be used to mask individual accumulation, and local elites can insert their own definitions to make them serve their interests (Berry, 1993: 120). As such, both customary and statutory law may be formulated and used to serve the interests of powerful individuals and groups.

The discussion in the literature on "the village against the center" (Bromley and Chapagain, 1984) is also occupied with resource degradation as a result of misguided and unsuccessful attempts by the state to replace communal management by a private property rights regime. Bromley (1991, chap. 6) states that the *real* tragedy of the commons is (1) the breakdown of indigenous property rights structure, and (2) the failure of the state to replace this with an effective regime with tenure security, which is necessary -- although not sufficient -- to make economic actors to include long-term effects in their decision-making. The combination of these two factors may result in a *de facto* open access regime, even though it is *de jure* private or state property. The institutional vacuum makes the environment more susceptible to overexploitation.

The state-local dichotomy could also explain changes in local property regimes. Using examples from India, Nepal, Indonesia, Nigeria and other countries, Bromley (1991, chap. 6) argues for the existence of a general disrespect of local management systems by the state, and the introduction of private property rights as a vehicle for wealth appropriation by powerful groups controlling the state.

This argument is challenged by Ault and Rutman (1979). They argue, in line with the property rights school, that individualized ownership is a natural evolution as land becomes more scarce. However, after independence the new governments in Africa viewed individual property system as a colonial heritage, and wanted to maintain or even reinstall communal tenure regimes. Even though indigenous systems were reasonable efficient under the conditions under which they evolved, the governments' attempts to preserve these systems prevented a natural evolution towards more individual rights. The result, Ault and Rutman argue, is an inappropriate property regime with tenure insecurity, with subsequent productivity and environmental losses.

> "Failure to recognise the relationship between land availability and individual property rights within the land tenure system has led to the creation of land tenure systems in the postindependence period that do not present incentives for the optimal use and development of agricultural land" (page 179).

The differing views of Bromley and Ault and Rutman can be seen in the light of the two above perspectives on the state. Bromley and others emphazise the predatory role of the state. In the Ault and Rutman description, the policy by African leaders was, at least in part, based on a social planners view. The intentions where good, but the outcome bad. Such unintended consequences could be attributed to lack of knowledge, or ideological blindness.

These two works illustrate the need to look at the state from both its potential predatory and contractarian roles, and within these two also consider misguided or misinformed policies which yield consequences contrary to their intentions. The state is normally playing both roles at the same time: the Indonesian government is creating plantations and issuing logging concessions to powerful individuals, which may conflict with local and environmental interests. At the same time, protection forests and national reserves are established, and large programmes for rural poverty alleviation and improving local infrastructure and services are implemented. Ignoring this dualism, and focus on only *one* of the roles played by the state, would limit the understanding of state behaviour.

To summarize, within the state-local perspective a driving force is a state in the hands of the national elite, ignoring customary and community based tenure rights to serve their interests. The state only recognises the statutory law, which is based on private property rights. This forces local farmers to obtain formal rights based on statutory law in order to protect their land against external claimants.

3.4 Cultural changes: Commoditization of land

The rational choice model underlying the NIE has as one of its key assumptions that the preferences are constant, or at least exogenous. This is one of the limitations of the model if one wants to study economic change, particularly over a longer period of time. Conventional neo-classical economics seeks to explain changes in behaviour by changes in the choice set, in particular relative prices, rather than changes in preferences, a case forcefully argued by Stigler and Becker (1977). Others, including economists such as North (1981, chap. 3), argue that this is insufficient to explain change.

Preferences are related to culture. There is no generally accepted definition of culture, and the term is used in a number of ways depending on the topic discussed. Often, the concept is taken to be so wide that it is difficult to handle analytically. A delineation is therefore necessary. In the institutional literature it often refers to *informal rules or moral codes of behaviour.* On the other hand, the concept of *preferences* in the rational choice model overlaps with "culture" as used in social anthropological literature.

Culture both used in the sense of *informal rules* and of *preferences* has a bearing on the EPPR hypothesis. First, several authors attribute the evolution of private property rights to changes in the perceptions or preferences related to land. In the discussion of the enclosure movement in England, Cohen and Weitzman (1975: 321) hold that the main force was a "fundamental change in attitudes and ideas" or more specifically "an urge to maximize profits from the land". This change is attributed to many factors:

> "There is some consensus that the relative increase in internal stability (even if only temporary) caused by the rise of a centralized authority, the long term influence of trade expansion, innovations in military technology, secularization of religious doctrine, the growth of new opportunities and new consumption desires, each in some fashion supported the development of a profit-oriented society."

During the enclosure movement land (and labour) emerged as economic commodities. Land became a source of individual income rather than a means for obtaining prestige and power and something to be used for the common benefits. Ellen (1993: 131) describes a similar development in Seram, Indonesia:

> "<By the early 1970s> land <was> becoming a truly exchangeable commodity. ... individualism with respect to land is the cumulative ideological product of structural shifts resulting from resettlement, confrontation, and participation in a new political and economic order."

Both in a historical context and to describe changes in traditional agrarian societies in developing countries today one could describe this phenomenon as a *commoditization of land.*

Changes in preferences can create the demand for individualized and more secure property rights. Alternatively, this cultural change can be viewed as a change in informal rules which make it more acceptable for members of the community to take more individual control of the land. This points to the problems of a clear distinction within the rational choice model between preferences and informal constraints. As Elster (1979; 1983) argues forcefully, men are sometimes free to choose their own constraints (*Ulysses and the Sirens*), and conversely, preferences may be shaped by the constraints (*Sour Grapes*).

This issue also reflects a long standing debate in social sciences: are preferences and moral behavioural codes the reflection of economic forces, or do they have a life on their own? Popular debates sometimes tend to view culture as a constraint to rational behaviour, as reflected in the "maximizing man" *v.* the "social man" debate. Peters (1993: 1072) considers this to be a false dichotomy; "interests and opportunities are always culturally coded". North (1977), taking issue with the work of Karl Polanyi (1944) on non-economic transactional modes, argues that these modes can be understood within a rational choice framework with transaction costs. Thus, culture (or at least parts of it) becomes an expression of economic rationality.

Summarizing, the introduction of "culture" challenges NIE's rational choice framework at three levels:

1. It will modify the choice set (constraints) by including the social cost when informal rules are violated, for example, in the form of social sanctions for free riding.
2. It can also be analyzed as a change in preferences whereby, for example, more emphasis is put on (individual) consumption of commodities. Another example would be changes in the extent of which the well being of other members of the community is included into your own utility function (altruism in the Becker sense).
3. It may challenge the idea of rational choice as an approximation to actual behaviour. The alternative may, for example, be a theory of behaviour guided by norms, customs, search for identity and belonging to a group (see Peters, 1993).

A critical question here is to what extent this critique can be incorporated in the rational choice framework by modifying the preferences and the constraints. We suggest that one can go further than most of those criticising NIE seem to think, and that rational choice, as a conceptual model, is more flexible than commonly thought of. The anthropological critique (point 3 above) is not necessarily in conflict with the rational choice approach, which main idea is ends-means consistency. It should rather be interpreted as a critique against the narrow set of objectives (and constraints) normally included in economic models.

The NIE tries to incorporate the first two points, but there are some problems involved. Social costs are easy to integrate in conceptual models, but difficult to quantify. Related to the second point, changes in preferences could be treated as an exogenous change, even though there is some resistance against resorting to this kind of explanation. One of Nobel Laureate Gary Becker's three cardinal principles is that "'changes in taste' is the economist's admission of defeat" (Fuchs, 1994: 184).

Moreover, a complete theory of institutional change requires a theory of ideology, including endogenous changes in preferences (North, 1981; 1990). No coherent theory is yet at hand, to a large extent a reflection of the complexity of the issue. Ruttan (1989) notes that also the early development economists stressed that "culture matters". Scholars and practitioners of development are, however, still dealing with "cultural endowments at an intuitive level rather than in analytical terms" (page 1385).

Summarizing this approach, the main focus is on changes in the perceptions of land: land is increasingly regarded as a economic commodity, which can be used by individuals to extract as much surplus as possible. The initiation of such a development can be due to several factors; many writers emphazise the effect on the local economy of the integration into a larger national (or even global) economy. Related to this is the Marxian inspired explanation: when money is introduced and a monetarized economy replaces a traditional subsistence and barter economy, we have the seed of capitalism and the creation and stimulation of a profit motive guiding economic behaviour ("money as the seed of greed"). An anthropological elaboration of this view is given by Kopytoff (1986: 72):

> "One perceives in this a drive inherent in every exchange system towards optimum commoditization - the drive to extend the fundamentally seductive idea of exchange to as many items as the existing exchange technology will comfortably allow. Hence the universal acceptance of money whenever it has been introduced into non-monetized societies and its inexorable conquest of the internal economy of these societies, regardless of initial rejection and of individual unhappiness about it."

A change in preferences will normally be accompanied by a weakening of informal rules which would constrain exploitive behaviour, or by the sanctions necessary to enforce such rules. More open communities, increased mobility, etc. could contribute to a weakening of social enforcement mechanisms.

The four approaches outlined below are not separate boxes of analysis -- they can indeed be quite overlapping. Each of them focus, however, on certain *main* forces behind the change in the property rights institutions, as summarized in Table 1.

Theory/approach	*Main driving force behind EPPR*
Neo-institutional economics (NIE)	Relative prices, reflecting resource scarcity; higher land value.
Marxian class analysis	Technology, with subsequent class struggle.
State-periphery approaches	Predatory state intervention, disrespect of customary law by the state.
Cultural or ideological explanations	Views/attitudes towards land; commoditization of land.

Table 1. Summary of different approaches to the emerging private property rights (EPPR).

4 Empirical evidence from Indonesia

> "Land and water, and the natural resources contained therein, shall be controlled by the state and used for the maximum benefit of the people" (The Indonesian constitution of 1945).[14]

Much of the debate on land rights in Indonesia centres around the tension between customary and statutory land rights, i.e., within the third perspective presented in section 3. This section presents a discussion of customary (*adat*) law, followed by a brief description and discussion of the statutory law and its practice in relation to land use. The third part gives a description of (recent changes in) the study area of Seberida, Sumatra.

4.1 Customary (adat) land rights[15]

Customary (*adat*) law obviously varies throughout Indonesia, and some 16 broad forms of *adat* law have been identified (SKEPHI and Kiddell-Monroe, 1993: 232). There is, however, also a great degree of similarity, which indeed also would resemble traditional tenure regimes found in other agrarian societies in the developing world (among the best discussions of this is still Boserup, 1965). The *adat* (literally custom or tradition) in Indonesia covers a number of other aspects of human life and interaction than just land use and tenure. We shall use it here in the meaning of the set of informal, customary rules that regulate the rights (access and permissible uses) to land and forest among members of the local community.

Land is under *adat* law regarded as the property of the community, in the sense that the transfer right belongs to the community. Communal land cannot be bought, sold or leased. This right is known as *hak ulayat* (literally area rights). When it comes to the use and income rights two general patterns are present, and was also observed in our study district of Seberida.

1. *Common use and income rights:* This will typically cover the collection of many *forest products,* where every member of the community is free to collect from the forest under *hak ulayat.*

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[14] Article 33 (1), quoted in SKEPHI and Kiddell-Monroe (1993: 236)

[15] Besides my own fieldwork, this section draws on particularly Dove (1983), SKEPHI and Kiddell-Monroe (1993), and Østergaard (1994).

2. *Individual (household) usufructuary rights:* The individual use and income rights apply in particular to two areas. First, forest may be cleared and used for swidden cultivation by the household, and the household has the right to the income derived from agricultural production. Second, for some valuable forest products, where demarcation is possible, individuals may get rights to harvest these. This was the case in Seberida for, among others, honey trees and wild growing rubber (*jelutung*).

Of particular interest is the rights related to swidden cultivation. Income and use rights are acquired by clearance of forest and working on the land. Thus the output from swidden rests with the person or household who works on the swidden. There is a widespread "myth ... that swidden agriculturists own their own land communally (or not at all), work it communally, and consume it yields communally" (Dove, 1983: 85).

In Seberida the household or lineage who cleared the forest initially has a priority right for later cultivation. This is a widespread way of acquiring rights: "Throughout Southeast Asia, rights to secondary forest are usually held by specific, individual households; these rights being initially acquired by virtue of opening of the primary forest on that land, and then extending to the secondary reforestation which follows each subsequent cropping there" (Dove, 1983: 86-87). Moreover, anthropologists have for long recognized that in traditional societies people commonly have "possessive rights" (Basu, 1995: 21); whoever first gets to possess an asset has the right to it.

A number of modifications of this "first come first served" rule exist in *adat* system in Seberida. A rightholder cannot refuse others to open swidden on "her" land, provided she is not going to use it in the near future. The person borrowing the land can normally only plant rice and other annual crops, not any perennials. Further, the strength of rights a person has to the land depends on how many times the land has been reopened, the number of years since it was opened last time, as well as the distance from the village, partly because a remote location of the field makes enforcement more costly. The *adat* law is therefore ambiguous, and open to interpretations and local adaptations. Indeed, one could find marked differences within the Seberida district.

Planting of rubber or other perennials would extend the usufructury rights a person has over land, and "in practice such usufruct amounts more or less to a permanent right to the land" (Østergaard, 1994: 76). Planting of perennials is therefore the most efficient way to get more permanent individual rights to land within the *adat* system.

What would be the appropriate classification of the *adat* land tenure system, taking up the discussion from section 2? Dove (1983: 88), with reference to a similar shifting cultivation system in Kalimantan, holds that "it is clearly misleading to label such systems of land use as 'communal'". First, there is a large variation in households' access to land though rights accumulated over time. Second, as is clearly seen in Seberida, the most important of the property rights -- that is use and income rights to land for agricultural purposes as well as to some of the most valuable forest products -- are individualized. This makes it important to distinguish between common property and community based rules of *mainly individual property rights,* i.e., the most important of these -- the use and income rights.

4.2 Statutory law and practice related to land use in Indonesia[16]

The *Agrarian Act of 1870* passed by the Dutch colonial government gave full protection to the farmers of land kept under *constant* cultivation. Fallow land used under the shifting cultivation system was grouped as "virgin or waste land", and designated as state dominions. Thus there was no protection given to traditional rights under the shifting cultivation system.[17]

The *Basic Agrarian Law of 1960* aimed at "the abolition of Western-*adat* dualism by basing agrarian law on *adat* land law" (SKEPHI and Kiddell-Monroe, 1993: 236). The law states that:

> "The agrarian law over the earth, water, and space is a *hukum adat* (traditional law) so long as it still exists and does not hamper the national and state needs."[18]

Even though the Basic Agrarian Law recognizes the traditional law, the reservation made that it should be in accord with national interests, and that it cannot conflict with any higher laws and regulations (article 3) has preserved the dualism and ambiguity it intended to remove.

Furthermore, the law distinguishes between two types of land rights: the customary rights of avail (*hak ulayat*) and rights of ownership (*hak milik*). Even though the law states that also customary rights must be recognized except when in conflict with national interests, in practice, the burden of proof is reversed:

> "All development officials know the wording of this article by heart, and they take it to mean -- and they in fact employ it as meaning -- that whenever and wherever rights of avail conflict with their projects, these rights can automatically be ignored or overridden. This failure to either prove or contest these claims of national interest obviously raises the possibility that such claims are sometimes used to override rights of avail for purposes other than the national interest or even contrary to national interest" (Dove, 1987: 266)

Sometimes traditional rights are dismissed on the basis of being undocumented, ignoring the fact that documentary proof is irrelevant in traditional law (SKEPHI and Kiddell-Monroe, 1993: 237). Further, the 1960 law states that:

> "every person and every corporate body having a certain right on agricultural land is in principle obliged to cultivate or to exploit it actively by himself while avoiding extortionate methods".[19]

This opens up for charging traditional swidden practices with violations of the law, based on both the burning of forest (extortionate) and the long fallow periods (not active exploitation).

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16 This section is based on Dove (1987) and SKEPHI and Kiddell-Monroe (1993).

17 The use of "waste" land and the provisions given by this law spurred a development of private cash-crop estates. Traditional swiddening was excluded rather than included in the new economy. This dualism is still very present in provinces like Riau and Jambi in Sumatra.

18 Article 5, quoted in SKEPHI and Kiddell-Monroe (1993: 236)

19 Article 10, quoted in SKEPHI and Kiddell-Monroe (1993: 237)

A final area which opens up for vested interests in the practice of the law is the distinction between *hak ulayat* and *hak milik*, where the farmers rights to land classified under the former will be very weak in any conflict with the state. By classifying land rights as rights of avail it may be appropriated by the state without compensation.

The *Basic Act of Forestry of 1967* states that all forest is to be considered state property, and traditional rights should not interfere with forestry operations. Compared to the agrarian law, this law represents a *de jure* weakening of the *adat* rights, and is as such more in line with actual practice. A *Forestry Agreement of 1975* mandates that logging companies "observe the rights of local people, for example to trees and products".[20] In practice, however, this agreement has had little effect, including in our study area in Seberida.

Another area of relevance is the strong emphasis on centralization (often justified by "national unity") in Indonesian law and politics. Of particular relevance is the Act no. 5 of 1979 on village administration.[21] Until 1979 village administration on the outer islands of Indonesia (all islands except Java and Bali) was mainly based on *adat* law. While both the Agrarian and Forestry laws made some recognition of traditional rights, "the 1979 Village Government Act formally removed this potent link between individual and communal resource management based on traditional law and a village level political entity also based on such law" (Sandbukt, 1995: 62). This was replaced by a Javanese inspired, national model of village administration.

According to this Act a village headman (*kepala desa*) is elected by his constituents for a period of eight years, but the election has to be confirmed -- and may be dismissed -- by the district head. A village council (LMD) is not an elected body, but consisting of prominent community members and sub-village leaders, appointed by the village headman. Neither the LMD or the Village Development Organization (LKMD) are generally functioning well, and attract little interest, partly because of their unrepresentative nature and lack of rooting in traditional law. Thus, a *potentially* viable local resource management system based on traditional law has been replaced by a more or less non-functioning centrally imposed village administration.

In conclusion, statutory law recognises traditional *adat* rights, but its ambiguity and the priority given to national interests in the day-to-day interpretation of the law have made this recognition of limited value to the farmers in any conflict with external claimants. Furthermore, the recognition of such rights in statutory law has been weakened over time since Independence in 1945. The various rights related to different types of land uses under the customary and statutory laws are summarized in Table 2.

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[20] SKEPHI and Kiddell-Monroe (1993: 240).

[21] The following on the Village Administration Act draws on Sandbukt (1995).

Land use (increasing intensity)	**Customary (*adat*) law (i.e., rights in relation to other members of community)**			**National (statutory) law (i.e., security of rights in relation to external claims)**
	Use and income rights		**Transfer rights**	
	Agricultural production	**Collection of forest products**		
Primary forest	All members of community free to open forest for swidden and plant perennials	All members of the community has rights, except for some individually marked products (trees)	Vested with the community	State forest
Long fallow forest	Rights belong to the initial clearer of primary forest; others may temporary use it for swiddening			Defined as waste land, and under state domains
Short fallow forest				More secure rights than above, but still very weak
Traditional rubber gardens	Belong to the family that planted rubber	As above, but less relevant	Unclear, may be used as collateral and transferred	Some, but still small chances for compensation if land expropriated.
Intensive rubber gardens				Relatively good, particularly if planted under an intensification programme

Table 2: Overview of land rights according to customary (adat) and statutory law.

4.3 Recent changes in Seberida district, Sumatra

The case study draws on fieldwork conducted in 1991-1992 in the district (*kecamatan*) of Seberida in the regency (*kabupaten*) Indragiri Hulu in Riau province, Sumatra, Indonesia. I have discussed the shifting cultivation economy and the recent changes at some length in Angelsen (1995a; 1995b), and intend only to give a very brief summary here. Seberida is 2 800 km^2 in extent. A hill massif in the south, the Tigapuluh Hills, consists mainly of primary forest, even though large areas have been logged. The north and east parts are covered by flat, swampy land, whereas the western part is dominated by the low undulating country of the Cinaku valley. The natural vegetation consists of lowland rain forest and swamp forest. Along the roads and rivers, the vegetation is a mosaic of secondary forest, swiddens, and traditional rubber forests.

Traditional subsistence has been based on shifting cultivation and collection of forest products, but during this century forest collecting has increasingly been replaced by swidden-based rubber planting. Permanent cultivation is found in the transmigration settlements (Government sponsored migrants from Java and Bali) along the Cinaku valley. The population density has been relatively stable throughout most of this century. The censuses of 1930 and 1961 show a density of slightly above 3 persons/km^2, the ratio increasing to 4 in 1980, and 5.5 in 1991, which is still not very high (14.3 including the transmigration settlements).[22] There are at present more than 41 500 inhabitants in Seberida. An extremely high annual population growth rate of 13.1 percent during the 1980s was mainly due to a massive inflow of transmigrants, which now comprise more than 60 percent of the total population.

Most of the shifting cultivation practice (*padi ladang*) in Seberida can be defined as a *bush-fallow system* (fallow period from 5 to 10 years), but also with a significant share of *forest-fallow* (fallow length of more than 10 years, see Rutenberg, 1980). This demonstrates that the shifting cultivation system in Seberida is at a relatively early stage in its evolution, implying that the "degradation syndrome" (soil and nutrient mining through short fallow periods) has not yet occurred. 7 out of 10 households cleared forest for swidden cultivation at least one of the last two years (1990-1991). The average rice output per swidden is very low, only around 480 kg per swidden or 400 kg per ha in 1991 (average swidden size is 1.2 ha), and with huge variations (high yield risk), which is only about one fifth of the national average for dryland rice. This is sufficient for only 4-5 months consumption on average. The low yield is a reflection of the poor soil quality (acidity) in the area, as well as problems related to pests, particularly wild boar (forest pig).

8 out of 10 households have rubber gardens (*Hevea brasiliensis*), more than 97 percent being planted with traditional, low yielding trees (*karet rakyat*). The number having mature rubber gardens that can be tapped is much lower, reflecting a sharp increase in rubber planting from the mid-1980s. In addition 11 percent had immature, high yielding rubber planted through the World Bank and Government funded Smallholder Rubber Development Programme (SRDP). The area of rubber holdings by the non-transmigrant population is about 12 000 ha, which is about a quarter of the secondary forest and 4.3 percent of the total area of these villages. The average annual income from one ha of tappable rubber garden (Rp 340 000 or USD 170) exceeds the income from the annual crops (mainly rice) planted on the first year on the swidden (Rp 250 000). Moreover, traditional rubber can be tapped continuously for 30-40 years after an initial maturation period of 10-12 years, whereas rice presently is harvested in only one out of about every nine years.

Whereas some of the basic features of the swidden-rubber system have been more or less constant over several decades, since the early 1980s there has been a number of significant changes in the exogenous environment of the shifting cultivators:

1. Increased land claims from external users, mainly government sponsored projects in the form of *logging*; *transmigration,* where partly fallow forest and rubber gardens were appropriated to the transmigration development; and *plantations* (oil palm), which is of more recent date, but may become the most important external land claim in the future.

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[22] See Østergaard (1994) for a discussion of the history of the district.

2. Changes in relative prices, in particular due to improved infrastructure (roads) and market access following the logging and transmigration projects. Better market access means higher prices for cash crops, whereas consumption commodities become cheaper. Thus, it will be more profitable, *ceteris paribus*, to move from production for household consumption toward cash crops and more specialized production. Moreover, world market rubber prices increased steadily from 1985 to mid 1988, after which they levelled off and stabilized at the 1985-86 level.
3. Declining profitability of non-timber forest products, as a result of overexploitation, and lower farm gate price of the main product -- rattan.
4. Population growth. The population in the 20 traditional (non-transmigrant) villages grew from 11 413 in 1980 to 15 406 in 1991; an annual growth rate of 2.8 percent.
5. "Commercialization" of village life. As part of a general national drive for development in then conventional sense, increasing emphasis is being put on individual consumption, which creates increased "needs" for cash. In microeconomic terms, this suggests that preferences have changed in favour of income and consumption relative to leisure.
6. Changes in the village administration, as discussed above.

These changes can be summarized as augmented land rent (or land value) due to internal and external land claims, higher rubber price, and lower transport or travel costs. The opportunity cost of labour has also decreased, because of the declining profitability of forest produce, and population growth not absorbed in the off-farm economy. Further, as a result of both internal and external factors, the customary land tenure system has eroded.

The changes described above have resulted in significant modifications in the shifting cultivators' adaptations. There has been a transition from a relatively stable rice based shifting cultivation system to a smallholder rubber system which encroaches on previously unused old-growth forest. The most significant changes over the period 1985-1991, which the household survey covered, are:

1. ***Increasing share of households opening swidden.*** About 42 percent of the households opened swidden in 1985; this share increased to 61 percent in 1991.
2. *Increased rubber planting*. During 1985-1986 about one third of the swiddens were planted with rubber. This has increased steadily to more than 90 percent in 1991.
3. *Increased primary forest clearance.* The share of primary forest clearance has almost doubled from 7 percent in 1989 to 13 percent in 1991. Data about the farmers plans for 1992 confirm the trend of increased clearing of primary forest.

Total forest area cleared by shifting cultivators from about 1 400 ha in 1985 to 2 400 ha in 1991, whereas the annual primary forest clearing has increased from 160 to 420 ha over the same time period.[23]

The sharp increase in the share of households engaged in shifting cultivation, in forest clearing, and in rubber planting could be viewed and explained from at least three perspectives, as elaborated in Angelsen (1995a). First, it can be viewed as a rational response to increased

[23] As discussed in some detail in Angelsen (1995a), these figures should *not* be taken as a measure of deforestation.

profitability of rubber, following a conventional economic logic. Second, increased land scarcity is generally seen as a major driving force for agricultural intensification (Boserup, 1965; Ruthenberg, 1980). Whereas both these approaches are useful to understand the changes in Seberida, this paper will concentrate on a third perspective which view the switch to rubber and increased land clearance as a strategy for obtaining and securing land rights. The next section develops a conceptual model based on the theories in section three to explain and understand the changes just described.

5 Discussion and an integrated framework

> "The supply of institutional change is important; trends in the demand, although necessary, are not sufficient for understanding the path of change. Elements of political economy analysis are crucial; the political and economic costs and benefits to the ruling elites are a key to explain the nature and scope of change" (Feeny, 1993: 168).

The development in the study area can be summarized as increased land scarcity (implying higher land value or land rent), partly because of an increase in the number of external claims to what is considered community land according to customary law (*hak ulayat*). This development is not unique to the Seberida district, in fact, the forces of change and the subsequent response by local farmers are common throughout Southeast Asia.

From a property rights perspective, the response by the farmers has been twofold:

1. A strengthening of the individual usufructuary rights to land under the *adat* law through rubber planting and expansion of the swidden cultivation area (opening of land which no one previously has claims to). This development represents a strengthening of the individual use and income rights relative to the common rights (cf. Table 2. When land is used intensively the usufructuary rights evolve into more permanent rights under the customary law.
2. The individual rights are increasingly, though still on a relatively small scale, formalized by acquiring protection in statutory law, i.e., through obtaining land certificates. In addition to use and income rights, this also gives the person transfer rights.

A general increase in land scarcity combined with the high profitability of rubber, have increased the benefits from securing the rights to a particular piece of land. Moreover, because rubber itself gives usufructuary rights to land, there is no extra cost of establishing and strengthening the customary rights to the land. The limitation of such rights is, as discussed above, that *adat* mainly gives protection against claims from members of the community, whereas it is of limited value in conflicts with external claimants.[24]

Statutory law and title deeds provide better protection against external claims, but depends also on a number of other factors. Rubber planting increases the possibilities for the land being accepted as the property of the planter in a possible conflict with the state or with private

[24] It is not only in conflicts with the state that local users may lose, but also against potential users from outside the community. Michon *et al.* (1995: 5) discuss such a case from Lampung Sumatra, where "communal control did not appear able to protect the interest of legitimate owners against external unauthorized tappers <of resins>".

companies, for example, if plantations are established and the question of compensation arise. This would be the case even without a formal title. Higher intensity of production, for example, planting of high yielding rubber varieties, high density of rubber trees, and a well maintained rubber garden also enhance the tenure security.

Formal land titles can be obtained at various levels, generally with increasing security and higher costs the higher the level of authority issuing the title; village (*desa*), district (*kecamatan*), regency (*kabupaten*), and national level. So far the farmers in Seberida have not been rushing for formal registration of the land which they have rights to according to *adat* law. Yet, the village headmen have encouraged formal land titling, which over time will undermine the customary law.

Why this reluctance to obtain titles? The main answer lies in the high costs involved. A certificate would be very expensive for the average farmer, when both official and unofficial dues have to be paid. The area a household has rights to according to customary law could well be 10 - 15 hectare (ha), and the costs of titling all land would be well beyond the reach of most farmers. Deeds provided by the National Land Agency (BPN) at the district and provincial level are limited to two ha per person. Larger properties must be approved by the Jakarta office, with the extra expenses involved (Sandbukt, 1995: 57). Thus, title deeds are mainly relevant for the most intensively cultivated land. Plots planted with high yielding rubber under the Smallholder Rubber Development Programme (SRDP) get titled, and is -- if well tended -- regarded as secure property. Another kind of costs of land titling is related to the fact that people would consider this to be in conflict with, or at least not recognised by the *adat* law.

Even though formal land registration has been limited so far, we believe this will be more frequent in the future for several reasons. First, the external claims may continue increasing, making the securing of rights in statutory law more important. As elaborated in Angelsen (1995a), farmers' *expectations* about future external claims and land scarcity is the important factor here. The household survey showed that most farmers expect increasing difficulties to find land for swidden cultivation. Second, as shown formally in section six, increased intensification would make it more attractive to also secure the land through titling. Third, some of the initial hesitation because it represents a break with the *adat* law may be weakened over time. A documentation of the latter from Lampung, Sumatra is found in Michon *et al.* (1995): a traditional prohibition of planting perennials was removed, and individual appropriation of land through planting of profitable resins became acceptable also according to customary law.

Returning to the four approaches outlined in section three, which one are the most useful or have the most explanatory power to explain the development? A definite test would obviously be impossible to undertake; rather "the ability to tell a consistent story is an important test of the analytical framework" (Feeny, 1993: 174). We would argue that neo-institutional economics (NIE) provides the most consistent framework, which at the same time is sufficiently flexible to include elements from the other approaches. In particular, the state - local dichotomy, and the related tension between customary and statutory law should be incorporated in the analysis.

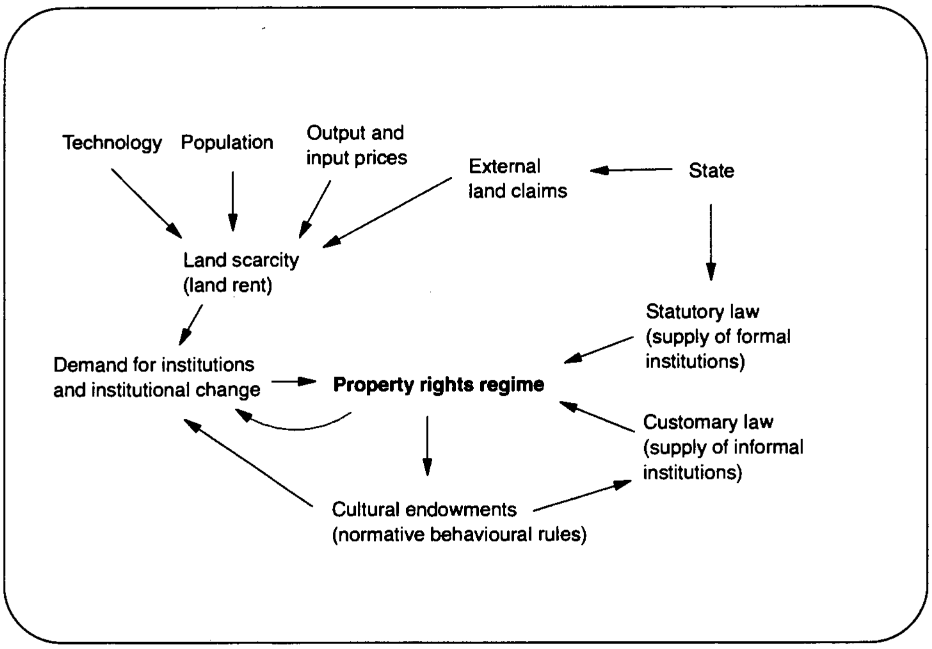

Figure 1: Main forces determining changes in the property rights regime.[25]

Figure 1 sketches a conceptual framework which can explain the changes in the property rights regime. We apply a "demand and supply for institutional change" metaphor, which should not be taken too literally or stretched too far (Feeny, 1993: 198).[26] It may, however, be useful to think of the demand (left side in the figure) as representing the resource users' benefits from different institutional arrangements. The benefits would be a function of, *inter alia*, the protection given against external claims. The supply (right side in the figure) is given in terms of the costs of providing various degrees and types of protection against third party interference.

The main strength of NIE is on the demand side of the figure. The key variable here is land scarcity, which will be reflected in the land rent or land value. A number of factors can contribute to increased land scarcity. In the Seberida district higher rubber prices, population growth, and external land claims have been the most important. In addition to total land scarcity, the *composition* of land demand between internal (within the community) and external claimants is important for the demand for institutional change.

Higher land value creates a demand for institutional change. First, as a simple but important fact, when land rent increases, higher transaction costs can be incurred while still retaining a positive

[25] One could, obviously, add more elements and arrows to the figure. We have limited to the main variables and the main connections. A framework which relates everything to everything, as done in Ruttan and Hayami (1984) is not very helpful to understand the main mechanisms at work.

[26] The market analogy is far from perfect: there is no clear commodity, nor a single price, as in a market. The metaphor applies to a variety of market structures, with often discrete and multidimensional goods. See Lin and Nugent (1995) for a broad based discussion of demand and supply of institutions and institutional change.

profit. Second, higher land value goes in tandem with more investments in land.[27] However, farmers are only able to pick the fruits, sometimes literally, of their investments if the tenure is secure. Thus, the increased potential value of land could only be captured by the individual farmers by securing their land rights.

On the supply side, we distinguish between two sets of institutions which can provide tenure security: statutory and customary law. These are examples of (1) institutions provided from *above* by the state, and (2) institutions provided from *below* by collective action by a group of individuals. Within these laws, there are various degrees of protection against third party intervention. Generally, increased protection can only be obtained by incurring higher transaction costs (contract and enforcement costs), but this need not always be the case: the Seberida case study provides an example where the most profitable crop alternative (rubber) is also the one which gives highest tenure security.

The state has two roles, according to the framework of Figure 1. First, government sponsored projects such as transmigration, logging, plantation, mining, etc. have been the main source of external land claims. Second, the state has a role to play as a supplier of formal rules and legal protection of property rights through the laws and acts which regulate land use, and the enforcement of these. As discussed in section 4.2, there are interactions between these two sets of institutions. First, the statutory law recognises the customary law formally, although not much in practice. Second, some variables, such as intensity of production, affect the tenure security under both systems.

A final element included in the figure is the cultural endowments (Ruttan and Hayami, 1984), or normative behavioural rules or moral behavioural codes (North, 1981). These are important for the stability of the system. As discussed in section 3.4, their influence within our framework would be twofold. Cultural endowments have an impact on the demand for institutional change: changing norms towards regarding land as an economic commodity, or changes in preference towards material consumption can strengthen the pressure on land, and thereby the demand for change in the property rights regime. Second, the moral behavioural codes are important in shaping the customary land law, and its practice and efficiency.

The cultural endowments are more fundamental institutions, but would also change over time, even though at a slower pace. They would be influenced by, *inter alia,* the actual property rights regime (operating rules, or secondary institutional arrangements). This process is put clearly by North and Thomas (1971: 786):

> "The forces of change ... will first induce pressure to change contractual forms - that is to alter secondary institutional arrangements. The cumulative forces of such changes which violate, modify,

[27] For example, in a subsistence economy higher population density leads to less land per family and higher land value. In order to produce sufficient for the family's consumption, the inputs and investments in land must increase.

> or otherwise bypass existing fundamental institutional arrangements will induce growing pressure for more basic - and more costly - modifications in primary institutional arrangements."

The modifications in the property rights regime would take place in the interplay between the demand and supply factors. In simple terms, the increased land value creates a demand for higher tenure security. The supply side gives a menu of varying degrees of protection, generally with higher costs the higher the protection is.

Increased land scarcity provides the main driving force towards individualization of the property rights. The increase in external claims (which relates to the *composition* of the increased demand) strengthen this tendency, and also makes farmers increasingly secure their rights in statutory law. Thus the evolution of private property rights is reflected in both the fact that within the customary land tenure system individual rights are strengthened relative to rights held in common, and by an increased reliance on statutory law -- which only recognize individual rights -- relative to the customary law.

Does increased land scarcity lead to a move from informal to formal property rights institutions, from customary to statutory law? The answer depends critically on the amount of external claims, and to what extent there exist effective local management institutions which give protection against claimants. The latter is a key issue in the debate on communal resource management: can village institutions (1) provide security against internal, and possibly also external, claimants, and (2) regulate the resource use when the pressure on these resources increase, both by limiting the access by outsiders, and constraining the exploitation by the community members. The demand put on such institutions would clearly be much less in situations of land abundance.[28]

The existence and viability of such resource management institutions vary considerably. In the case of Seberida, the minority Talang Mamak group do have an *adat* system that in some respects remain a potent institution for resource management. The Malay ethnic group, which constitutes more than 90 percent of the traditional (non-transmigrant) population of Seberida, lack a corporate organization for resource management apart from the traditional village organization (Sandbukt, 1995: 63). Thus the two groups to some extent resemble the distinction made between regulated and unregulated common property regimes in section 2. However, uncertainty related to village boundaries arising from the 1979 village administration reform makes it difficult for the villages to exercise any jurisdiction. Thus, it remains an open question in our case to what extent the traditional tenure system could have provided an efficient management tool, even in a case when the demand on land only came from within the community.

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[28] See Baland and Platteau (1996) for a further discussion.

6 Endogenous tenure (in)security in a farm household model

There has, generally, been a marked lack of formal modelling of institutional change, which in part reflects the complexity of the issue, the many factors involved, and the difficulties of capturing these variables and their dynamic interrelations in a model.[29] It may also be a reflection of the institutional critique of conventional positions in economic theory, failing to distinguish between a critique of substance and a critique of methodology and level of formalism. We believe that much can be gained by formal modelling by clarifying the theory, sharpening the arguments, and ensuring consistency between the assumptions and conclusions.

The appendix presents an formal economic model which captures some of the main arguments in section five, and also can be applied to explain the development in the Seberida district (section 4.3). The main results of that model are presented and discussed in this section. The model focuses on tenure (in)security. Unlike most agricultural household models, including the ones presented in Angelsen (1994; 1996), tenure security is an endogenous variable; farmers choose the optimal level of security. How does this extension modify or change the results of conventional economic models?

By tenure security is meant the probability of keeping the land. In addition to being crop specific (rice and rubber), tenure security depends on three variables in the model (cf. Barzel, 1989: 2):

1. *Intensity of production.* Under both customary and statutory laws is a function of the labour efforts and other investments in the cultivation of the land. Much of the literature in the property rights school focus on the reverse link, i.e., higher tenure security leading to higher investments. In actual fact, the causality runs both ways, as it does in the model developed in the appendix.
2. *Enforcement efforts.* These include the process of obtaining land certificates (title deeds) at different levels of security and costs.
3. *External land claims.* These are claims to the land by users outside the community, against which customary law provides little protection.

The first two variables are chosen by the farmer, whereas the extent of external claims must be taken as given. In choosing the optimal level of intensity in production, a farmer not only looks at the *output-enhancing* effect of higher intensity, but also the *security-enhancing* effect. A model with *exogenous* tenure insecurity gives lower intensity compared to a full-security model. In the present model with *endogenous* tenure insecurity, however, the level of intensity might be higher than in a full-security model due to the reduced tenure-risk resulting from higher intensity.

The appendix analyzes the effects of more external land claims. The farmers' response could well be to *increase* the intensity of production and the enforcement efforts; higher "external" risk gives incentives for higher intensity and enforcement efforts to augment tenure security. This

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[29] One exception is Feder and Feeny (1991; 1993).

could outweigh the conventional economic effect of higher risk reducing the intensity of production.

An increase in intensity is more likely to be the outcome if land with low intensity of cultivation becomes relatively more probable to be lost to external claimants than high-intensity land. This is likely to the case in many empirical settings; increased intensity then becomes a strategy to secure land rights.

More external land claims could also affect the crop choice. We have argued that perennials (rubber) gives higher protection against external claims than annuals (rice). Consider a situation with no external claims, where rice is the most profitable crop. Introducing tenure insecurity in the form of external claims could make rubber yielding a higher *expected* profit than rice due to its higher tenure security. Thus other factors than changes in relative prices might be important in explaining crop choice changes.

The response to the tenure insecurity incurred by external claimants predicted by the model could, therefore, be a threefold strategy: rubber, intensification, and land certificates. This result is in line with empirical observations in our study area of Seberida (section 4.3 and Angelsen, 1995a; 1995b).

Another result which goes beyond the results of conventional economic models relates to the effect of land titling programmes, which could be considered a means to reduce the costs of enforcing property rights. It is generally argued that such programmes will increase the intensity of agricultural production by providing more secure land rights. The effect of lower enforcement costs is, however, ambiguous in the model. We have made the fair assumption that high intensity and enforcement are alternative means of securing land rights. Higher enforcement efforts (land titling) will therefore reduce the incentives for farmers to choose a high level of intensity due to its security-augmenting effect.

The possibility that the tenure security function is not globally concave in intensity and enforcement could result in discontinuities in farmers' adaptation. Both under customary and statutory law, it may well be that intensity and/or enforcement efforts must be beyond a certain level to have any significant impact on tenure security. This might result in large jumps in the optimal intensity and enforcement following small changes in prices, technology or external claims.

7 Conclusions

This paper has examined and tried to integrate various approaches to the study of the evolution of private property rights (EPPR) in traditional agrarian societies in general, and the shifting cultivation system in Seberida, Sumatra in particular. We have argued that neo-institutional economics (NIE) provides the most consistent and richest framework, which also can integrate elements from the three other approaches. The focus in NIE is on the demand for land or land scarcity, which again create increased competition and higher land value. The boost in land value was caused by the increase in the external claims for land, population growth, and improved profitability of rubber. This is one of two key factors to explain the development over then last decade in our study area, and represents the demand side in the "demand and supply for institutional change" metaphor.

The second main factor of empirical relevance to our case study is the tension between customary (*adat*) and statutory law, which is to a large extent overlapping with the conflict between state supported external claimants (logging, transmigration, plantation, and mining projects) and traditional, local farmers. This factor needs to be integrated in the NIE framework. As shown in section five, it could be done by regarding the customary and statutory law as two different institutions, providing the farmers with different degrees and forms of protection against third party interference. This gives the supply side in the demand-supply metaphor. The customary law gives one set of rules on how rights are obtained and secured, basically against claims from other members within the community. The statutory law, though it on paper recognizes customary law, has a different set of rules. Land certificates and intensive production are two major strategies to improve tenure security according to statutory law.

Increased land scarcity provides the main driving force towards individualization of the property rights. The increase in external claims strengthen this tendency, and also makes farmers increasingly secure their land claims in statutory law. Thus the evolution of private property rights is reflected in both the fact that within the customary land tenure system the individual rights are strengthened relative to common rights, and by an increased reliance on statutory law -- which only recognize individual rights -- relative to the customary law.

These tendencies express themselves on the ground by changes in the shifting cultivators' adaptation: an expansion of the area used by shifting cultivation, a sharp increase in rubber planting -- which also represents an intensification of the system, and an incipient tendency of obtaining land certificates. These observations are in line with the conclusions in the formal farm household model, which indicates that the farmers act according to basic economic logic. One needs, however, to extend conventional economic models to include how farmers' decisions influence tenure security to understand and explain the behaviour.

There are several reasons as to why one could expect the land value to increase in the future, both in our study area and in other areas of traditional agriculture: population growth, improvements in infrastructure which improves accessibility, and environmental problems in intensive agriculture which may lead to higher food prices. According to the NIE theory, we should therefore expect to see an increasing individualization of land rights. To what degree this mainly takes place within the customary law, or if customary law is replaced by statutory law, is more of a policy issue. It depends particularly on the state's protection of rights based on customary law and its support to external claimants.

Appendix: An analytical farm model with endogenous tenure security

The model analyzes farmers' decisions in a situation where their choices affect their land tenure security. We consider a plot of land, where two crops can be grown: rice (*C*) or rubber (*B*).[30] Tenure security, that is, the probability of keeping the land (*q*), is determined by three factors: the intensity of production (*I*), the enforcement efforts (*T*), for example, buying land titles[31], and the external land claims (*E*), cf. the discussion in section 6. Unlike *I* and *T*, *E* is not a decision variable to the farmer, and therefore exogenous in the model.

Intensity of production is used as a proxy for labour inputs, but can also incorporate other factors. If rice is selected, *I* could also reflect the frequency of cropping (as measured by years of cropping divided by the years of fallow). If rubber is selected, *I* could reflect the density of rubber trees (trees per ha) and the type of trees (high yielding *v.* traditional low yielding varieties).

$$(1) \qquad q^i = q^i(I^i, T^i, E); \quad q^i \in [0,1]; \; q^i_I, q^i_T > 0; q^i_E < 0; q^i_{II}, q^i_{TT}, q^i_{IT} < 0; q^i_{IE}, q^i_{TE} > 0; \; i = B, C$$

We assume that intensity of production and enforcement are alternative means of augmenting tenure security, i.e., $q^i_{IT} = q^i_{TI} < 0$. Whereas more external claims reduce tenure security ($q^i_E < 0$), it increases the marginal effect on tenure security of both intensity and enforcement (q^i_{IE}, $q^i_{TE} > 0$). For given values of *I*, *T* and *E*, rubber is assumed to give higher tenure security than rice ($q^B > q^C$), which is in line with empirical observations.

Output is a concave function of the intensity of production, $f^i(I^i)$. The expected net income (V^i) for a particular crop from the plot can be written as;

$$(2) \qquad V^i(I^i, T^i; E, p^i, w) = q^i(I^i, T^i, E)p^i f^i(I^i) - wI^i - vT^i; \quad i = B, C$$

p^i is the output price, w is the unit cost of intensity, for example, the opportunity costs of labour (nominal wage rate), and v is the unit cost of enforcement, reflecting, for example, the costs of obtaining a land certificate. This corresponds to a small, open economy assumption (all prices are exogenous), cf. Angelsen (1996). For simplicity the unit costs of both intensity and enforcement are assumed to be the same in both rice and rubber production; any differences are reflected in the production functions. Whereas the costs occur for certain, the value of the output ($p^i f^i$) must be multiplied by the probability of keeping the land. We assume that farmers are risk neutral, i.e., they maximize the expected income, which is another simplification that helps to

[30] To simplify the model we ignore time, including the fact that rice is an annual crop, grown at certain time intervals (rotation period) in a shifting cultivation system, whereas rubber is a perennial crop which after a lead period of some 6-12 years (depending on the type) can be tapped for several decades. We also abstract from the fact that rice is commonly grown the first year on the plot after clearance, before rubber is planted. Even if time is not modelled explicitly, the model is, in fact, equivalent to a two-period model *without discounting*, where the costs occur in the first period and the income in the second (cf. the somewhat different two period model in Feder and Feeny, 1993).

[31] In reality this would obviously be a discontinuous variable, a fact we abstract from in this model.

concentrate on the main points of the model.[32] Finally, we assume that V^i is concave in T and I, although this is relaxed later.

The choices for the farmers would then be:

- Which crop to select: rice or rubber?
- What should be the intensity of production?
- How much should be spent on obtaining a land certificate and other efforts in enforcing the property rights?

The solution to these problems is partly recursive; the farmer's problem is first to maximize (2) with respect to I and T for both rice and rubber, and then to select the crop which gives the highest net income.

The case with tenure based on customary law only (no external claims)

We consider first an isolated community (village) in the sense that there are no external land claims ($E = 0$). The tenure system is based on customary law; we then presume that there is no need to buy land certificates ($T = 0$). The optimal level of intensity (I) is characterized by;

$$(3) \qquad q^i(I^i,0,0)f_I^i + q_I^i(I^i,0,0)f^i(I^i) = \tfrac{w}{p^i}$$

Compared to a situation with full tenure security ($q^i = 1$), uncertainty introduces two new elements in the optimality condition. First, the fact that production is risky ($q^i < 1$) reduces the (expected) marginal output, and therefore also the optimal intensity and output level. Second, higher intensity augments tenure security, which pulls the level of intensity in the other direction. Unlike in a model with *exogenous* tenure insecurity ($q^i = \overline{q} < 1$), we *cannot* in the present model generally conclude that the level of intensity will be lower than in a model with full tenure security.

The effect of an increase in the real wage is;[33]

$$(4) \qquad \tfrac{dI^i}{d(w/p^i)} = \left[2q_I^i f_I^i + q^i f_{II}^i + q_{II}^i f^i(I^i)\right]^{-1} < 0$$

The effect of, for example, an output price increase is to augment intensity of production, as would be the case in a model with full tenure security.[34] This conclusion may, however, be modified when we also taken into account crop choice. Assume the initial adaptation is to produce rice. The rubber price increases, and if the increase is sufficiently large, it may induce a shift from rice to rubber production. The switch in crops *could* reduce the intensity, particularly

[32] Note that higher risk (lower q) in our model implies lower expected yield. Higher risk in terms of higher variance ("mean preserving risk") is not important as only expected values matter in the model.

[33] This result follows from the concavity assumption for V^i: $V^i_{II} < 0$ (second order conditions for maximum).

[34] As already noted, this model does not include time, and therefore not the rotation aspect of rice production in a shifting cultivation system. We know, however, that a forest multi-rotation model for shifting cultivation (with exogenous tenure security) also would give that higher output price results in intensification of the production system, both in terms of higher labour inputs and shorter fallow periods (Angelsen, 1994).

since rubber provides higher tenure security than rice, and therefore may reduce the incentives for choosing a high level of intensity due to its security-enhancing effect.

The case with external claims

In the case when there are external claims to the land ($E > 0$), the farmers have an incentive to make some enforcement to protect the land and increase tenure security. Assuming an interior solution ($T > 0$), the optimality conditions are (superscripts for crops are omitted to simplify notation);

(5) $qf_I + q_I f(I) = \frac{w}{p}$

(6) $q_T f(I) = \frac{v}{p}$

(5) is similar to (3), whereas (6) gives that the optimal level of enforcement is characterized by the last rupee spend on enforcement being equal to the gain in terms of the production value of the increase in tenure security.

Differentiation of (5) and (6) gives;

(7) $$\begin{bmatrix} 2q_I f_I + qf_{II} + q_{II} f(I) & q_{TI} f(I) + q_T f_I \\ q_T f_I + q_{IT} f(I) & q_{TT} f(I) \end{bmatrix} \begin{bmatrix} dI \\ dT \end{bmatrix} = \begin{bmatrix} -q_E f_I - q_{IE} f(I) & 1 & 0 \\ -q_{TE} f(I) & 0 & 1 \end{bmatrix} \begin{bmatrix} dE \\ d\frac{w}{p} \\ d\frac{v}{p} \end{bmatrix}$$

The determinant of the Hessian is assumed to be positive;

(8) $$D = \begin{vmatrix} 2q_I f_I + qf_{II} + q_{II} f(I) & q_{TI} f(I) + q_T f_I \\ q_T f_I + q_{IT} f(I) & q_{TT} f(I) \end{vmatrix} > 0$$

Together with the assumption of $q_{TT} < 0$, this gives the second order sufficient conditions for maximum.

Effects of more external claims

Using Cramer's rule, the effect an increase in external claims on the level of intensity can now be written as;

(9) $$\frac{dI}{dE} = -\frac{1}{D}\{q_{TT} f(I)[q_E f_I + q_{IE} f(I)] - q_{TE} f(I)[q_{TI} f(I) + q_T f_I]\} \gtrless 0$$

There are three different effects to consider. First, higher E increases the tenure risk, which reduces the expected marginal productivity of intensity. This is a standard effect in the theory of the firm: reduced expected value of output (i.e., higher risk in our model) makes the firm reduce the production. The risk is, however, also affected by the level of intensity. More external claims *increases* the risk-reducing effect of high intensity ($q_{IE} > 0$), and this provides an incentive to *increase* intensity of production. These effects are similar to those discussed in relation to (4). A third effect concerns the effect on I of changes in T. As discussed below, T is likely to increase. As a high level of intensity and enforcement are assumed to be alternative means of securing land rights ($q_{TI} < 0$), this effect will then pull in the direction of reduced intensity. The net effect on intensity is therefore ambiguous.

The effect on the enforcement efforts of more external land claims is given by;

$$(10)\qquad \frac{dT}{dE} = -\frac{1}{D}\{q_{TE}f(I)[2q_I f_I + qf_{II} + q_{II}f(I)] - [q_T f_I + q_{IT}f(I)][q_E f_I + q_{IE}f(I)]\} \gtrless 0$$

The direct effect of higher competition for land in the form of more external claims is to increase the effect on tenure security of property rights enforcement ($q_{TE} > 0$). There is, further, an indirect effect due to changes in I. If I is reduced (conventional case), this provides an additional incentive to increase T. If I increases, this effect will be the opposite of the direct effect. Hence in the case when I decreases, we can conclude that T will increase, whereas the net effect is ambiguous in the case when I increases following an increase in E.

Figure 2 provides an illustration of how intensity of production may depend on the level of external claims. We still consider only one crop. The figure assumes that T is chosen optimally given the different levels of I. The effect of an increase in external claims (E) depends critically on the way it affects q at different levels of intensity. If the reduction in q is the same for all levels of intensity, the effect of an increase in external claims is equivalent to an output price reduction. The result is *reduced* intensity of production.

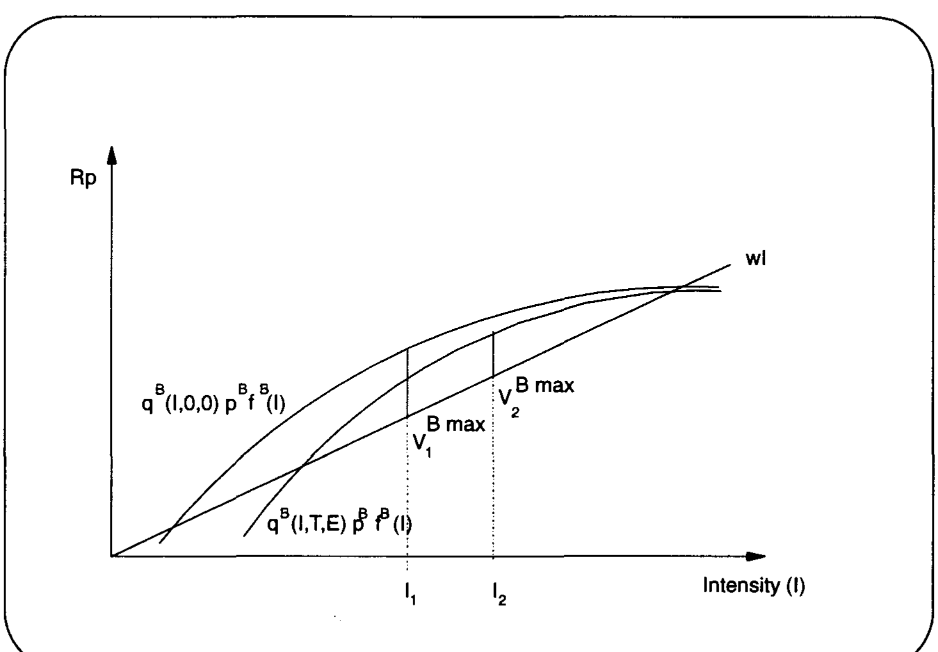

Figure 2. The effect of external land claims on intensity of rubber production.

A more realistic description would be that the effect on tenure security of external claims is highest at low intensity levels, as we have assumed in the model ($q_{EI} = q_{IE} > 0$). In Figure 2 we compare two situations; without (1) and with (2) external land claims. Assume, for example, that without external claimants farmers have full security at all levels of intensity. When external claimants enter the scene, low intensity land is more likely to be lost to external claimants compared to land under intensive production. Intensification has on the margin become more beneficial because it increases tenure security more than it did in the first place. The effect of more external claims may now be to *increase* the intensity of production, contrary to conventional economic logic which suggests that lower expected yield (higher risk) will reduce the scale of the activity.

Effects of price changes

The effects of changes in the real price of intensity are;

(11) $$\frac{dI}{d\frac{w}{p}} = \frac{1}{D} q_{TT} f(I) < 0$$

(12) $$\frac{dT}{d\frac{w}{p}} = -\frac{1}{D}[q_T f_I + q_{IT} f(I)] \gtrless 0$$

As in the case with no external land claims, one can unambiguously conclude that higher real costs of intensity (e.g., real wage) will reduce the level of intensity, as intuitively expected. The effect on enforcement efforts is ambiguous. The fact that I is reduced and production declines implies a smaller harvest to protect. This reduces the incentives to undertake enforcement of property rights. Reduced intensity, however, also implies higher marginal gains in terms of improved tenure security of the enforcement efforts ($q_{IT} < 0$). Intuitively, one could expect the first effect to dominate such that a real wage increase will lower the enforcement.

The effects of changes in the costs of enforcement are;

(13) $$\frac{dT}{d\frac{v}{p}} = \frac{1}{D}[2q_I f_I + q f_{II} + q_{II} f(I)] < 0$$

(14) $$\frac{dI}{d\frac{v}{p}} = -\frac{1}{D}[q_{TI} f(I) + q_T f_I] \gtrless 0$$

Higher real costs of property rights enforcement will, as expected, reduce the enforcement efforts. A reduction in T has two opposite effects on the optimal level of intensity. Again, since intensity and enforcement are alternative ways of improving tenure security, lower T provides an incentive for higher I. Lower T, however, also reduces the absolute level of tenure security, which means that production is more risky, which pulls in the direction in lower intensity.

Land titling programmes to provide cheaper (and more secure) titles to farmers could be viewed as reduction in v. One argument for such programmes is that more secure property rights will increase the incentives for more intensive cultivation as well as better management of the resources. Whereas this certainly is an important effect in our model, the net effect is ambiguous;

lower costs of enforcement could *reduce* the intensity of production because the role of high intensity in protection land rights has become less important.

Rice-rubber choice

So far we have looked at only one crop. Figure 3 illustrates the choice between rice and rubber, and how this choice may be affected by external claims. We assume an initial situation with no external claim, and where rice cultivation gives the highest income; the curve for the expected value of rice is higher than the corresponding curve for rubber when $E = 0$. In drawing the curves we have assumed that I and T are optimally chosen for each level of E.

When introducing external claims, the expected rice-income curve will fall more rapidly than the expected rubber-income curve, because the fields growing rice, for example, in a shifting cultivation system, will have their tenure security reduced more than the rubber fields, i.e., $|q_E^C| > |q_E^B|$. When the amount of external claims reaches a certain level, E^*, it will be beneficial for the farmer to switch from rice to rubber. The tenure insecurity under rice cultivation has become so high that it has more than outweighed the initial superior profitability of rice cultivation.[35]

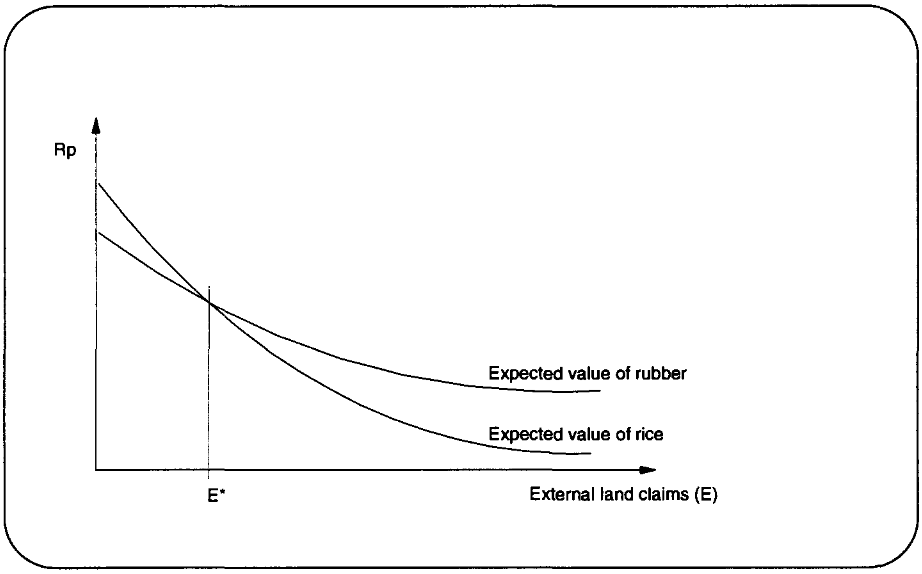

Figure 3. The effect of external land claims on crop selection.

This illustrates that other factors than relative prices may be important in determining farmers' choices. The shift from rice to rubber which has taken place in the Seberida, Sumatra could in part be explained by such tenure security considerations (Angelsen, 1995a; 1995b).

Discontinuities

So far we have assumed that the tenure security function is concave in intensity ($q_{II} < 0$). An alternative formulation is that $q()$ is concave for small values of I, then convex for intermediate

[35] Note that the effect of a price increase discussed in the previous sub-section is easily illustrated in this figure, by moving up/down the expected value curves.

values, before it turns concave for high values of *I*. One argument for this shape would be that there exists a kind of threshold level when it comes to the effect of intensification on tenure security; for low intensities small intensity changes do not affect the tenure security significantly. Related to the discussion in section 4.2, land is still considered under *hak ulayat* and receives almost no legal protection in conflicts with "national interests". Beyond a certain level of intensity, the farmer could expect the land to be under *hak milik* with much better legal protection. Such a shape of *q()* could make also the V^i-function have a convex segment for medium values of intensity, as illustrated in Figure 4.

Suppose we initially are in situation 1, where intensity of production is relatively low. Then the output price increase or the costs of intensity (w) decrease. It is then possible to get a large jump in intensity, as we move from the low intensity concave segment to the high intensity concave segment of the curve for the expected value of output. Small changes in the prices of output or intensity may therefore cause large shifts in the intensity, even if the same crop is produced in situation 1 and 2.

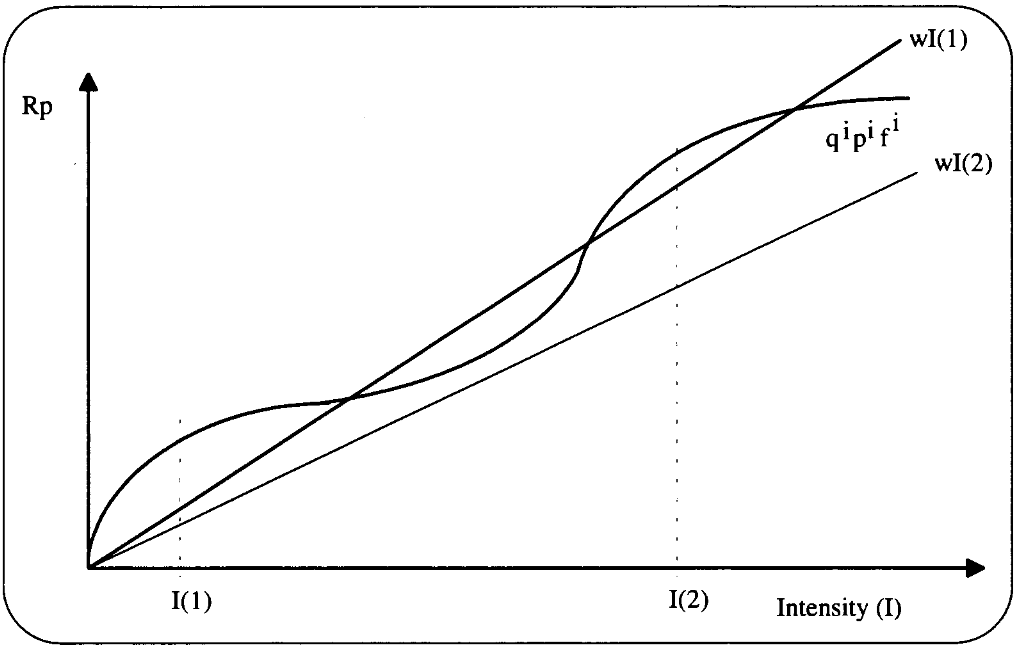

Figure 4. The case when the Vi-function has a convex segment for medium levels of intensity.

Similarly, one could argue for the possibility that the q-function is convex in T for intermediate values, which may cause large jumps in enforcement efforts following small changes in, for example, the costs of enforcement (v).

Possible extensions

The above model is based on a number of simplifying assumptions, which could be modified. The small open economy approach (all prices exogenous) could be replaced by a situation where the households are quantity constrained in the labour market, cf. Angelsen (1996). In that case the households' objective should be to maximize utility rather than income. This will introduce income effects in the comparative statics, which could modify or even turn around some of the results. The (expected) utility approach also allows for a discussion of risk aversion.

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Chapter 6

State - Local Community Games of Forest Land Appropriation*

Abstract:

This paper explores possible strategic interactions between the state and local community in games of tropical forest land appropriation. Two key questions are addressed. First, how does the structure of the game influence the extent of deforestation? Second, under which circumstances does higher forest appropriation by the state promote local deforestation? Three different cases are discussed, corresponding to a development over time towards increased forest land competition and integration of the local community into the national economy. Particular attention is given to the assumptions made about the local economy and the local costs of state deforestation. The local response to more state appropriation depends critically on these assumptions, and less on the structure of the game (Cournot or Stackelberg). The state will fuel local deforestation if state deforestation is associated with provision of infrastructure (roads) which reduces the local costs of agricultural expansion, or if the local economy is isolated (autarky) and local behaviour is determined by survival needs rather than income maximization.

* Thanks to Rögnvaldur Hannesson, Karl O. Moene, Ottar Mæstad, Karl R. Pedersen, Ussif Rashid Sumaila, and Arne Wiig and other colleagues at CMI for comments to a draft version of the paper.

1 Introduction

Several studies of deforestation within the political economy tradition focus on the conflict between the state or state sponsored users and local, traditional users in the utilization of tropical forest resources (e.g., Colchester, 1994; Colchester and Lohmann, 1993; Bromley and Chapagain, 1984). There have, however, been few (none?) attempts on formal modelling of such conflicts and the strategic behaviour they may give rise to.[1] This paper attempts to formalize the interaction between the state and a local community in forest land appropriation by applying relatively simple game theoretic models.

A central issue to be addressed is the effect on local forest clearing of higher forest appropriation by the state. Does state deforestation stimulate or replace local deforestation? Under which circumstances does the state fuel local "land grabbing"? Further we want to explore the impact on the overall level of deforestation (state and local) of different kinds of strategic interaction between the state and the local community (structure of the game).

The models of this paper are complementary to Angelsen (1996b), which studies the effects of external land appropriation on farmers' choices related to tenure security, and Angelsen (1994; 1996a), which study the effects on agricultural land expansion. These models assume parametric interaction. The present paper focuses on *strategic* behaviour and interactions, that is, where the players take into account the effect of their choice on the other player's choice of forest appropriation.

There is a substantial literature which uses game theory to study resource problems. A large share of this literature analyzes resource management issues by using binary choice models, for example, prisoner's dilemma (PD) or assurance games. Baland and Platteau (1996) and Ostrom *et al.* (1994) are among the best examples of the usefulness of such an approach, which -- due to its simplicity and flexibility -- can be used to study a variety of resource games. The Cournot game presented in this paper can be considered a continuous choice version of the conventional (binary choice) PD game. The continuous choice model offers, however, a richer approach as one can study the local response to exogenous changes in situations where one, both before and after the change, has non-cooperation in a PD game.

Another large sub-category of the literature deals with dynamic games, which in addition to the multi-period strategic interaction between economic agents, also incorporates the resource dynamics (differential games). The latter is particularly important in games involving renewable resources with high growth rates, for example, fish (e.g., Levari and Mirman, 1980). In our model, which is a game of land appropriation, this aspect is of much less relevance. Compared to the static games studied in this paper, dynamic games could offer additional insights by studying

[1] A comprehensive review by Kaimowitz and Angelsen (1997) on economic models of deforestation does not find any such models.

the interaction over time. The approach of this paper is, however, to explore the implications of the underlying assumptions in relatively simple games rather than to use simplistic assumptions in more complex, dynamic games. Hopefully, static (Cournot) or simple sequential (Stackelberg) games reveal important structures and incentives of real-life games which, obviously, are dynamic.

A critical assumption for applying game theoretic models of only two players is that the local community and the state can be viewed as single actors. Are there mechanisms, for example, in terms of local resource management institutions, uniform ways of thinking and responding, etc. within the local community which make it appropriate to study the local community as one agent? If not, the situation is better studied as one of open access, that is, games with a very large number of players. As is well known from the literature, the Nash-Cournot equilibrium converges to the competitive market equilibrium when the number of players increases. The latter situation has already been discussed in Angelsen (1994; 1996a). The game models of this paper explore another extreme with only two players. Thus the models of the present and the complementary papers analyze two extreme situations, while we keep in mind that actual behaviour shows great variation between these.

The outline of the paper is as follows. Section two presents the basic elements of the models. Three different cases or games are discussed in the following sections. In section three we focus on a poor, isolated local community. The interaction with the state is studied as a static game with simultaneous moves (Cournot). Section four discusses a situation with higher forest land scarcity and a local-led land race, that is, the local community is the leader in a Stackelberg game. Section five analyzes a case with intense resource scarcity and competition, and a local community integrated into the regional/national economy. The state is assumed to be the Stackelberg leader in this case. Section six compares the different cases, discusses possible developments over time in the local response, and the possibilities for cooperation in forest management. The final section concludes.

2 Preliminaries

We consider a given forest area (H^T) which has three uses: it can be converted to agricultural land by the local community (H^L), to plantations, logging or other large scale projects by the state (H^S), or it can remain virgin/natural/primary/pristine/old-growth forest (H^F).

(1) $$H^T = H^L + H^S + H^F$$

We assume that the state and local community each choose the level of H^S and H^L, respectively. New forest land is allocated on a first-come-first-served-basis.[2]

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[2] Forest clearing may give more permanent land rights, as assumed in model IV in Angelsen (1996a). In this case the income and cost variables should be interpreted as discounted values. Tenure

Local income

The income to the local community and the state are functions of land area converted for their own use, as well as the remaining natural forest. The local forest benefits of primary forest would be in the form of non-timber forest products and various protective functions, whereas the state would benefit from it in the form of, for example, eco-tourism and protective functions, as well as more intangible benefits such as existence values and a green image.[3] The net income to the local community is given by;

$$(2) \qquad L = l(H^L, H^S) = r(H^L) + t(H^F) - \int_0^{H^L} c(H^T - H^S - x, H^S)dx$$

$r(H^L)$ is the gross revenue of forest clearing for agricultural production, for simplicity assumed to be a function of land area only (decisions about, for example, labour input are not included). $t(H^F)$ gives the income from primary forest as a function of total forest area. We do not distinguish between gross and net benefits of virgin forest. We assume decreasing returns, for example, because land is of heterogeneous quality (t_1, $r_1 > 0$, t_{11}, $r_{11} < 0$).

The last element in (2) gives the aggregate cost of agricultural production. The properties of the local cost function are critical for some of the later results. $c(H^F,H^S)$ is the marginal costs of land expansion. First, a larger primary forest area will reduce the costs as new land is more easily available ($c_1 < 0$), but this effect is diminishing ($c_{11} > 0$). Second, state forest clearing has a cost reducing effect on the marginal costs of expansion, as it provides infrastructure, particularly roads ($c_2 < 0$), also at a decreasing rate ($c_{22} > 0$). The net effect of increased state appropriation on the costs is therefore ambiguous: $\frac{\partial c}{\partial H^S} = c_2 - c_1 \gtrless 0$. A land scarcity effect increases the marginal costs, whereas an infrastructure effect reduces the cost of agricultural land expansion. From the assumptions made, the first effect will increase relative to the second as H^S increases: $\frac{\partial c^2}{\partial^2 H^S} = c_{11} + c_{22} > 0$.[4] We then have three possibilities: (1) the expression (c_2 - c_1) is negative for all relevant combinations of H^S and H^L, (2) it is positive for all relevant combinations, and (3) it

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insecurity could then be included by reducing the discounted values, a practice known as risk discounting. If local tenure security is inversely related to the level of state appropriation (as in the model of endogenous tenure security in Angelsen, 1996b), this could also be included in the model in a relatively straightforward manner. To keep the focus on the main mechanisms of the game we shall, however, abstract from the issue of tenure insecurity, noting that the chosen model formulation can be given alternative interpretations.

3 Virgin forest is to be considered a public good both in the sense that there is *no rivalry* between local and state uses in consumption of services derived from *a certain virgin forest area,* and *exclusion is impossible.* (The latter requirement is, in fact, redundant as there would be no incentive to exclude others since there is no rivalry and the public good is provided for free.) Note that the non-rivalry assumption relates to the two actors in our model at the aggregate level, and not, for example, between villagers in the utilization of fuelwood from a given forest area. Finally, we note that the *total* forest benefits depend on total virgin forest area; thus there is rivalry in land allocation.

4 We assume $c_{12} = c_{21} = 0$.

is negative for low levels of H^S (and H^L) and positive for high levels. Intuitively, the last two possibilities appear to be the most realistic ones.

State income

The state revenue is determined in a similar manner, except that local forest clearing does not have any cost reducing effects through provision of infrastructure. We assume that the state is only concerned with maximizing own income (a predatory state) and not total income (a developmental state). This assumption is discussed further in case 1 and relaxed in Appendix 1.

(3) $$S = s(H^S, H^L) = v(H^S) + g(H^F) - \int_0^{H^S} h(H^T - H^L - y)dy$$

v() is the gross income from forest appropriation by the state, whereas *g()* is the state's benefits from primary forest. The benefit functions are strictly concave (g_I, $v_I > 0$, g_{II}, $v_{II} < 0$). The marginal cost of forest appropriation, $h(H^F)$, is lower the larger the area of virgin forest, but this effect is diminishing ($h_I < 0$, $h_{II} > 0$).

The formulation in (1) implicitly assumes that state and local land uses are mutually exclusive. This may be a fair assumption for land uses which involves forest clearing and permanent use of the land, for example, permanent agriculture, plantations, hydropower and infrastructure developments. For other uses, particularly logging, this may not be the case. Logging companies are basically interested in the big trees, not the land. Farmers' main interest is in the land (soil) for cultivation. Thus, as observed throughout Asia, shifting cultivators may follow in the wheel tracks and clear logged forest. Related to our model, this could be interpreted as each hectare of state deforestation having a strong infrastructure component; the infrastructure effect will be strong relative to the land scarcity effect ($c_2 - c_I < 0$).

Three key assumptions

We identify three critical assumptions in the modelling of state local interactions, cf. also Appendix 2: (i) the effect of state deforestation on local expansion cost, (ii) the degree of openness of the local economy, and (iii) the structure of the game. Each of these reflects the empirical variation found in developing countries, and they are briefly examined below.

First, *the effect of state forest appropriation on the marginal costs of local forest clearing*, as discussed above. The strength of the land scarcity effect *v.* the infrastructure effect of higher state forest clearing depends on particularly two factors. In a forest abundant situation the infrastructure effect will be relatively stronger, as included in the assumptions about the cost function. It also depends on the type of forest conversion by the state: logging has a stronger infrastructure component relative to area directly cleared compared to, for example, plantations or commercial agriculture.

Second, *the openness of the local economy.* As shown elsewhere (Angelsen, 1996a), the response of farm households depends critically on the market assumptions. In particular, it is crucial whether an off-farm labour market exists or not, for example, through migration, such that the opportunity costs of labour can be taken as exogenous in the model. In that case the model becomes recursive: the production decisions can be separated from the consumption decisions and studied as a profit maximizing problem. If some prices are *not* market-determined, the production and consumption decisions must be solved simultaneously and the behaviour of the local community is studied as a utility maximizing problem; see Angelsen (1996a) for a further discussion.

The distinction between profit and utility maximizing local behaviour relates particularly to the labour market assumption. This depends, *inter alia,* on the openness of the local economy and the existence of an off-farm sector and its size relative to the agriculture/forestry sector. It also relates to the time horizon for the analysis; the small, open economy assumption is relatively more relevant for long term analysis when migration is an option. In the first two cases we assume a local autarky, i.e., the local community's deforestation decisions are studied as a utility maximizing problem. In the third we use the conventional profit-maximizing approach, which corresponds to the small, open economy assumption.

Third, *the structure of game*. We analyze three types of games. In the first case we assume a static game with simultaneous moves (Cournot). Then we look at sequential, two period games (Stackelberg). In the second case the local community moves first (leader) and the state second (follower). In the third case, we reverse the sequence, and let the state be the leader.

In each game we study the Nash equilibrium, being defined as "a set of strategies, one for each player, such that given the strategies being played by others, no player can improve her pay-off by adopting an alternative strategy" (Heap *et al.,* 1992: 101). The equilibrium in the Cournot game is often referred to as the Nash, Nash-Cournot or Cournot equilibrium; we use the term Cournot equilibrium as all equilibria studied in this paper (including Stackelberg) are Nash equilibria.

The Cournot equilibrium is at times referred to as a zero conjecture or independent adjustment equilibrium; the players do not expect any change in the opponent's decision variable when they change their own decision variable, and the equilibrium is reached after an adjustment process. An alternative, more appropriate and "modern" interpretation of how the equilibrium is reached is the following: when the players move simultaneously, both assume the other to make a rational choice, they have rational expectations about the opponent's choice, and then both select simultaneously the best strategy given that the opponent does the same.

The structure of the game is similar to a standard Cournot game of duopoly (e.g., Shapiro, 1989; Friedman, 1983), and have also similarities to games of public goods provision (e.g., Cornes and Sandler, 1986).[5] A special feature of this paper is a careful specification of the local objective function (preferences and market assumption) and the cost structure, and the analysis shows that conventional conclusions from this literature cannot readily be replicated in state-local resource games.

In a leader-follower or Stackelberg game, the follower observes the leader's choice and chooses the optimal strategy based on that in a similar manner as in the Cournot game. The leader, choosing first, anticipates the response of the follower, and includes the follower's response in his optimization problem.

Three cases

As already indicated, formal modelling of state-local interactions in forest resource use represents a new research area. It is therefore hard to find factual evidence for which games that will apply in different empirical contexts. Even in empirical research it may be difficult to reveal the exact structure of the game and the sequence of the moves. Indeed, this is a general problem in applying game theory: the theory provides few empirically verifiable criteria for which structure of the game that should be assumed in the model. The discussion of the empirical relevance of the different structures of the game therefore becomes somewhat tentative, and clearly calls for further investigations. One argument could be that the Stackelberg games represent situations where one of the players is more aggressive than the other.

By varying the three key assumptions discussed above we get 12 different games, cf. Appendix 2. We have chosen to focus on three cases. The case studies have been selected partly based on their perceived empirical relevance, and partly to review the implications of different assumptions: how robust are the conclusions to variations in the assumptions?

Case 1 deals with a poor, isolated local community, where the interaction with the state is studied as a Cournot game. Case 2 discusses a situation with higher forest land scarcity and a local-led land race, that is, the local community is the leader in a Stackelberg game. Case 3 analyzes a situation with intense resource scarcity and competition, and a local community integrated into the regional/national economy. The state is assumed to be the Stackelberg leader in this case. In some respects, the three cases correspond to a possible development over time in

[5] Whereas there are some similarities with the standard duopoly games, one should also note some important differences. First, there is no competition in an output market in our model, only in forest appropriation. Second, and related to the first, there is no price as such in the model; thus we only have games of quantity competition. Third (and more relevant to dynamic models), there are no separation between investment and production decisions, as the income is a function of only land investments (forest clearing). Fourth, as will be seen below, the local response curve may be forward bending.

terms of (i) increased resource scarcity, (ii) increased integration of the local community in the regional/national economy, and (iii) more aggressive behaviour by one of the players.

3 Case 1: Poor, isolated local community

In the first case we consider the interaction between state and local deforestation in the context of a poor, isolated local community. This case could describe the situation for many tribal communities. Their livelihood, based on forest income from hunting, gathering and extensive forms of agriculture such as long-fallow shifting cultivation, is being undermined as the area of natural forest declines through state appropriation. Examples of this situation are found in the Amazon and Southeast Asia, e.g., Colchester and Lohmann (1994).

We have identified three key assumptions in state - local games: the type of game, the local economy, and the local cost effects of state deforestation. In the poor, isolated local community case we assume the following for each of these.

Type of game: The most difficult assumption relates to the type of game that should be modelled; it is hard *a priori* to determine the game formulation that most realistically describe the situation. We shall analyze a Cournot game in this case, that is, a static game with complete information, and both players choose their strategy simultaneously.

Local economy: In our case when the local community is isolated, the utility maximizing approach is the relevant one. We make the assumption that all income is derived from agriculture and direct forest uses (no off-farm income).

Local cost structure: Poor, isolated forest communities are normally associated with forest abundance, which suggest that the infrastructure effect will dominate. The technological level among such communities -- most transport is done by foot -- implies, however, that they may not make much use of state provided infrastructure. We shall therefore not make any *a priori* assumptions about which effect dominates.

The state's response curve

The objective of the state is to maximize income as given in (3). The state will then choose the amount of land for plantations, logging, etc. such that the following first order condition is satisfied;[6]

(4) $$s_1 = v_1 - g_1 - h(H^F) = 0$$

The first element gives the marginal gross income from forest conversion, whereas the last two are the costs in terms of reduced forest benefits (opportunity costs) and the direct costs related to forest clearing.

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[6] It follows from the assumptions made that $s_{11} < 0$.

The optimal amount of land clearing by one agent is a function of the amount appropriated by the other. We define the optimal levels of H^S as a function of the local community's choice, i.e., the *response or reaction function* for the state;

$$(5) \qquad H^{S*} = H^S(H^L)$$

To explore the characteristics of the response function, we differentiate (4) to obtain;

$$(6) \qquad \frac{dH^{S*}}{dH^L} = -\frac{s_{12}}{s_{11}} = -\frac{g_{11}+h_1}{v_{11}+g_{11}+h_1} < 0$$

The response curve of the state of backward sloping in an H^L- H^S diagramme for two reasons. More local forest clearing implies that the remaining forest becomes more valuable, i.e., the net marginal benefits of virgin forest (g_{11}) and the opportunity costs of conversion increase. Further, the marginal costs of forest conversion will be higher as the remaining forest is less suitable or accessible (h_1).

The iso-profit curves for the state are defined by setting $S = \bar{S}$. The shape of the curves is found by total differentiation of (3);

$$(7) \qquad \frac{dH^L}{dH^S} = -\frac{s_1}{s_2} = -\frac{v_1-g_1-h(.)}{-g_1+\int_0^{H^S} h_1 dy}$$

Whereas the response curve shows the *optimal* response to changes in the other player's choice, the iso-profit curves simply show the change necessary to maintain the same income. s_2 is always negative, whereas s_1 is positive for small values of H^S, zero in optimum (cf. (4)), and negative for larger values. Thus the state's iso-profit curves will therefore be inverted C-shaped in an H^L-H^S diagramme.

We have assumed a rather narrow objective function for the state, in the way that only own income is maximized. The implications of including local income in the state's objective function (a developmental state) are examined in Appendix 1. Under realistic assumptions the response curve will still be downward sloping, but the location and slope will change. If the land scarcity effect dominates, for example, the curve will move downwards. Nevertheless, since the qualitative results only depend on the slope of the response curve we do not pursue the case with a more developmental state.

The local response curve

Local behaviour is studied as a problem of balancing the utility of consumption and the disutility of labour. This is known as the Chayanovian model in agricultural economics. The cost related to agricultural expansion and cultivation is expressed in terms of labour; $c(H^F,H^S)$ therefore represents the labour input required for a marginal expansion of agricultural land. Formally, the problem is one of maximizing;

(8) $$U = U\left(r(H^L) + t(H^F), \int_0^{H^L} c(H^T - H^S - x, H^S)dx \right) = u(H^L, H^S)$$

We assume the utility function to be well-behaved, cf. Angelsen (1996a). The optimality condition is given by;

(9) $$u_1 = 0 \Leftrightarrow r_1 - t_1 - zc(H^T - H^S - H^{L*}) = 0; \; z \equiv -\frac{U_2}{U_1}$$

Net marginal income from forest conversion (r_1 - t_1) should in optimum equal the marginal labour requirement for land expansion multiplied by the shadow wage rate (z). z can also be given the interpretation as the virtual price of labour. As discussed in Angelsen (1996a: appendix 1), the use of virtual prices facilitates the comparative statics. The substitution effect is given by keeping z constant, whereas the income effect is determined by the change in z.

(9) implicitly defines the optimal local deforestation (H^{L*}) as a function of H^S, or the response function.

(10) $$H^{L*} = H^L(H^S)$$

The inverse of the slope of the response curve H^L-H^S diagramme is;

(11) $$\frac{dH^{L*}}{dH^S} = -\frac{u_{12}}{u_{11}} = -\frac{t_{11} - z(c_2 - c_1) - c(.)z_{HS}}{r_{11} + t_{11} + zc_1 - c(.)z_{HL}} \gtrless 0; \; z_{H^S} \equiv \frac{\partial z}{dH^S}, z_{H^L} \equiv \frac{\partial z}{dH^L}$$

The denominator in (11) is negative, corresponding to the second order conditions for maximum ($u_{11} < 0$). The response of the local community to higher H^S, i.e., the sign of u_{12}, is ambiguous. The analysis of the sign of the numerator in (11) is done in two steps. In the first step, we assume that z is fixed, corresponding to a small open economy approach (only substitution effects apply). There are three effects to consider. *First*, more land appropriated by the state means that the net marginal benefits of virgin forest increases (t_{11}), i.e., the opportunity costs of agricultural conversion increases. *Second*, the marginal costs of land expansion will be higher as the remaining forest is less suitable for agricultural production or is less accessible (c_1). *Third*, state clearing provides infrastructure which has the opposite effect on land expansion (c_2). If the latter effect is sufficiently large, the response may be positive. As shown above, the third (infrastructure) effect will be relatively larger to the second (land scarcity) effect the lower the level of H^S, whereas the impact on the first effect cannot be determined from the assumptions made. However, we can conclude that if the infrastructure effect is sufficiently strong the expression (t_{11} - $z(c_2$ - $c_1)$) in (10) will be positive.

In the second step, we must also consider the effect of changes in the shadow wage rate (z), which reflects the income effects. We always have $z_{H^L} > 0$ as higher H^L increases income and labour input, both of which augment the shadow wage rate. The effect of higher H^S is more complicated. Assuming additive utility (U_{12} = U_{21} = 0), we get;

$$(12) \qquad z_{H^S} = -\frac{U_{22}U_1\int_0^{H^L}(c_2-c_1)dx+U_{11}U_2t_1}{U_1^2} \gtrless 0$$

There are two different effects on z. First, higher H^S affects the total costs as shown by the first element in the numerator. If the land scarcity effect is strong (c_2 - c_1 > 0), more state deforestation implies higher labour input and therefore higher z. If the infrastructure effect is strong, however, more state deforestation will reduce z. Second, higher H^S will reduce the income by lowering the primary forest area, which reduces z. In the case where the infrastructure effect is strong, (12) is therefore unambiguously negative.

In the case of small infrastructure effects, (12) may be positive or negative. I have in Angelsen (1996a; 1996c) used and discussed an additive utility function with a subsistence consumption level. This formulation gives, in accord with economic intuition, that the income effect dominates the substitution effect when consumption is close to the subsistence level, or when the preferences are such that marginal utility of consumption above the subsistence level is rapidly declining. This implies that the absolute value of U_{11} will be large and the second element in the numerator dominates. Hence in poor local communities we could expect $z_{H^S} < 0$.

Returning to the numerator of (11), there is now a fourth effect to consider related to the change in z (income effect). A lower z will pull in the direction of more local forest conversion as the (subjective) costs are lowered; a higher z will reduce local deforestation.

In summary, if the infrastructure *or* the income effects (or both) are strong, we get a forward bending local response curve ($u_{12} > 0$). In our case we have assumed the local community to be poor, which implies strong income effects. The qualitative response will in this case be as in a "full belly" model, that is, when the local preferences are such that they minimize labour efforts given a subsistence target.[7]

The local indifference curves are defined by setting $U=\overline{U}$, and the curvature is found by differentiation of (8);

$$(13) \qquad \frac{dH^S}{dH^L} = -\frac{u_1}{u_2} = -\frac{r_1-t_1-zc(.)}{-t_1-z\int_0^{H^L}(c_2-c_1)dx}$$

[7] An extreme version of the utility maximizing approach is to assume that the local community has lexicographic preferences: the households shall reach a subsistence level of consumption or income (Q) at minimum labour costs ("full belly" preferences). The optimization problem is very simple in this case: the local community gets a basic income from natural forest, $t(H^F)$, and then clears as much forest as required to reach the subsistence target, given by $r(H^L) + t(H^F) = Q$. This also defines the response curve of the local community. Differentiation yields the inverse of the slope of the response curve; $dH^{L*}/dH^S = t_1 / (r_1 - t_1) > 0$, i.e., the response curve is forward sloping. More state deforestation reduces the local forest income, and this has to be compensated for by expanding agricultural land area. The slope depends on the marginal income from the two types of land use. If the marginal benefits from non-timber forest products are small relative to the benefits from agricultural land, state forest clearing only has modest effect on local agricultural expansion.

u_1 goes from being positive to negative as H^L increases, and is zero in optimum. The shape of the indifference curves depends on the sign of u_2, which may be either positive or negative. When the infrastructure effect is small, $u_2 < 0$. The local iso-profit curves are then inverted U-shaped.

Note that the conditions for inverted U-shaped indifference curves are not the same as the condition for a backward bending response curve, although they are related. The latter condition ($u_{12} < 0$) concerns the effect of higher state clearing on the *marginal* utility of local agricultural expansion, whereas the first ($u_2 < 0$) reflects the effect on *total* utility. Moreover, the sign of u_{12} is influenced by the relative strength of the income effect, whereas u_2 is not.

Given our assumptions about the cost function, it is possible for a certain range of values of H^S that $u_{12} < 0$ and $u_2 > 0$. In addition, it may well be that the infrastructure effects are small ($u_2 < 0$) but that the response curve is forward bending due to strong income effects ($u_{12} > 0$). To simplify the presentation, we shall in the following assume a forward bending response curve due to strong income effects and that the indifference curves are inverted U-shaped, i.e., there are small infrastructure effects of state deforestation.

Cournot equilibrium

The Cournot equilibrium is given where the two response curves intersect (*A*) in Figure 1. This is the only point where the level of forest clearing, for both players, is the best reply to the level chosen by the other. In other words, there is consistency for both players between their own optimal level of forest clearing and the level chosen by the other.

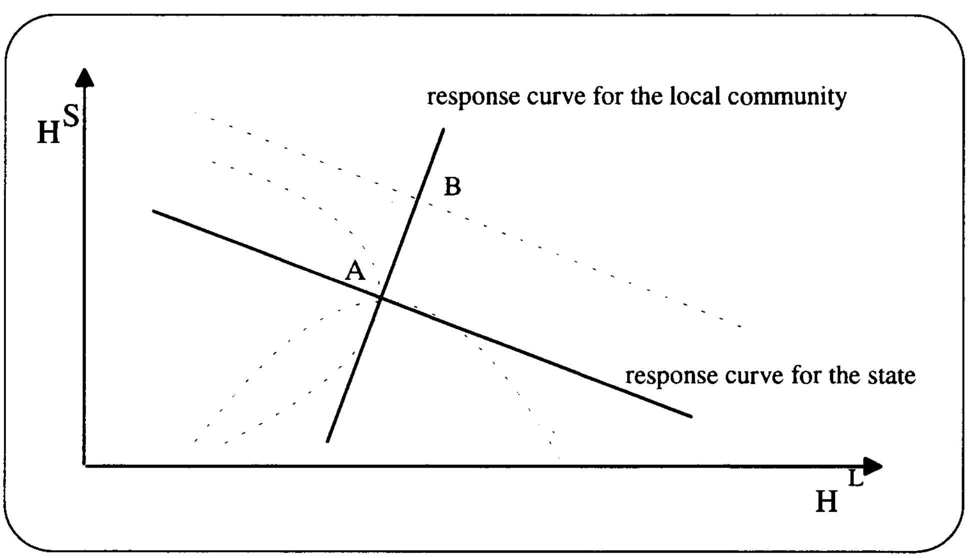

Figure 1: The response curves for the local community and the state in the poor, isolated community case.

The condition for stability of the system is;[8]

[8] See, for example, Shapiro (1989: 386)

(14) $u_{11}s_{11} - u_{12}s_{12} > 0$

As seen from (11) and (6), we have u_{11}, s_{11}, $s_{12} < 0$; $u_{11} < u_{12}$; $s_{11} < s_{12}$. It then follows that the necessary condition for a stable equilibrium is met. Graphically, this implies that the local response curve, when moving south, must intersect with the state's response curve from above.

Consider an exogenous shift in the state's response curve, represented by the dotted line in the figure. For any given value of H^L the state wants to appropriate more land than before. This could be due to, for example, higher prices of plantation products, technological progress, or less value attached to virgin forest. The local response will be more forest clearing, and the new equilibrium is in point *B*.

State deforestation fuels local deforestation in this case. The main mechanism is that state appropriation of forest reduces local forest income, which must be compensated for by expanding the local agricultural area. If state deforestation in addition provides infrastructure such that the cost of agricultural expansion is reduced, this gives an additional argument for local land expansion.

An illustration of the empirical relevance of this case is given in a review of local studies on poverty and tropical forest degradation by Kates and Haarmann (1992). They identify two major sources of displacement of indigenous hunter-gatherers or poor farmers; one is by (state-sponsored) commercial activities, the other by spontaneous immigrants or government planned resettlement programmes. This leads to degradation of forest resources on which the traditional users depend, and forces them to expand their activities into new forest areas.

4 Case 2: Increased forest land competition; local-led land race

When forest land scarcity and competition increases, one possibility is that we move from a Cournot game to a Stackelberg game with the local community as the leader and the state as the follower. This game would then describe a race for primary forest where the local community is the "aggressive" player, and clear forest in order to squeeze the state. As discussed towards the end of this section, this game could describe an important aspect of the process of deforestation in many locations in Indonesia and Latin America.

Why is it fair to assume the local community to be a Stackelberg leader? Besides the need to test the implications of different game assumptions, there are some reasons that make the case with the local community as the leader a relevant one to study. One could argue that the local community has greater flexibility than the state in adjusting its forest clearing, for example, because the state's decisions must move through a bureaucracy, and often require heavy capital investments. Further, the local community may know the decision procedures of the state, and therefore be able to predict the state's actions.

We make no *a priori* assumptions about the local economy, and discuss the autarky (utility maximizing) case which could be considered the most general one as both income and substitution effects are present. We further assume in this game that the land scarcity effect of state deforestation is large compared to the infrastructure effects. This is related to the type of game studied; the Stackelberg game with a local leader appears to be most reasonable in a situation where state deforestation is costly to the local community (cf. Appendix 2).

Local behaviour and the Stackelberg equilibrium

The problem for the local community as a leader is to maximize utility as given in (8), subject to the response function for the state as given in (5). The state will as a follower be on its response curve. The optimal level of forest clearing by the local community is such that the following condition is met;

$$(15) \quad u_1 + u_2 \frac{dH^{S*}}{dH^L} = r_1 - t_1 - zc(.) + \frac{dH^{S*}}{dH^L}\left[-t_1 - z\int_0^{H^L}(c_2 - c_1)dx\right] = 0$$

The first part of the expression (u_1) is similar to the Cournot case, cf. (9). In addition, the local community takes into account the state's response on local forest clearing, $\frac{dH^{S*}}{dH^L} < 0$. In the case where state deforestation is costly to the local community (the land scarcity effect dominates), $u_2 < 0$ and the indifference curves are inverted U-shaped in the H^L-H^S diagramme, cf. (13). Compared to a Cournot game we have added a negative element in the optimality condition. Local forest clearing has become *less costly* on the margin because local deforestation reduces state deforestation, which both increase the forest income (t_1) and reduces the costs of agricultural expansion.

The Stackelberg equilibrium is presented in Figure 2. The local community's preference direction is south, and the equilibrium is given in point *B* where the local indifference curve tangents the state's response curve.

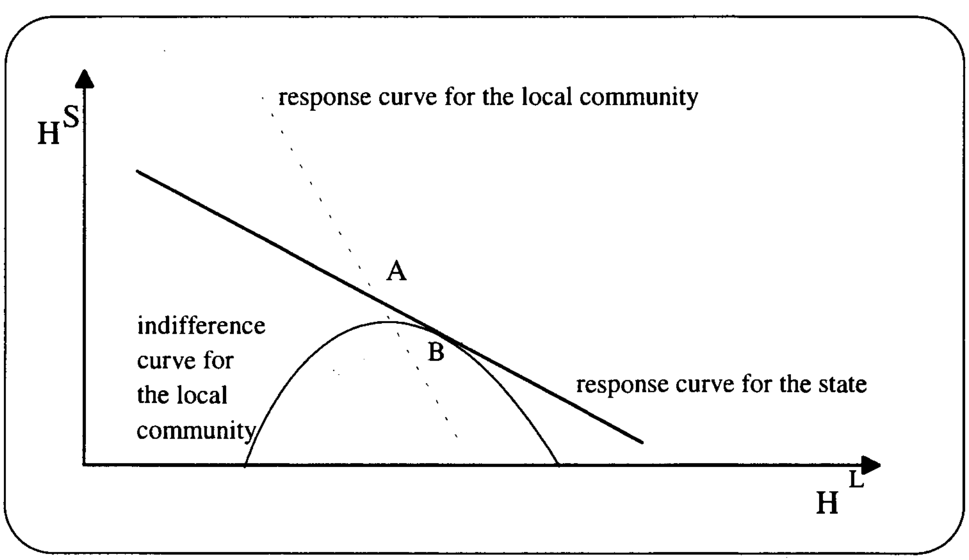

Figure 2: Local community as the leader in a Stackelberg game.

Compared to a Cournot equilibrium (A), the local community will clear more and the state less forest. The local community is aware of its strategic position as the leader, and uses it to "squeeze the state" from converting as much forest as the state would have done in a Cournot game.

A Stackelberg game with the local community as the leader gives more overall deforestation compared to a Cournot game as the absolute value of the slope of the state's response curve is less than one. The local community will receive a higher utility, whereas the state's profit will be lower in *B* compared to *A*. Note that the above results do not depend on the slope of the local response curve; hence the conclusions so far are valid both in situations where either income or substitution effects dominate.

Local response to higher state deforestation

The effect of an exogenous upward shift in the state's response function is found by differentiation of (15);

$$(16) \qquad \frac{dH^{L*}}{dH^S} = -\frac{u_{12} + \frac{dH^{S*}}{dH^L} u_{22} + \frac{\partial (dH^{S*}/dH^L)}{\partial H^S} u_2}{u_{11} + \frac{dH^{S*}}{dH^L} u_{21} + \frac{\partial (dH^{S*}/dH^L)}{\partial H^L} u_2}$$

$$= -\frac{t_{11} - z(c_2 - c_1) - c(.)z_{HS} + \frac{dH^{S*}}{dH^L}\left(t_{11} - z\int_0^{H^L}(c_{22}+c_{11})dx - z_{HS}\int_0^{H^L}(c_2-c_1)dx\right) + \frac{\partial (dH^{S*}/dH^L)}{\partial H^S}\left(-t_1 - z\int_0^{H^L}(c_2-c_1)dx\right)}{r_{11} + t_{11} + zc_1 - c(.)x_{HL} + \frac{dH^{S*}}{dH^L}\left(t_{11} - z(c_2-c_1) - z_{HL}\int_0^{H^L}(c_2-c_1)dx\right) + \frac{\partial (dH^{S*}/dH^L)}{\partial H^L}\left(-t_1 - z\int_0^{H^L}(c_2-c_1)dx\right)}$$

We assume the denominator to be negative (second order conditions for maximum). The numerator consists of three terms. The first term, which gives the Cournot response (u_{12}) can be either negative or positive. We showed in the analysis of case 1 that if both the infrastructure and the income effects are small, this effect is negative. We are now considering the case when the infrastructure effect is small, hence the sign depends on the strength of the income effect relative to the substitution effect.

The second term relates to the change in the local costs (benefits) of higher (lower) state clearing. Consider first the case when z is determined exogenously (small, open economy). For a given slope of the state's response curve, more state clearing implies that on the margin, state clearing is more costly to the local community. However, as higher local forest clearing reduces state clearing, this effect will push in the direction of higher local deforestation. The gain from squeezing the state is higher.

Then we must take into account that z will change in an autarky. As argued earlier, if the income effect is weak, then $z_{H^S} > 0$, and the second effect in (16) is unambiguously positive ($u_{22} < 0$). If, on the other hand, the income effect is sufficiently strong, the sign will change.

The third term relates to the changes in the slope of the state's response curve. From the assumptions made so far we cannot determine the sign of this effect. $\partial(dH^{S*}/dH^{L})/\partial H^{S}$ denotes the change in the slope of the response curve as one moves north. If this is negative, i.e., the response curve becomes steeper, the "state squeeze per hectare local forest clearing" is higher, hence the third effect is positive and this contributes to higher H^L following an increase in H^S.

Thus, we cannot in general determine the sign of (16). Intuitively, one could expect the first and most direct effect to dominate over the second and third. This will be the case if the slope of the state's response curve is close to zero (second effect small), and the slope of the state's response curves in the relevant region is relatively constant (third effect small).

In the case with *small income effects* the first effect is negative, the second positive, whereas the third is ambiguous. If we maintain that the first effect dominates the second and third, we conclude that higher state deforestation gives *less* local deforestation.

In the case when the *income effects are dominating*, e.g., the consumption is close to the subsistence level, the picture is reversed. In this case the first effect is positive and the second is negative. Now we could expect that higher state forest clearing also gives *more* local deforestation, as in case 1.

Empirical relevance

Two major conclusions emerge from the analysis of this case. First, compared to a Cournot game there will be more local and less state deforestation, and more overall deforestation. The local community gains and the state loses compared to a Cournot game. These results do not depend on the relative strength of the income and substitution effects.

Second, the local response to an exogenous increase in state deforestation is similar to case 1. If there are strong income effects, the result is more deforestation. More state deforestation reduces forest income, and the need to meet a subsistence target dominates in local decisions, thus agricultural land expansion will increase. If the income effects are small, or we are in the open economy case where only substitution effects apply, then more state deforestation implies less local deforestation, as local land expansion has become more costly.

The local community uses its position as the leader to squeeze the state, as expressed by the difference between point *B* and *A* in Figure 2. Such a local-led land race that results from a change in the local strategy (from Cournot to Stackelberg leader) has been observed empirically. The development since the mid-1980s in the Seberida district in Sumatra could be interpreted as such a shift (Angelsen, 1995). The local community is not just passively adopting to forest appropriation by the state, but they play strategically in the way that they clear forest that otherwise could have been appropriated by the state. Similar land races have frequently been observed at the forest frontier in Latin America (see Kaimowitz (1995) for a review of Central America).

Note that there are several different "strategic" effects involved in land races. First, there may be speculative motives in the way that forest is cleared for later sale to get capital gains ("rational bubbles"). Second, when forest clearing gives farmers land rights, there are incentives to clear forest beyond the point where the current land rent is zero, cf. model IV in Angelsen (1996a). Third, and the effect studied in this paper, local deforestation might be expanded to squeeze other actors.

It may be difficult in empirical research to isolate the different effects. The present paper should therefore be seen as complementary to other explanations of how a race for forest land can be initiated and maintained.

5 Case 3: Fierce land competition; the state as the leader

As a third case we discuss a situation where the competition for forest land is strong, and the local economy is well integrated into the regional/national strong economy. Compared to the two previous cases, one could think of this case to describe the situation at a later stage in the economic development of a region or a country. This game could therefore be used to illustrate the interaction between the state and local communities in central parts of, for example, Indonesia, the Philippines and Thailand, where there is relatively little forest left and farmers are well integrated into markets.

Related to our main assumptions, this situation implies that the land scarcity effect dominates the infrastructure effect in the local costs function, and that we can assume a perfect labour market and study the local adaptation as a profit maximizing problem.

We assume that the game played is a Stackelberg game with the state as the leader. The following story could provide an argument for this to be a reasonable assumption. The three cases presented may represent a historical development. Assume that the state as a response to the game in case 2 wants to be the leader, which means we enter a period of Stackelberg warfare, as discussed in more details in Appendix 3. There will be excessive forest clearing when the warfare is going on.[9] Both actors would gain by moving back to their response curves, but it would be even better if the other player gives in. The Stackelberg warfare could therefore be studied as a chicken game. The state may have higher credibility in claiming to be the leader, for example, in the form of irreversible commitments to a certain level of forest clearing. Hence we may eventually end up in a Stackelberg game with the state as the leader.

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[9] As will be seen, the conclusion that the state will clear more as a leader compared to the Cournot equilibrium assumes that the local response curve is backward bending.

Local behaviour

The behaviour of the local community is under the open economy assumption studied as an income maximization problem, with the local income given in (2). This gives the following optimality condition;

(17) $l_1 = r_1 - t_1 - c(H^F, H^S) = 0$

The inverse of the slope of the response curve is given by;

(18) $\frac{dH^{L*}}{dH^S} = -\frac{l_{12}}{l_{11}} = -\frac{t_{11}+c_1-c_2}{r_{11}+t_{11}+c_1} < 0$

The local response curve is backward bending as we have assumed that land scarcity effect dominates infrastructure effect ($l_{12} < 0$).

State behaviour and the Stackelberg equilibrium

The objective of the state is to choose its level of H^S such that the revenue given in (3) is maximized, taking into account the response of the local community as given in (18);

(19) $Max\ S = s(H^S, H^L(H^S))$

The revenue is maximized when;

(20) $s_1 + s_2 \frac{dH^{L*}}{dH^S} = v_1 - g_1 - h(H^F) + \frac{dH^{L*}}{dH^S}\left[-g_1 + \int_0^{H^S} h_1 dy\right] = 0$

This is a modified version of the optimality condition in the Cournot game, cf. (4). The state now takes into account the effect on local clearance when deciding its own level of deforestation, given by $\frac{dH^{L*}}{dH^S} < 0$. One hectare reduced local deforestation always increase the net benefits to the state ($s_2 < 0$).

Figure 3 illustrates this case. The Stackelberg equilibrium will be where the (highest possible) iso-profit curve is tangent to the response curve of the local community, that is, in point *B*. Compared to the Cournot solution (A), the present game gives *more* forest clearing by the state and *less* by the local community. The intuition behind these results is straightforward, and parallel to case 2. Forest conversion by the state is less costly to the state because it knows that local deforestation is reduced when its own increases. The state uses its strategic position to squeeze the local community. The distance between *A* and *B* (measured on the x-axis) gives the optimal "squeeze" of local forest appropriation. As the absolute value of the slope of the local response curve is greater than one, the Stackelberg solution also implies higher *total* forest clearing and reduced H^F.

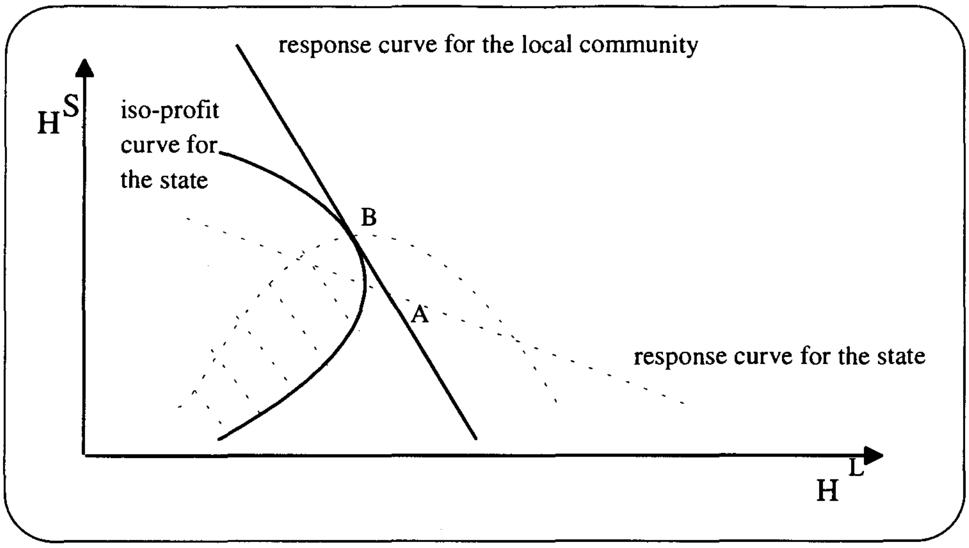

Figure 3. State as the leader in a Stackelberg game: backward bending local response curve.

We also note that the income to the state is higher compared to a Cournot equilibrium, whereas it is lower for the local community. As is generally known from the oligopoly and game theoretic literature, there is a first-mover advantage in games where quantities are the decision variables: the leader could have chosen the Cournot quantity if it were to yield higher income. The last-mover disadvantage is seen both by studying the iso-profit curves, and from the fact that both H^L and H^F are smaller in the Stackelberg model.

A positive exogenous shift in the revenue function of the state (iso-profit curves shift upwards) will obviously make the local community reduce its forest clearing. Total deforestation will, however, increase as the slope of the local response curve is greater than minus one, i.e., the reduction in local deforestation is less than the increase in state deforestation.

It is common that national governments view forest clearing by local farmers as the real problem of deforestation, sometimes referred to as "unplanned" deforestation, whereas "planned" deforestation by the state is desirable. This view is reflected in the assumptions underlying the state's objective function. Given this view, the model provides an explanation of the commonly observed "aggressive" behaviour of the state in forest conversion. By being the leader the state not only increases its own forest clearing and income, but it will also reduce what is considered the real environmental problem -- local deforestation.

6 Discussion

We have studies three different empirically relevant cases of state-local games, corresponding to different assumptions about the local economy, the local cost effects of state deforestation, and the structure of the game. The number of *possible* games by combining these assumptions is much larger, and Appendix 2 gives an overview of 12 possible games.

In the first case of a poor, isolated local community, the response of the local community was determined by the survival needs. Higher state deforestation entails a loss in forest derived income, which must be compensated for by converting more forest into agricultural land; hence local deforestation will increase.

The second case was used to illustrate a local-led land race. The local community uses its position as the leader in a Stackelberg game to squeeze the state. State deforestation is costly to the local community, and the community knows that by increasing own deforestation, state deforestation will be reduced. This provides an incentive for higher local deforestation compared with a Cournot equilibrium, and overall deforestation will also be higher. The response to an exogenous increase in state deforestation is ambiguous in this case. If the income effect is strong relative to the substitution effect, local deforestation will also increase. On the other hand, if the substitution effect dominates in an autarky, or the households are unconstrained in the labour market (small, open economy), then local deforestation will be reduced.

In the third case, the state is the leader in a Stackelberg game, there is strong competition for land (land scarcity effect dominates), and the local community is well integrated into the regional/national economy (small, open economy). In this situation the *state* will use its leader-position to squeeze the local community. The local level of deforestation is determined by the relative profitability of forest conversion and agriculture compared to off-farm employment opportunities, and not by survival needs. The local response to more state deforestation is then reduced deforestation.

Combining the analysis of the three cases with the overview of Appendix 2, we are now able to make some general conclusions regarding the two main questions raised in this paper: which game structures promote deforestation, and what is the local response to higher deforestation by the state.

Which games promote deforestation?

In the small, open economy situation with small infrastructure effects (backward bending local response curve), a Stackelberg game with either the state or the local community as leader gives more overall deforestation than a Cournot game. The leader will use its position to squeeze the follower. Since the "squeezing effort" by the leader is larger than the "squeeze" of the follower, the result is more deforestation than in a Cournot equilibrium. This was the situation both in case 3 where the state was the leader, and in case 2 where the local community was the leader.

One might think that a leader would take some responsibility for environmental conservation and the provision of the public good, and that the Stackelberg games therefore reduce overall deforestation, cf. the discussion in Baland and Platteau (1996, chap. 5). This is not the case here.

Each player knows that increased own forest clearing will reduce the clearing by the other player, thus forest clearing is less costly for the leader.

How robust is this result, or, in other words, will Stackelberg games always lead to more deforestation? Consider first games where the state is the leader. When the local response curve is backward bending, either due to strong infrastructure effect or strong income effects, more state deforestation will *increase* local deforestation. Forest appropriation has become *more* costly to the state when they take into account the local response. This provides an incentive for the state to reduce own deforestation, and the result is less overall deforestation. The critical factor in determining whether a Stackelberg game with the state as the leader will lead to more or less deforestation is therefore the slope of the local response curve.

In situations where the local community is the leader, we found in case 2 that irrespective of whether income or substitution effects dominate, the Stackelberg equilibrium yields more deforestation than the Cournot equilibrium. This assumes that the land scarcity effect dominates the infrastructure effect in the local cost function. If the infrastructure effect dominates, however, the conclusion is reversed. This situation yields an intuitively rather strange (though logically correct) result: the local community will reduce its own clearing to promote state clearing, which is beneficial to them, cf. Appendix 2. The empirical relevance of this result is unclear.

In conclusion, even though we found in cases 2 and 3 that the Stackelberg equilibria give more deforestation than the Cournot equilibrium, this conclusion in sensitive to the other assumptions. In particular, in situations when the local response curve is forward bending, a income maximizing and rational state should as a leader reduce its level of forest clearing (compared to the Cournot equilibrium) as state deforestation stimulates local deforestation with a loss of forest derived benefits to the state.

When does state deforestation fuel local deforestation?

The second main question is in which situations increased forest appropriation by the state will stimulate local forest clearing. The answer is quite simple: if the local response curve is backward bending, more state deforestation reduces local deforestation. In other words, when (i) the infrastructure effect is small, and (ii) the income effect is small in an autarky, or in small open economy, higher state deforestation will to some extent replace local deforestation. The result holds in all three game structures.

If either the infrastructure effect or the income effect in an autarky (or both) are strong, the result is reversed. State deforestation fuels local deforestation in any of the three games. The case with strong infrastructure effect has received some attention in the literature on tropical deforestation. It is generally argued that plantations, logging and other large-scale projects provide infrastructure, particularly roads, which gives farmers easier access to primary forest. In this way state appropriation may *increase* the net marginal benefits of agricultural expansion and thereby deforestation by the local community. This phenomenon is sometimes referred to as the "logging-shifting cultivation tandem", common in many Asian countries (Grainger, 1993).

The other possibility for a state stimulated local deforestation is when the need to survival determined the local response (strong income effects), which was discussed in relation to case 1.

The local level of deforestation is also affected by the game played, as discussed above. Moving from Cournot to a game with the local community as the Stackelberg leader will increase local deforestation if the infrastructure effect is weak. Local deforestation will decrease if the infrastructure effect is strong, although this is considered an odd case. Moving from a Cournot game to a Stackelberg game with the state as the leader will always imply less local deforestation, irrespective of the slope of the local response curve. Thus by playing the role as a leader the state will always induce less local forest appropriation. Note, however, that the state's strategy for achieving this will vary with the slope of the local response curve.

If both players want to be a leader, we get a situation with Stackelberg warfare which might, for some period of time, lead to excessive forest clearing, even though this is not a stable (Nash) equilibrium. This situation is discussed further in Appendix 3.

From the table in Appendix 2 and the above discussion we can conclude that the qualitative answer to the question about the local response to higher state deforestation is robust with respect to the type of game played, whereas it is sensitive to the local cost structure and market assumptions. The other question raised relates to whether a Stackelberg game will result in more deforestation than a Cournot game. In addition to the assumptions about local expansion costs and markets, the structure of the game also matter. Moreover, in the very relevant case when land scarcity and income effects dominate (as in case 2), the answer not only depends on whether we have a Cournot or Stackelberg game, but also who is the leader in the game.

A forward-then-backward bending local response curve

One could argue that a forward bending local response curve can describe a forest abundant situation: there is plenty of forest land for expansion, hence there is no strong spatial competition (land scarcity effects small). The main constraint on agricultural expansion is accessibility, and state conversion is commonly linked with the provision of infrastructure which reduces access costs. Furthermore, a large area of virgin forest means that the reduction in benefits from that forest is relatively small (the absolute value of t_{11} is small, cf. (11)).

A plausible hypothesis is therefore that for *large* values of H^F (low values of H^L and H^S) the slope of the response curve of the local community will be positive. For *small* values of H^F, on the other hand, the competition for remaining land is more intense and a further reduction in virgin forest has strong negative impacts, thus the slope will be negative. Such a possible path is reflected in the assumptions made about $c(H^F,H^S)$, cf. the discussion in relation to (2).

This hypothesis of a forward-then-backward bending response curve of the local community is illustrated in Figure 4. Consider a Cournot game. The response of the local community of a shift in the state's response curve now depends on the initial situation. In case *A*, where state appropriation is small, the local community will respond by increasing its appropriation of virgin forest. In case *B*, the response will be the opposite.

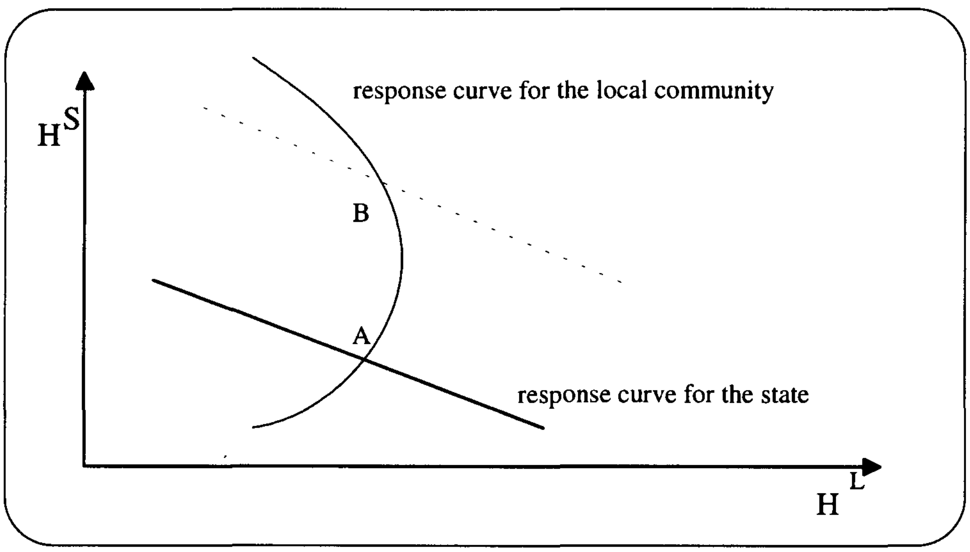

Figure 4: The case with a forward-then-backward bending response curve for the local community.

The hypothesis of a forward-then-backward bending response curve suggests that in forest abundant situations increased state appropriation will stimulate forest clearance by the local community, whereas it will discourage it in a setting with little forest left to expand on. Historically, most countries show a downward trend in the forest cover (the forest transformation hypothesis). Related to the hypothesis of Figure 4, one could argue that at the early stages of this transition, state clearing works in tandem with local clearing, whereas they compete at later stages.

A backward-then-forward bending local response curve

If we instead of looking at the infrastructure effect focus on how the strength of the income effect affects the shape of the local response curve, we may get the opposite story to the one just told. Consider a situation when the infrastructure effect is small (and not dominating at any level of H^S), with little forest appropriation by the state initially and a relatively high local income level. The response of the local community of increased state forest appropriation will be to reduce its own deforestation, cf. the discussion of case 2 and Angelsen (1996a: Model II). As the forest appropriation by the state increases, local income is squeezed, and approaches the subsistence level. Beyond a certain point it is possible that the response to a further increase in state forest appropriation will be dominated by the need to meet the subsistence requirement, thus the response curve becomes forward bending. In this way we could argue for a backward-then-forward sloping response curve, or the mirror image of the one presented in Figure 4.

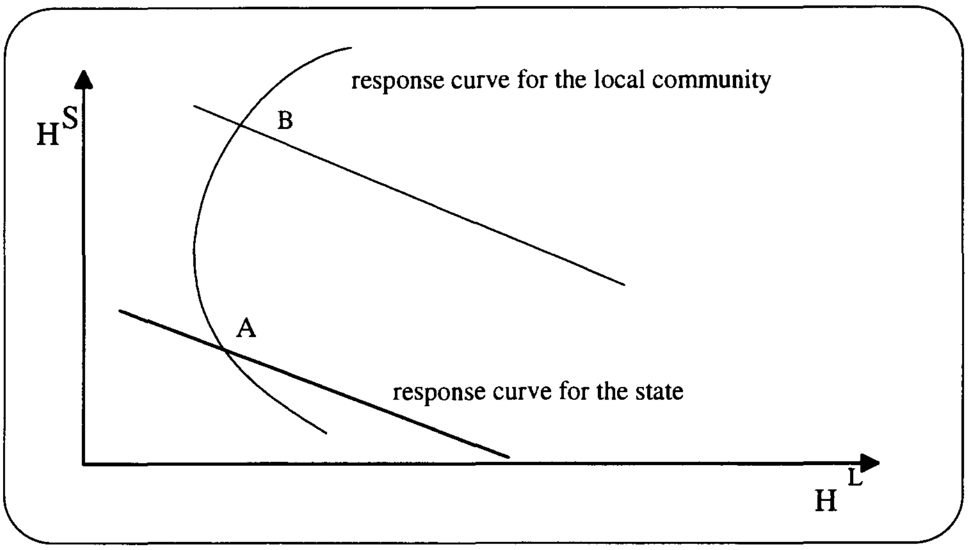

Figure 5. A backward-then-forward bending local response curve.

The C-shaped local response curve suggests the opposite development compared with the one discussed in relation to Figure 4. When state appropriation is relatively low, state deforestation to some extent replaces local deforestation (A). As the state increases its forest appropriation, it will promote local deforestation (B). Combining the arguments underlying the forward-then-backward and the backward-then-forward bending hypotheses could yield that either of the hypothesis will dominate, or an S-shaped or an inverted S-shaped local response curve. The exact shape is, of course, an empirical question. One lesson is that there are several different effects of higher state appropriation to consider, and therefore a number of possible shapes of the response curve.

Cooperation on forest management

The models of this paper can be utilized to illustrate the potential and problems of cooperation in forest management and conservation. Consider case 3. The shaded eye-shaped area in Figure 3 gives the set of combinations of H^L and H^S where both actors have at least as high income as in point *B*, i.e., the area for Pareto improvements. The well-known problem is that even if both parties would gain from being inside the shaded area compared to *B*, both would also have an incentive to defect an agreement. Related to the binary choice game literature, the choice between *B* and any point within the shaded area could be considered a prisoner's dilemma game.[10]

[10] This binary choice game literature normally considers games with simultaneous moves (Cournot), and not sequential moves (Stackelberg) as here. The problem of making self-enforceable agreement

The issues of community participation, co-management or state-local partnership in forest conservation can be viewed as attempts to establish a cooperative solution within the shaded area. Both agents reduce their conversion of forest to contribute to the preservation of the collective good -- primary forest. We shall not pursue the discussion about the design of such contracts, just note that the contract curve will be the line where the iso-profit curves of the two agents tangent each other. Chopra *et al.* (1990, chap. 6) provide a discussion of state-local contracts in forest management through the application of a bargaining model.

The games can also be used to explain why there are limited incentives for each party in unilateral actions for forest conservation. Reduced state appropriation will result in more local conversion in case 3, or more generally in games with small infrastructure and income effects. Particularly, if the slope of the response curve for the local community is close to minus one, a reduction in forest conversion of one hectare by the state will be offset by an almost equal increase in local deforestation. From (11) we see that this will be the case if c_2 and r_{11} are close to zero. The first implies that the cost reducing effect of infrastructure provision is small; the second that the gross marginal benefits of forest conversion are relatively constant, which will be the case when the products are sold in a large market, and there are few constraints on the labour input, for example, through migration. In this situation, the conservation effect of unilateral actions by the state will be negligible.

As a corollary to the above result, we also get that unilateral conservation efforts by the state will be particularly effective in the cases where state appropriation fuels local deforestation, as the local forest conversion will be reduced if the state decides to reduce its own. Unilateral conservation efforts by the local community will always be met by increased deforestation by the state.

Case 2 is similar to case 3 with respect to the possibilities for co-management of forests, with the role of the state and the local community reversed, whereas case 1 yields some new and interesting results. With a forward bending local response curve, it may well be that the local community would prefer the Stackelberg equilibrium with the state as the leader to the Cournot equilibrium, cf. Appendix 3. In fact, if we limit the discussion to the case when the land scarcity effect dominates the infrastructure effect, we always get that the local community would prefer to be the follower in a Stackelberg game compared to a Cournot game. Whereas this is a rather unusual result in a Stackelberg game with quantities as the decision variable, the logic is straightforward. With a forward bending local response curve, the state will as a Stackelberg leader reduce its deforestation compared to the Cournot equilibrium. This will benefit the local community. Furthermore, as shown in Appendix 3, the local community *may* even prefer the state to be the leader to being a leader itself in a Stackelberg game.

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is, however, similar in both the Cournot and Stackelberg games of this paper.

Whereas our modelling framework does not provide any theory for which game that will be played, one could intuitively expect a Cournot game with small infrastructure and strong income effects to be an unstable one; both the local community and the state would prefer a Stackelberg game with the state as the leader. This is, however, a premature conclusion. As further discussed in Appendix 3, there is no strictly dominant strategy for the state nor the local community in a game of leader selection.

7 Summary and concluding remarks

This paper has explored some possible strategic interactions between the state and a local community in games of appropriation of forest land. Particular attention has been given to the assumptions made about the local costs of land expansion and the degree of market integration. We found that Stackelberg games with either the local community or the state as the leader give more deforestation than Cournot games. The leader uses its position to squeeze the other actor, and the net result is more deforestation. In this way the kind of strategic behaviour that arise in Stackelberg games is bad from a forest conservation viewpoint. This is a robust result irrespective of the assumptions made about the strength of land scarcity *v.* the infrastructure effects, and the income *v.* substitution effects.

The second main question raised in this paper was under which circumstances higher forest appropriation by the state also will promote local deforestation. Contrary to the conclusions on the first question, the answer is now highly sensitive to the assumptions about the costs of local expansion and the local economy. If the infrastructure and/or the income effects are strong, i.e., the local response curve is forward bending, the state will stimulate local deforestation. If none of these effects dominate, we get conclusions similar to a more conventional duopoly game: higher state appropriation will squeeze the local community. These results are robust with respect to the assumptions made about the structure of the game (Cournot or either of the Stackelberg games). In some respects, this should be viewed as good news since the assumptions about the structure of the game may be the most difficult to test empirically.

Appendix 1: The developmental state

We have assumed throughout the paper that the state maximizes own income, thus disregarding the effect of state deforestation on local income or welfare. A more general formulation of the state's objective function is that the state gives a certain weight (γ) to local income relative to state income (we assume the small, open economy situation);

(21) $Max\ W = S + \gamma L; \quad \gamma \geq 0$

The case with $\gamma = 0$ can be defined as the predatory state, as assumed in the models. The developmental state could be defined as $\gamma \geq 1$, cf. the discussion in Angelsen (1996b: chap. 3.3). What are the implications of introducing a more development oriented state in the models? The first order condition of the state's optimization problem is now;

(22) $s_1 + \gamma l_2 = 0$

Assuming $\gamma > 0$ and $l_2 < 0$ (land scarcity effect dominates infrastructure effect) and given that $s_{11} < 0$, it follows that the "new" response curve for the state lies below the "old" one in the H^L-H^S diagramme, and the distance between the "old" and "new" one is larger the larger γ is. Thus in the case with small infrastructure effects (backward bending local response curve), introducing a more development oriented state results in less state and more local forest clearing.

In the case where infrastructure effects are strong ($l_2 > 0$), the state's "new" response curve will lie above the "old" one. With a forward bending local response curve, the effect will be both more state and local forest clearing. The slope of the state's response curve is now given by;

(23) $\frac{dH^{S*}}{dH^L} = -\frac{s_{12} + \gamma l_{21}}{s_{11} + \gamma l_{22}}$

$l_{22} < 0$, whereas $l_{21} = l_{12}$ can be either positive or negative as discussed above. However, it can be shown that $l_{21} > l_{22}$. We cannot *a priori* exclude the possibility that the state's response curve is forward sloping, when $l_{21} > 0$ and γ is large, although this intuitively appears to be an odd case.

Note that since the state cannot control local deforestation, the welfare optimum cannot be reached even if we set $\gamma = 1$. Thus even with a developmental state we are dealing with second best solutions.

The introduction of a broader state objective does not fundamentally change the game, although it will affect the location and slope of the state's response curve. The introduction of a more developmental state could be discussed as a downward shift in the state's response curve in the case where the infrastructure effect is small, and an upward shift when this effect dominates the land scarcity effect.

Appendix 2: Summary of possible games

By varying the three key assumptions focused on in section 2, we may distinguish between 12 different games. The conclusions in the games on the two main issues raised are summarized in the table below.

Cost structure and market assumptions for the local community		**Type of game**		
		1. Simultaneous moves (Cournot)	*Sequential moves (Stackelberg)*	
			2. Local community as the leader	*3. State as the leader*
A. Income max. (small, open economy), or utility max. (autarky) when substitution effects dominate income effects	*i. Land scarcity effect dominates*	I: n.a. II: decrease	I: higher II: decrease **(Case 2)**	I: higher II: decrease **(Case 3)**
	ii. Infrastructure effect dominates	I: n.a. II: increase	I: lower II: increase	I: lower II: increase
B. Local utility maximization (autarky) when income effects dominate substitution effects	*i. Land scarcity effect dominates*	I: n.a. II: increase **(Case 1)**	I: higher (same[1]) II: increase **(Case 2)**	I: lower II: increase
	ii. Infrastructure effect dominates	I: n.a. II: increase **(Case 1)**	I: lower (same[1]) II: increase	I: lower II: increase

[1] The level of deforestation will be the same in the full belly case.

Table 1: The main results of different local community-state games.
I: Total level of deforestation in the Stackelberg games compared to the Cournot equilibrium.
II: Effect on local deforestation of higher forest clearing by the state.

Regarding the market assumptions, the crucial difference in the qualitative results is between (i) the small open economy and the autarky when substitution effects dominate, and (ii) the autarky when income effects dominate or the "full belly" case.

Of the 12 possible games, some have been studied in some details as cases 1-3. Two important subsets have not, however, been discussed. One is the conventional Cournot duopoly game, that is, when the infrastructure and income effects are small (game 1.A.i in the table). The local response curve is backward bending. The effect of higher forest appropriation by the state is reduced local forest clearing, as in case 3.

Another important subset of games not dealt with is when the state is the Stackelberg leader, and the local response curve is forward bending. This could be due to either local autarky with full belly preferences or Chayanovian preferences with strong income effects, or because state conversion increases the marginal net benefits of local agricultural expansion. The conclusions are the opposite of the ones in case 3 (backward bending response curve). The local response to higher state deforestation is more local deforestation. Due to this fact, the state will as a leader *reduce* its level of deforestation compared to the Cournot equilibrium: from the state's viewpoint higher own forest conversion has an additional cost in terms of more local agricultural expansion and reduced primary forest area. Contrary to the case with a backward sloping local response curve, the Stackelberg game now helps *preserve* natural forest compared to a Cournot game.

As in case 3, the leader (state) will gain compared to the Cournot equilibrium. The local community may lose or gain. If the forward bending response curve is due to strong infrastructure effects such that also the indifference (iso-profit) curves are U-shaped (the preference direction is north), the local community will loose. If, however, the infrastructure effect is small such that the indifference curves are inverted U-shaped and the forward bending response curve is due to strong income effects in a local autarky, the local community will actually *gain* compared to the Cournot equilibrium.

As seen from the table, in a Cournot game and a Stackelberg game with the state as the leader, the key difference between the different games is related to the slope of the local response curve, i.e., the sign of l_{12} or u_{12}. When the local response curve is forward bending, either due to strong infrastructure effects or strong income effects (under autarky), the local response to more state deforestation is also more local deforestation. Furthermore, the Stackelberg game gives less forest clearing by the state and overall compared to the Cournot game.

In a Stackelberg game with the local community as the leader, the critical factor is the shape of the local iso-profit or indifference curves, i.e., the sign of l_2 or u_2. The condition for "large infrastructure effects" is therefore not the same in the different types of game. In this Stackelberg game the conclusions are more complex. In the cases when the infrastructure effect is small, the Stackelberg game gives more overall deforestation compared to a Cournot game. The local response to higher state deforestation depends, however, as shown in case 2 on the strength of the income effect relative to the substitution effect. If the income effect is weak or we have a small, open economy, then the result is less local deforestation than in the Cournot game.

Another sub-set of games not discussed is when the local community is the Stackelberg leader, and the infrastructure effect dominates. State deforestation is beneficial to the local community (lower expansion costs), thus, compared to the Cournot equilibrium, the local community will reduce its deforestation to push the state upwards along its response curve. This appears to be a rather strange form of strategic behaviour of the local community, and one could question the empirical relevance of this case. It is therefore not dealt with any further.

Appendix 3: Stackelberg warfare and leader selection

We have seen that it is an advantage to be a leader in a sequential (two period) game, thus we should expect that both players will wish to have that position. We may therefore get what is termed *Stackelberg warfare*. In the case with a backward sloping local response curve, this implies that both players choose an amount of forest clearing higher than the Cournot equilibrium, hoping that the other will be a follower. Both players want to squeeze the other to clear less forest than they would have in the Cournot equilibrium.

This situation clearly calls for a truly dynamic game model. Some major points can, however, be illustrated by using simple static binary game models, even though other elements will be missing (e.g., reputation building and credible threats). One possible way of thinking about the game discussed in this section is that it is played prior to one of the games studied.

Backward bending local response curve

A Stackelberg warfare (SW) situation is illustrated in Figure 6. Both the state and the local community choose the amount of forest clearing they would do as Stackelberg leaders (SS and SL respectively). The result is a level of overall deforestation which is higher than both the Nash-Cournot equilibrium (C) and either of the two Stackelberg equilibria.

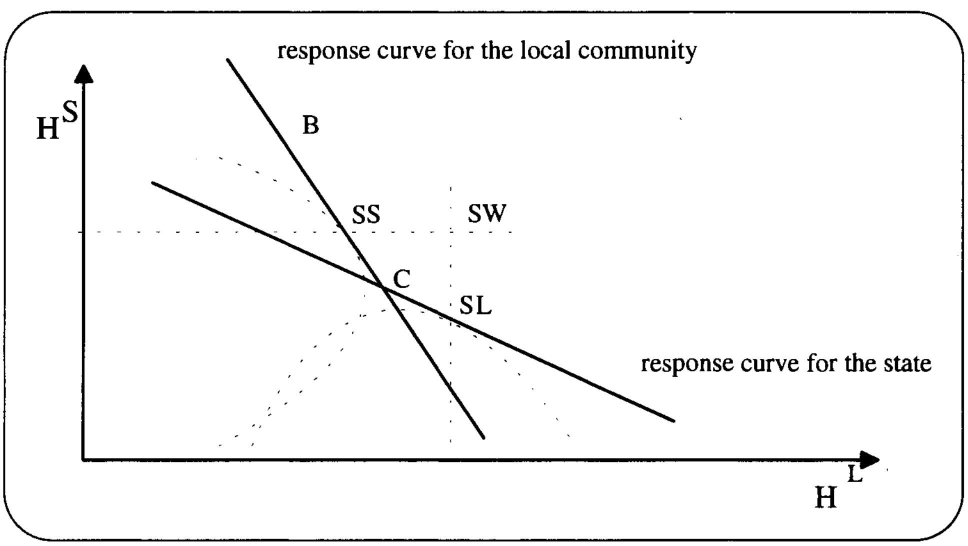

Figure 6. Stackelberg warfare with backward bending local response curve.

The warfare outcome is not stable: both agents will be better off by moving back on their response curve. We may therefore eventually end up in the Cournot equilibrium or that one of the players accept being the follower. As long as the war is ongoing, there will be excessive forest clearing.[11]

[11] In the models of this paper forest is cleared once and for all. To make this rather informal discussion about leader selection more meaningful, one should think within a dynamic perspective where forest clearing over time becomes more beneficial both for the state and the local community, e.g.,

The Stackelberg warfare can be illustrated as a binary choice game between the players about which strategy to pursue. Should one choose a deforestation level as a leader or as a follower? The game is given in Table 2. The ordinal numbering (ranking) of the four different outcomes is uniquely given from Figure 6, with 4 as the most preferred outcome.

		Local community	
		Follower	*Leader*
State	*Follower*	3,3	**2,4**
	Leader	**4,2**	1,1

Table 2. A chicken game on the selection of the leader.

This is a chicken game, which has two possible Nash equilibria (in bold) with either player as the leader and the other as the follower. We cannot within the game determine which of these equilibria will be the final outcome.

One could, nevertheless, provide some economic intuition to the game of leader selection outside the formal model. If one player expects the other to behave as a leader irrespective of what he is doing, then the best strategy would be to choose to be a follower. Thus we have to bring in the issues of expectations and credibility. Are there, for example, certain strategic bindings that make it more credible for one party to claim that he will be the leader? This could be in the form of officially approved plans for forest conversion or capital investments. Such strategic bindings are mainly relevant for the state, thus we could expect the state to be in a better position to make credible commitments.

Forward bending local response curve

A Stackelberg warfare appears to be most likely in a situation when the land scarcity effect dominates the infrastructure effect (inverted U-shaped local indifference curves), but it is still possible that in a local autarky situation the income effect will dominate the substitution effect such that the local response curve is forward bending. This case is illustrated in Figure 7.

increasing prices of agricultural and forest products. The warfare is therefore about the clearing of the virgin forest which has become profitable. To incorporate such dynamic aspects in the formal model would complicate it significantly.

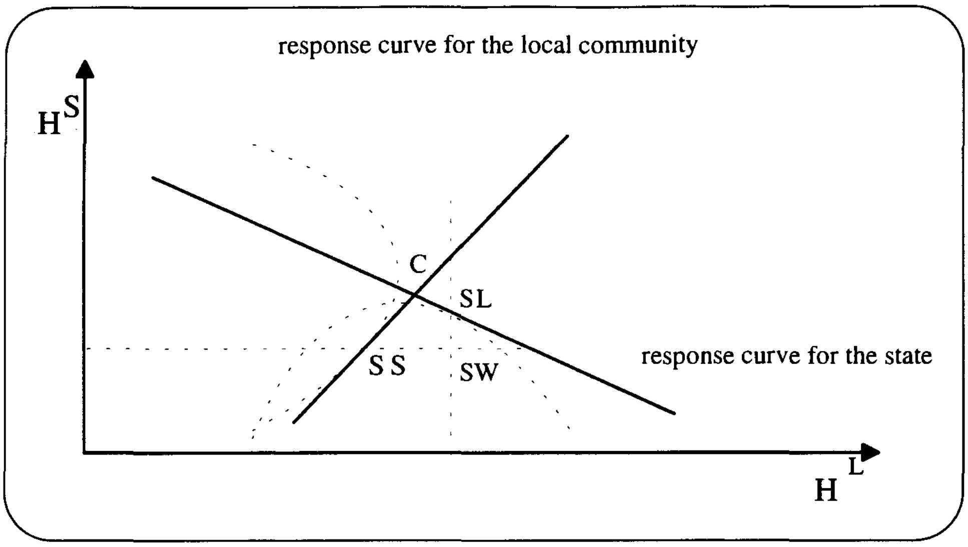

Figure 7. Stackelberg warfare with backward bending local response curve.

The state's ranking of the four different outcomes is the same as in Table 2. The ranking by the local community is more complex. We still have that they prefer, by definition, to be a leader in a Stackelberg game to the Cournot solution (SL $\succ$ C) and a Stackelberg game with the state as the leader is preferred to Stackelberg warfare (SS $\succ$ SW). However, with a forward response curve the local community now prefers the Stackelberg solution with the state as leader to the Cournot solution (SS $\succ$ C). We then have five possible local rankings:

R1: SS $\succ$ SW $\succ$ SL $\succ$ C

R2: SS $\succ$ SL $\succ$ SW $\succ$ C

R3: SS $\succ$ SL $\succ$ C $\succ$ SW

R4: SL $\succ$ SS $\succ$ C $\succ$ SW

R5: SL $\succ$ SS $\succ$ SW $\succ$ C

Figure 7 depicts the first ranking (R1). The game is presented in Table 3. At a first look the obvious solution appears to be a Stackelberg game with the state as the leader (SS), as it has the highest ranking for both the state and local community (Pareto dominating). A Stackelberg game with the local community as the leader is, however, also a Nash equilibrium. If we are in SL, the local community would not like to change strategy to be a follower, and also the state is better off than in SW.

Nevertheless, the state knows that if it starts a warfare the local community would be better off by choosing to be a follower, and in fact also better off than in SL. Similarly, the local community knows that if they choose to be a follower, the state will choose to be a leader. In both cases we end up with the state being the leader. We cannot, however, conclude that this will be the result since there are no single strictly dominant strategy for either of the players.

		Local community	
		Follower	*Leader*
State	*Follower*	3,1	2,2
	Leader	4,4	1,3

Table 3. A game of leader selection with forward bending local response curve, and SS $\succ$ SL for local community.

A possibly more empirically relevant case is when the local ranking is such that SL is preferred to SS as in rankings R4 and R5 above. R4 is presented in Table 4. We see that this game is almost identical to the one given in Table 2, with the exception that in the local ranking, SS is now preferred to C. We still have a chicken game with two Nash equilibria. Unlike the above game, the state have less reason to believe that the local community will choose to be a follower if Stackelberg warfare breaks out. This case is more similar to the one with a backward bending local response curve, and we cannot predict which of the two Nash equilibria that will be the final outcome of the game.

		Local community	
		Follower	*Leader*
State	*Follower*	3,2	2,4
	Leader	4,3	1,1

Table 4. A game of leader selection with forward bending local response curve, and SL $\succ$ SS for local community.

One can, however, conclude that it is less advantageous for the local community to be a leader and disadvantageous to "give" that role to the state in the case of a forward bending local response curve. The state will, as a leader, choose to reduce its forest clearing, which will benefit the local community.

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Chapter 7

Resource Conservation and Poverty in a Traditional Agrarian Economy: An Overlapping Generations Approach*

Abstract:

The paper explores the incentives for resource conservation and long term resource dynamics in a traditional agrarian economy, that is, a resource dependent economy with no external markets for labour and credit. The paper develops an overlapping generations (OLG) model: the young generation is responsible for production and resource investments, while the old receive a share of the output. This structure provides incentives, although not perfect, for resource conservation which are not found in conventional OLG models. In this way the paper adds an explanation to the debate on why a strong emphasis on resource conservation appears to be an important feature of such societies. The second main theme is the impact of poverty on resource investments and conservation, and how the consumption level affects the response to exogenous changes. The paper shows how a vicious circle of poverty may lead to resource exhaustion if the initial resource stock is below a critical level.

* This is a substantially revised version of a paper presented at the *Development Economics Conference,* 27-28 November 1995, Bergen, Norway. I would like to thank Turid Bøe, Odd-Helge Fjeldstad, Rögnvaldur Hannesson, Karl O. Moene, Halvor Mæhlum, Ottar Mæstad, Karl R. Pedersen, and Ussif Rashid Sumaila for useful discussions and comments on earlier versions of the paper.

1 Introduction

Traditional agrarian societies in developing countries are characterized by several generations living on the farm. Production (labour input) is the responsibility of the young, whereas the old generation -- who normally owns the land -- receive a share of the output. This paper addresses two issues within an overlapping generation (OLG) modelling framework. First, (how) does this structure of the economy create incentives for conservation of natural resources, compared with the more conventional assumption in OLG models of retirement savings taking place in financial markets? Second, how is the resource use influenced by the existence of widespread poverty in such societies?

OLG models have in recent years got a prominent position in long-term macroeconomic analysis. The typical structure of such models is an individual or generation living in two periods (young, working and saving; and old, retired and consuming the savings). At any point in time two generations are alive, and may be trading with each other. Compared to the infinitely lived representative agent of the traditional Ramsey-Solow (RS) growth models, the OLG structure provides a more realistic description of life-cycle motivated agents, and takes into account that individual behaviour is influenced by the fact that "in the long run we are all dead".

This differing structure of the RS and OLG models have some significant consequences when it comes to the analysis of intergenerational distribution and equity, and long term resource conservation -- two issues at the center of the sustainability debate. In the RS model "the single agent assumption and the infinite time horizon of the agent assumes a personal identification with the future that guarantees incentives to conserve resources for the future" (Farmer, 1993: 51-52). The allocation of assets across generations is obscured in RS models. OLG models, on the other hand, recognize that each generation may behave in a selfish way and not take account of environmental and other consequences that outlive themselves. This is a key problem in OLG models applied to sustainability analysis.

A number of different solutions to this problem has been put forward in the literature, some of which are briefly reviewed in section 2. Parent-offspring altruism and bequests, and sale of productive assets between generations may provide vehicles for intergenerational transfer. Others have argued for the creation of separate mechanisms and institutions to ensure that intergenerational fairness is achieved.

One purpose of this paper is to provide an alternative explanation of how resource conservation and intergenerational fairness can be achieved within the OLG framework. Our context is a traditional agrarian economy, which main characteristics are outlined in section 3. In this economy there is no public retirement scheme, nor any financial market where retirement savings can take place. The old generation survives by receiving a share of the output produced by the young generation. Output is a function of only natural resources and labour (supplied by the young generation). The only way of saving for old age is by increasing the natural resource base. A major topic of the paper is how the lack of alternative retirement saving opportunities can create incentives for resource conservation in the decisions taken by the young generation.

The second aim of the paper is to show how decisions related to resource conservation are influenced by the consumption level (poverty) in this economy. By applying an additive Stone-Geary type utility function (i.e., include a subsistence level of consumption), we show how the behaviour critically depends on how close consumption is to the subsistence level. In this way we can explain how poverty may contribute to resource degradation, and how a society may enter a vicious circle of poverty and environmental degradation. Related to our main working hypothesis of the traditional agrarian economy providing strong incentives for resource conservation, we explore how the existence of poverty can modify this result. Central in this discussion is the discount rate for consumption (the consumption rate of interest) which is endogenous in the model and determined by the consumption level in the two periods.

The outline of the paper is as follows: section 2 gives a brief review of the literature. Section 3 presents the basic structure of the model. Section 4 looks at the adaptations within a two-period framework. In order to get a more tractable solution of the model, a simplified version with exogenous labour is studied in section 5. Section 6 discusses the long term bioeconomic equilibrium or steady state solution. The importance of the lack of alternative retirement savings is elaborated in section 7. Section 8 discusses the optimal allocation between the two generations. Section 9 gives some remarks on the relevance of OLG models to the study of resource use in a traditional agrarian economy compared to alternative explanations. Section 10 summarizes and concludes.

2 Applications of OLG models to sustainability issues

> *"Since environmental damage may outlive its perpetrators, overlapping generations models provide an appropriate demographic structure for analysis of environmental externalities" (John and Pecchenino, 1994:1405).*

The pioneering work on overlapping generations (OLG) models was made by Allais (1947), Samuelson (1958) and Diamond (1965). The underlying topic being addressed in the bulk of OLG models is the same as the opening question of Ramsey's (1928) seminal paper: "how much of its income should a nation save?" This includes issues such as the aggregate implications on capital accumulation and interest rates of life-cycle savings by individuals, various modes of funding of pensions programmes (fully funding, or pay-as-you-go systems), and the funding of government budget deficits (see Blanchard and Fisher, 1989).

During the last five years or so, a number of studies have made use of OLG models to discuss issues related to sustainability. There are two issues at the core in the discussion on sustainable development, which can fruitfully be discussed within the OLG framework. First, and closely related to the mainstream applications of OLG models, is the question of *intergenerational distribution and justice*. Second, and also related to the first question, is the issue of how *natural* *capital* can be incorporated in OLG models: what is the effect of changes in natural capital on the welfare of future generations, what are the incentives of the present generation to conserve natural capital, and so on. We examine each of these issues below.

Intergenerational distribution

OLG models provide a framework which in several respects is more appropriate than traditional Ramsey-Solow (RS) models for the discussion of intergenerational distribution of natural resources and welfare, and causes and effects of changes in the natural resource base. A major argument is indicated in the above quotation from John and Pecchenino (1994): mortal individuals may not take sufficient account of the long term environmental consequences of their actions, that is, consequences beyond their own life on this planet. A relevant question is then how one can avoid such generational myopia, and achieve intergenerational fairness. I do not enter into the discussion about definitions and criteria for intergenerational justice (see, for example, Torvanger, 1994; and Farmer, 1993: chap. 2 for overviews).

Farmer (1993) and Farmer and Randall (1994) argue that through sale of productive assets between generations, there will -- under a set of very robust incentives -- be no exhaustion of a renewable resource. Farmer (1993) contends that current models of economic growth fail to take full account of the strong incentives for transfer of productive stocks between generations. According to this view the problem is at times overstated.

A second argument relates to how parent-offspring altruism can make the market solution move closer to the social planner's solution. Blanchard and Fisher (1989: 104ff) show how a market economy with altruism in the form of bequests may produce an outcome which is identical to the command optimum (golden rule) and to an RS-model. Howarth (1992) similarly argues that this kind of parent-offspring altruism (or nested altruism) creates a *chain of obligations* which help achieve intergenerational justice.

There is little doubt that parent-offspring altruism and bequests are important elements of economic life. In rich countries a large share of the wealth is obtained through bequests.[1] In traditional agrarian societies throughout the developing world, the main asset -- land -- is inherited from father to son (agnatic or patrilinear), from mother's brother to sister's son (matrilinear), or similar arrangements. Commonly the farm will also contain more than one adult generation.[2]

The above result therefore appears to be a strong one -- maybe "too good to be true". Does it imply that a competitive market economy will take care of the intergenerational distribution? Blanchard and Fisher (1989) discuss how the possibility of negative bequests considerably

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1 70 pct. of wealth in the US is attributable to bequests, not life-cycle savings (Kotlikoff and Summers, 1981).

2 62 pct. of all rural farm households in India contained at least two adult generations (Rosenzweig and Wolpin, 1985).

modifies their result. Another problem relates to the fact that bequests usually are in the form of money transfer, which may not fully substitute for a decline in environmental assets. And whereas bequests are private goods, many forms of natural capital (environmental goods) have strong public good characteristics, which will not be sufficiently conserved through parent-offspring altruism. A sufficient supply of this kind of natural capital for future generations would, therefore, require other forms of altruism (beyond the one for our own children) or other mechanisms to correct the market failure.

Given that parent-offspring altruism may prove insufficient, an alternative focus in the debate is on how to create mechanisms and institutions which ensure that sufficient capital, including natural capital, is handed over to the next generation to ensure that they can maintain the same welfare (e.g., Howarth and Nordgaard, 1990; Howarth 1991; Farmer and Randall, 1994). A general result in theoretical models is that competitive markets only ensure efficiency and not necessarily a just intergenerational allocation. The government "has to correct intertemporal market failures due to selfish behaviour of each generation" (Marini and Scaramozzino, 1995: 76). The debate on what kind of mechanisms and institutional set-up that is needed and how these can be implemented has not, however, come very far. This is certainly an area with a great need and potential for future research.

The discussion is also related to discounting. In welfare economics the choice of discount rate reflects how a welfare increase for future generations is valued against a welfare increase for the present generation. "The intergenerational distribution of income or welfare depends on the provision that each generation makes for its successors. The choice of social discount rate is, in effect, a policy decision about that distribution" (Krutilla and Fisher, 1975: 76). A solution which has been put forward in the popular debate is to lower the discount rate. This is, however, is a controversial suggestion.

I have discussed the murky issue of discounting at some length elsewhere (Angelsen, 1991; Angelsen *et al.*, 1994), and intend only to give some brief points in relation to OLG models here. First, discount rates are exogenous in many OLG models, thus they do not provide any assistance in determining what the social discount rates should be.[3] Second, the OLG approach has pointed to the need for distinguishing between two different discount rates: the discount rate applied within a generation, and the discount rate between generations. According to Burton (1993), it is the latter -- the inter-generational discount rate -- which determines the potential for resource extinction. In the model of this paper, however, it is the former discount rate which is the relevant one. Third, the "burden" put on the discount rate in RS models is reduced. "Naive concerns about discount rates are replaced with a more considered vulnerability of the physically unrepresented future agents to the current trade of living agents" (Farmer, 1993: 9). Finally, OLG

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[3] An exception is the model by Marini and Scaramozzino (1995), where the discount rate for future utility from the environment is a growth corrected social time preference rate, augmented by the rate at which the environment absorbs pollution.

models provide a useful tool for analysing the effects of different discount rates on the natural resource stock and intergenerational distribution, as will be done in this paper.

Yet another solution to the problem of generations behaving selfishly and not taking (sufficient) environmental considerations is the one presented in this paper. We focus on how natural resources are conserved and transferred to the next generation in a traditional agrarian economy. The key incentive rests in the fact that a generation depends on natural resources also after retirement, as they receive a share of the output produced, partly from the natural resource base.

Natural capital in OLG models

The second issue of relevance to the sustainability debate relates to the inclusion of natural resources and environmental capital in growth models. From the early/mid 1970s there has been a considerable research effort on how scarcity of natural resources will affect long term welfare and intergenerational distribution (see, among others, Hartwick, 1977; Solow, 1974; Dasgupta and Heal, 1979). Whereas these studies were done mainly within a capital theoretic framework and in the RS growth models tradition, more recent efforts have attempted to include natural resources into OLG models. These include Howarth and Nordgaard (1990) and Howarth (1991) who use a very simple three period model with a non-renewable resource, and Farmer (1993) who studies the use of a non-renewable resource and capital transfer between generations within a similar three period framework. A model with both man-made and environmental capital in an infinite horizon setting is given by John and Pecchenino (1994). Marini and Scaramozzino (1995) develop a continuos time OLG model with natural resources -- a structure which allows for a discussion of population growth.

The main advantage of using OLG models for the study of intergenerational allocation of natural resource use is already given above: it represents a more realistic demographic structure, and thereby a better framework for analyzing the problem of maintaining the long term natural capital. A number of familiar problems from the earlier literature on natural resources and long term growth is present in OLG models, and may even be articulated in a better way: the provision of collective environmental goods in a market system, and the effects of myopia and short time horizons.

Applications to developing countries

This paper develops an OLG model for a traditional agrarian, developing country economy. The application of OLG models to study resource use in this setting, where one takes into account explicitly the particular characteristics of a traditional agrarian economy, has -- to my knowledge -- not been done previously. There are, however, elements of such a discussion in Farmer (1993) and John and Pecchenino (1994). Both show how economies with agents not sufficiently endowed initially may experience degradation of the environment.

More explicit applications to developing countries include the model of Rosenzweig and Wolpin (1985) on land and labour arrangements on family farms in developing countries. The focus is not on resource degradation (land is non-depreciable), but rather the incentives for farm offspring to purchase the family land, and for parents to employ their offspring and sell the land to them. Their result is largely driven by farm specific knowledge and technology. Daveri (1991) studies the link between consumption and productivity (efficiency wage) within an OLG framework. Nerlove *et al.* (1986) discuss the parents' decision about how many children to get, given that parents care about both the number and the welfare of their children.

3 An OLG model for a traditional agrarian economy

3.1 Description of the economy

The basic structure of the model of this paper is the same as in most discrete time OLG models: Each generation lives in two periods: they work and consume in the first period (as young), whereas they only consume in the second period (as old). There are no opportunities for savings in a financial market, public pension system, or similar (this assumption is relaxed in section 7). The lack of any financial retirement savings is a distinct characteristic of agriculture-based, rural economies in developing countries. In their second period they receive an exogenously determined share of the output produced by the young generation.

This economy can be thought of as a family farm, common throughout the developing world. The old generation (parents) live on the farm also after "retirement" (a foreign concept in most such societies), and consume a share of the farm produce. In traditional agriculture the two main inputs are family labour and natural resources. The latter can be thought of as both the amount and quality of land.

A key focus of OLG models is on the mechanisms of trade between the two generations that are alive at any point in time. The old own the land, and it is not handed over to the next generation before they die. The young work on the land, and give a share of the output to the old. In this way the relationship between the young and old generations resembles a sharecropping system (principal - agent relationship), where the old are the landowners (principals) and the young are the farmers (agents).

The young determine their labour input based on selfish calculations; there is no altruism in the model (see section 9). This also implies that one cannot *as old* influence the consumption as old. However, one can *as young* influence one's consumption as old through the effect the decisions have on the resource stock carried over, both directly (the resource is an input in production) and indirectly via the way the stock size affects the labour supply by the young in the next period. The only type of savings for old age is by conserving/increasing the resource stock. This can be done in two ways in the model: increasing the direct resource investments, or reducing the intensity of production (labour input).

In a more general model, one should also include the option of enhancing the production possibilities on the farm by producing more labour (children). To simplify the model we assume no population growth, which means the number of (surviving) children is fixed to two.[4]

The natural resource studied is not a public good, but a private one over which the household has full control, including secure property rights.

There are no explicit markets in the model, thus there is no need to discuss the market clearing conditions as is common in OLG models. Equally significant as the financial market assumption is the assumption of no external labour market in the economy.[5] The assumption of no land market is in accord with empirical observations: the lion's share of farmland is obtained through inheritance (or, in some land abundant areas, by clearing of new land), and not through land purchases.[6] As for the output market, it is of less importance in the model whether the output is consumed directly or sold in a competitive market (at a price equal to unity).

3.2 Basic model

Consider the problem of generation t in period t (when they are young). People only work when they are young (the first period), but consume in both periods. The problem is to maximize life-time welfare or utility, given by;

$$(1) \qquad U_t = U(c_{t,t}, l_t, c_{t,t+1}) = (c_{t,t} - c^s)^{\alpha} + v(l^m - l_t)^{\beta} + b(c_{t,t+1} - c^s)^{\alpha}$$

$$v > 0; \alpha, \beta \in (0,1); b \in (0,1]$$

The lifetime utility function is assumed to be additive, both between consumption (c) and work (l) in period t, and between the two periods. $c^s > 0$ is the subsistence level of consumption, whereas $l^m > 0$ is the maximum labour input, thus $(l^m - l_t)$ is leisure. We shall assume throughout the analysis that the technology and resource stock are such that $(l^m - l_t) > 0$ and $(c_t - c^s) > 0$ are possible.

For simplicity the per-period utility (felicity) function for consumption is identical in both periods. Period $t+1$ utility is discounted by a discount factor $b = 1/(1+\rho)$; $\rho \geq 0$ is the rate of pure time preference. The functional forms used implies that the utility function U_t is concave in its arguments, with positive but diminishing marginal utility of consumption and leisure. α and β are constants, where $\alpha - 1$ is the elasticity of marginal utility with respect to consumption above the subsistence level (surplus consumption), and similarly for $\beta - 1$ with respect to leisure.

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4 In order to include children explicitly, one would have to use three periods (child, adult, old) in the model, something which will make the model quite difficult to handle.

5 See Angelsen (1995: section 3; 1996) for a discussion of the difference between closed economy models (as chosen here), and open economy models when it comes to analysis of agrarian societies. For a discussion of the effects of poverty and resource degradation, the closed economy model is more appropriate. In the open economy model the consumption and production decisions can be separated, thus the link from poverty to resource use is less direct.

6 Most of the land sale taking place is characterized as "despair sale".

We use an additive form of a Stone-Geary type utility function for period t utility, and not the more common multiplicative version. If $\alpha = \beta$ the period t utility function is actually equivalent to using a CES function, see Angelsen (1996). The conventional Stone-Geary function does *not* give some of the later comparative statics results, where the sign of the response is dependent on the consumption (poverty) level (that is, if subsistence or income effects dominate depends on the consumption level). The additive formulation of the utility function is therefore more flexible than the multiplicative.

Consumption in period t of the generation that came into existence in period t ($c_{t,t}$) is given by the share $(1-a)$ of the output y_t that the young generation will keep, minus any investments (i) in the resource (land). Similarly, after retirement the t-generation obtains a share a of the output their offspring produce on the family farm. a is taken as exogenously given and constant over time, for example, culturally determined. The optimal allocation between the generations is discussed in section 8.[7]

(2) $$c_{t,t} = (1-a)y_t - i_t;\ a \in (0,1)$$

(3) $$c_{t,t+1} = ay_{t+1}$$

We use a Cobb-Douglas production function, which implies complementarity between the two inputs, labour (l) and the resource stock (r). We use the same function in all periods. A is the technology (scale) parameter (same in both periods). This implies no technical progress. We further assume constant returns to scale, which simplifies the model, and may not be an unreasonable assumption. To simplify notation, subscripts for time are omitted when referring to general functions or when the time period referred to is well understood from the context.

(4) $$y = f(r,l) = Ar^{\gamma}l^{1-\gamma};\ \gamma \in (0,1)$$

Note that individuals do not make any choices after retirement; l_{t+1} is determined by the offspring, whereas r_{t+1} is determined by period t decisions (when young) in the following way;

(5) $$r_{t+1} = g(l_t, i_t; r_t, r^c) = r_t + h(r_t; r^c) - ml_t^{\varepsilon} + ni_t^{\tau};\quad k, r^c, m, n > 0;\ \varepsilon > 1; \tau \in (0,1)$$

$$h(r_t; r^c) = kr_t\left(1 - \frac{r_t}{r^c}\right);\ h(.) > 0\ for\ r_t < r^c;\ h_{r^c} = \frac{kr_t^2}{(r^c)^2} > 0$$

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7 Several alternative formulations would be possible here. One alternative is to specify two types of labour: one used in production and the other used for conservation of or investments in the resource. The investments would then be a function of this type of labour. Both formulations have their merits, and selecting the alternative formulation would not change the fundamental mechanisms of the model.
Another alternative formulation is to let the old generation "pay" a share $(1-a)$ for the investments, that is $c_{t,t} = (1-a)[y_t - i_t]$. This kind of cost sharing may be a better description for some kinds of investments, for example, when the investments reduce the output directly. For others, for example, when the output is used to invest in resource conservation, the chosen formulation would be more appropriate. In the simplified version of the model the chosen formulation is critical to make the model dynamic recursive.

$$h_r = k(1 - \tfrac{2r_t}{r^c}) \gtrless 0 \Leftrightarrow r_t \lessgtr \tfrac{r^c}{2};\; h_{rr} = -\tfrac{2k}{r^c} < 0;$$

$$g_{r_t} = 1 + k\left(1 - \tfrac{2r_t}{r^c}\right) \gtrless 0 \Leftrightarrow r_t \lessgtr \tfrac{r^c(1+k)}{2k};\; g_{rr} = -\tfrac{2k}{r^c} < 0$$

The resource stock links the two periods together. The stock in period $t+1$ is determined by four factors. *First*, the resource stock which is carried over from the end of period t. *Second*, the natural resource growth. This is expressed by a logistic function, which gives an inverted U-shaped growth curve in the growth-stock diagram: k is the intrinsic growth rate, and r^c is the maximum sustainable stock (carrying capacity).[8] The function yields positive growth ($h(r_t) > 0$) within the most interesting range of the resource stock ($r_t < r^c$), and is strictly concave ($h_{rr} < 0$). The sign of the change in the growth rate (h_r) depends on the size of the resource stock, being positive for small and medium resource stocks, that is, for $r_t < r^c/2$. The total effect of higher resource stock (r_t) on the stock in the next period (r_{t+1}), that is g_r, may be positive or negative. However, for realistic parameter values and resource stocks it is positive, which we shall assume throughout the paper. If, for example, $k = 0.1$, the condition for $g_r > 0$ is $r_t < 5.5\, r^c$, that is, the resource stock must be much higher than the carrying capacity. For some biological resources like a natural forest k will be even lower (for example, 0.04 - 0.05).

Third, there is a resource loss from period t to $t+1$ due to production. This is positively related to the intensity of production as measured by the labour input. *Fourth*, the resource stock can be augmented by investments in resource conservation.

There is a disagreement in the literature on the effect of higher output prices on resource degradation in agriculture, which in part reflects the way degradation is modelled (Barrett, 1991). Some only consider degradation to be a side-effect of production, and higher output prices will increase degradation (e.g., Lipton, 1987). Others model degradation as an investment decision, and a price increase has positive environmental effects (e.g., Repetto, 1987). We include both aspects in the original model. In the simplified version in section 5, only the latter aspect is included.

The carrying capacity is commonly used as a measure of how many people an ecological system can feed (carry). As we look at a model with a given population, the r^c would inform us about the resource richness of the economy. Alternatively r^c may be interpreted as the population density, that is, population size in relation to resources available.

3.3 The relationship between risk aversion, discounting and poverty in the model

Poverty is often linked to environmental management in the way that poor people are assumed to be myopic, have high discount rates, and be very risk averse, factors that may lead to long term environmental effects being neglected in their decisions. The way this aspect is included in economic models is often somewhat *ad hoc*; commonly it is limited to the discussion of the

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8 See, for example, Clark (1990: 11).

model without being integrated into it, *per se*. In our model we have introduced a subsistence level of consumption (c^s), which proves to be a very useful way to discuss the effect of low consumption levels (close to subsistence level) on resource use. Moreover, by this formulation it is easy to show that there may be a close link between *poverty* (closeness to c^s), *a high discount rate* for consumption and a high degree of *risk aversion*. These three elements represent essentially the same phenomenon.

The discount factor in (1), *b*, is the discount factor for *utility* (welfare), reflecting the pure time preference. The discount rate for *consumption* or the consumption rate of interest (CRI) is generally defined as the rate at which the value of consumption falls over time.[9] In our two period model this yields (we omit the first subscript referring to generation *t*);

$$(6) \qquad CRI \equiv \frac{U_1}{U_3} - 1 = \frac{(c_{t+1}-c^s)^{1-\alpha}}{b(c_t-c^s)^{1-\alpha}} - 1$$

$$\lim_{c_t \to c^s} CRI \to \infty; \ \lim_{c_{t+1} \to c^s} CRI = -1$$

$$c_t = c_{t+1} \Leftrightarrow CRI = \rho$$

$$CRI > 0 \Leftrightarrow \frac{c_{t+1}-c^s}{c_t-c^s} > b^{\frac{1}{1-\alpha}} \leq 1$$

The discount rate for consumption (CRI) increases as the consumption level in period *t* approaches the subsistence level; poverty in the current period gives high discount rates. We need to consider, however, also the consumption level in the next period. When the consumption level in period *t+1* approaches c^s, *CRI* becomes negative and is minus one at the limit. *CRI* will be positive for any positive consumption growth, and may also be positive for a negative growth rate, depending on the pure time preference and the parameter α. Finally, when consumption is the same in both periods, the *CRI* equals the rate of pure time preference, regardless of the level of consumption.[10]

The closeness to the subsistence level is also related to the degree of risk aversion. The standard Arrow-Pratt definition of the degree of risk aversion is limited to utility functions with only one variable. One possibility would therefore be to define risk aversion only in terms of consumption in any given period (*c*). The absolute risk aversion coefficient (R_a) is then;[11]

$$(7) \qquad R_a = -\frac{U_{cc}}{U_c} = -\frac{\alpha(\alpha-1)(c-c^s)^{\alpha-2}}{\alpha(c-c^s)^{\alpha-1}} = \frac{1-\alpha}{c-c^s}$$

[9] In the commonly used continuous time (and constant elasticity) version of the utility function, *CRI* is given by the rate of pure time preference plus the elasticity of marginal utility with respect to consumption multiplied by the expected consumption growth (see, for example, Ray, 1984).

[10] Note that the rate of pure time preference may also be affected by the poverty level, an aspect not included in this model. One argument for a positive rate is the risk of death (e.g., Pearce and Nash, 1981). As poverty increases the risk of death, economic theory provides a rational explanation as to why poverty increases the pure time preferences.

[11] See Arrow (1970). He assumes, based on empirical observations, that R_a is decreasing with *c* (or wealth), which is consistent with our formulation. Arrow also introduces a measure of *relative* risk aversion: $R_r = -(c_t - c^s)\, U_{cc} / U_c$, which in our model is constant and equal to $1-\alpha$.

$$\lim_{c \to c^s} R_a = \infty; \ \lim_{c \to \infty} R_a = 0$$

Our specification of the utility function produces a very significant result: when the consumption level approaches the subsistence limit, the agent becomes increasingly risk averse (R_a is infinite on the limit). Conversely, the higher the consumption level is, the more willing (s)he would be to take risk (R_a approaches zero). This result is both intuitively appealing and turns out to be very useful in the later discussion of the model. It has also got a solid empirical foundation (see e.g., Holden *et al,* 1996).

A more elaborate theory on measures of risk aversion with many arguments in the utility function is given by Kihlstrom and Mirman (1974, 1981). The appropriate measure in the case of three commodities is (formula 2.3.2 in Kihlstrom and Mirman, 1974);

(8) $$R_A = \frac{-\Delta_3}{\left(-\Delta_3^b\right)^{\frac{3}{4}}}$$

where Δ_3 is the Hessian and Δ_3^b is the bordered Hessian of (1). Appendix 1 shows that the results from (7) hold. In addition, absolute risk aversion increases as the consumption in period $t+1$ approaches c^s, and when labour input approaches the maximum labour time available;

(9) $$\lim_{c_t \to c^s} R_A = \infty; \ \lim_{c_t \to \infty} R_A = 0$$

$$\lim_{l_t \to l^m} R_A = \infty$$

$$\lim_{c_{t+1} \to c^s} R_A = \infty; \ \lim_{c_{t+1} \to \infty} R_A = 0$$

In short, in our model a high discount rate for consumption and a high degree of risk aversion are the result of current consumption being close to the subsistence level, that is, poverty. Whereas either of these three factors often are used as explanations on environmental degradation and viewed in isolation, it is difficult to separate them in our model as they describe the same underlying phenomenon.

3.4 Farm firm and subsistence effects in the comparative statics

In the comparative statics of sections 4 and 5 we shall distinguish between two different effects of exogenous changes. These relate to the classical discussion of the family farm as both a farm *firm* and as a labourers' and consumers' *household* (e.g., Nakajima, 1986). In its first role the family farm acts like a profit maximizing firm. In its second role it acts as a consumer, in particular, it has to meet the subsistence target.

1. *"Farm-as-a-firm" effect:* This is the effect one gets when analyzing the problem as one of maximizing the profit from the production in the two periods. The *farm firm* effect can be studied within the model by setting $U_1 = U_2 = U_3 = 1$ ($U_{11} = U_{22} = U_{33} = 0$), which implies that *the shadow wage rate* (defined as $-U_2/U_1$, see section 4.1.) or the *CRI* (section 4.2 and 5) are constant.

2. *"Farm-as-a-household" or subsistence effect:* When the consumption is close to the subsistence level, considerations about how to meet this target dominate. In the comparative statics, this implies that the effect related to a change in the *shadow wage rate* or *CRI* will dominate.

As discussed in Angelsen (1996: appendix 1), the farm firm and subsistence effects are similar to the *substitution* and *income* effects in the standard theory of the consumer. We shall in this paper use the terms farm firm and subsistence effects, as they refer directly to the two roles of agricultural households. As further argued in Angelsen (1996) the distinction between farm firm and subsistence effects helps considerable to understand some controversies in the debate about the effect of, for example, higher agricultural output prices on farmers' behaviour and environmental degradation. The farm-firm effect refers to the response keeping the shadow prices (shadow wage rate or CRI) constant, whereas the subsistence effect refers to the effect of changes in shadow prices.

The comparative statics highlights the crucial role of the market assumptions in agricultural household models. Whereas such models normally focus on the importance of the (lack of) labour market integration, in this model it is the lack of a credit market that causes the subsistence effect to play a critical role in the comparative statics. This will be highlighted further in section 7, where a market rate of interest is introduced.

4 A two-period model

"This sounds easy, but actually it is very hard, so hard that I shall have to make drastic simplifications in order to arrive at exact results" (Samuelson, 1958: 467, on the problems of giving a complete general equilibrium solution in the pioneering work on OLG models).

The model as formulated in section 3 proves to be quite complicated to solve analytically, as it is not dynamic recursive; the decisions of generation $t+1$ are influenced by generations t's decisions, *and* the labour input decision in period $t+1$ influences the decisions in period t. The same is, of course, true for generation $t+1$, $t+2$, and so on, hence the decisions of generation t should take into account the effects of its decisions on all future generations' decisions. There are at least three different ways of handling this problem:

1. Make a two-period model and solve it backwards, which is the option chosen in this section.
2. Make a numerical model and solve it backwards by recursive methods, for example, dynamic programming (DP).[12]
3. Simplify the model such that it becomes dynamic recursive. This is done in the next section, where labour input is exogenous.

In a two-period model the decisions in the end period ($t+1$) are simplified (no third period), thus we shall mainly focus on the decisions in the first period (t). The main purpose of the analysis of

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[12] An example of this is Stokey and Lucas (1989, chap. 17.1). This would, obviously, require a specification and calibration of the model based on real data or "best guesses".

the end period is to derive the response or labour supply function, that is, the labour input (l_{t+1}) as a function of the period t decisions (l_t and i_t) and the exogenous variables.

4.1 Optimality condition for the end period

As this is the end period, the problem for generation $t+1$ in period $t+1$ is simply to maximize the utility for the period when they are young. There is no incentive to invest in resource conservation, thus $i_{t+1} = 0$.[13] It also implies that the resource loss due to labour input is not taken into account in the optimizing problem. The objective of generation $t+1$ would then be;

$$(10) \quad \underset{l_{t+1}}{Max}\ U_{t+1} = U[(1-a)f(r_{t+1}, l_{t+1}),\ l_{t+1}]$$

In the further analysis we shall assume that the resource endowments, technology and preferences are such that an interior solution is possible, i.e., that the minimum consumption can be reached with the resource stock, technology and labour available. The first order condition (FOC) is;

$$(11) \quad (1-a)f_l = w; \quad w \equiv -\frac{U_2}{U_1} = \frac{\nu\beta(c_{t+1}-c^s)^{1-\alpha}}{\alpha(l^m - l_{t+1})^{1-\beta}}$$

In optimum the marginal rate of substitution between consumption and labour or shadow wage rate (w) should equal the marginal productivity of labour, weighted by the share that the young receive.

In spite of the simple structure of the model, it is not possible to find the explicit solution for l_{t+1}, partly due to the use of c^s and l^m in the utility function, which is central to derive some of the later results. Implicitly we find the effect of exogenous changes in a and r_{t+1} by total differentiation of (11). The full derivation is given in appendix 2, and only the main results are presented below;

$$(12) \quad \frac{dl_{t+1}}{dr_{t+1}} = -\frac{1}{H}\left[-(1-a)f_{l_{t+1}r_{t+1}} + \frac{dw}{dr_{t+1}}\right] \gtrless 0 \Leftrightarrow c_{t+1} \gtrless \frac{c^s}{\alpha};\ H>0$$

$$(13) \quad \frac{dl_{t+1}}{da} = -\frac{1}{H}\left[f_{l_{t+1}} + \frac{dw}{da}\right] \lessgtr 0 \Leftrightarrow c_{t+1} \gtrless \frac{c^s}{\alpha};\ H>0$$

As discussed in section 3.4 the response to exogenous changes can be divided into two different effects; the *farm firm* effect, which gives the response in the case when the wage rate is kept fixed (e.g., market determined), and the *subsistence* effect, which reflects changes in the shadow wage rate. A higher resource stock has a positive effect on the labour input, following from the assumption of complementarity between labour and the natural resource. The subsistence effect has the opposite sign: higher production and consumption will lower the marginal utility of consumption, thus the shadow wage rate increases.

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13 Alternatively, we could have set the investment to a fixed level greater than zero, or introduced a salvage value on the resource stock. The introduction of any of these would not have any significant effects on the results of the model.

A lower share (higher a) also shows contradicting effects. The farm firm effect is negative, as a lower share of the output reduces the physical quantity the generation retains. Lower consumption will, on the other hand, reduce the shadow wage rate, hence the subsistence effect pulls in the direction of higher labour input.

In both cases we find that the subsistence effect will dominate for poor households, that is, for consumption levels below a critical level, c^s/α (appendix 2). In this case the need for survival dominates, as reflected in the shadow wage rate being very sensitive to changes in consumption. In situations with a consumption above this critical level the farm firm effect will dominate, and the sign of the household's response is as if they were price taking profit maximizers. We can therefore distinguish between two cases:[14]

Case A: Relatively wealthy economy ($c_{t+1} > c^s/\alpha$)

(14a) $l_{t+1} = s(a, r_{t+1});\ s_a \equiv \frac{dl_{t+1}}{da} < 0;\ s_{r_{t+1}} \equiv \frac{dl_{t+1}}{dr_{t+1}} > 0$

Case B: Poor (subsistence) economy ($c_{t+1} < c^s/\alpha$)[15]

(14b) $l_{t+1} = s(a, r_{t+1});\ \ s_a > 0; s_{r_{t+1}} < 0$

The signs of the effects depend on the actual consumption, the subsistence level and α. The consumption level is, of course, a function of all parameters and exogenous variables of the model, in particular, the level of the resource stock in period $t+1$. Ideally, the condition for which effects dominate should be characterized in terms of only parameters and exogenous variables. It is, however, impossible to derive such an explicit expression in the present model.

For use when discussing the optimality conditions in period t we shall briefly examine the combined output effect on an increase in the resource stock in period $t+1$. The effect of higher r_{t+1} when including both the direct effect on production and the indirect effect via changes in the labour input is;

(15) $\frac{\partial y_{t+1}}{\partial r_{t+1}} = f_r + f_l s_r > 0$

It is not readily seen that the total effect is positive also in the poor economy case when s_r is negative. However, the possible negative labour supply effect is a derived effect based on an increase in production, and can therefore never dominate the direct effect (f_r).

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14 In addition to the consumption level, the criterion also depends on α, and this can be given an intuitive cultural interpretation: A high absolute value of the elasticity of marginal utility (α-1) indicates that more leisure rather than higher consumption is preferred when income increases. Thus, if the household has such "non-materialistic" preferences, the subsistence effect will dominate even for high consumption levels. See the discussion of model II in Angelsen (1996). Note, also, that the parameter αalso can be interpreted to express attitudes towards risk, see section 3.3.

15 I use the term subsistence in this context to indicate a level of consumption close to the subsistence level, and not necessarily in the other, and frequently used, meaning of the term as an economy where the output is consumed directly and not sold in a market.

4.2 Optimality conditions for the first period

(5) gives the effect of period t decisions on the *resource stock* in the next period, whereas (14) combined with (5) give the effect on the *labour supply* in the next period. Together, these determine consumption in the second period. We can now derive the optimality conditions for the first period (t). The objective of generation t is to maximize (1) given (2) - (5) and (14);

$$(16) \quad \underset{l_t, i_t}{Max} \; U_t = U[(1-a)f(l_t, r_t) - i_t,\; l_t,\; af(s(a, g()), g())]$$

The first order conditions (FOC) are;[16]

$$(1-a)U_1 f_{l_t} + U_2 + U_3 a g_{l_t}(f_{r_{t+1}} + f_{l_{t+1}} s_{r_{t+1}}) = 0$$

$$-U_1 + U_3 a g_{i_t}(f_{r_{t+1}} + f_{l_{t+1}} s_{r_{t+1}}) = 0$$

It can be shown that the second order conditions (SOC) for maximum are also met.[17] The FOC can be rearranged in order to give a more intuitive economic interpretation;

$$(17) \quad (1-a)f_l = w - \frac{a g_{l_t}\left(f_{r_{t+1}} + f_{l_{t+1}} s_{r_{t+1}}\right)}{CRI+1}$$

$$(18) \quad CRI = a g_{i_t}(f_{r_{t+1}} + f_{l_{t+1}} s_{r_{t+1}}) - 1$$

w and CRI are given in (11) and (6). (17) is a modified version of (11). The marginal productivity of labour, corrected for the share the young receive, should equal the shadow wage rate less the present value of changes in next period consumption following higher labour input. The latter cost includes both the direct resource degrading effect of labour input, and the labour supply response of next generation to changes in the resource stock. The combined effect of a lower resource stock is always negative, cf. (15), even though the labour supply response is positive in the subsistence case.

(18) states that the consumption rate of interest (CRI) should equal the net return on resource investments. Thus a standard result of consumption-investment models is confirmed in our model. Again, the return includes both the direct production augmenting effect of resource investments, and the indirect labour supply response in period $t+1$.

One should note that in a poor (subsistence) economy the effect in the model of including the behaviour of the next generation is to further *increase* resource degradation. The reason is that a lower resource stock makes the young in the next generation work more in order to reach the subsistence target. Thus the costs of resource degradation (l) and the benefits on investments (i) for the present generation are reduced.

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16 We assume in the following that we get an interior solution of the maximization problem.

17 This is shown by differentiating the model with respect to l_t and i_t, take the determinant, and simplify the expression by factoring the positive and negative elements.

The comparative statics of this model do, unfortunately, produce few unambiguous results: there are contradicting effects, and without further simplification or using a numerical model we cannot determine analytically the net effect. The formal analysis is therefore not included. Before simplifying the model further, we shall nevertheless briefly discuss intuitively some of the effects of exogenous changes.

A lower share to the young implies that generation t receives less for their work, which will reduce the labour input. In addition comes the fact that higher a means that they will receive a larger share as old, thus it becomes more beneficial to conserve the resource, and reduce the labour input. The fact that they will receive a larger share as old will also give an incentive to increase resource investments.

This conclusion may be reversed in the case where generation t is close to the poverty level. A smaller share of the output in period t implies that generation t has to work more to reach the subsistence target, and they will also invest less. Even though resource conservation has become more profitable in money terms, the need to survive (subsistence effect) dominate the decision making.

A similar reasoning applies to the effect of an increase in the resource stock. The effect of a higher resource stock (r_t) is crucial in a study of the long term equilibrium (steady state). In the wealthy case the result is straightforward: due to the complementarity between labour and resources in the production function, labour inputs will increase when the resource stock is increased. Furthermore, a higher resource stock implies lower marginal productivity of the resource in period $t+1$. Thus, the marginal costs of resource deterioration or the marginal benefits of resource conservation will decline. The result is higher labour inputs and lower resource investments.

In the case when the consumption is close to subsistence level we may get the opposite effect. The direct effect on an increase in the resource stock inherited is to boost production in period t. Farmers, who have worked hard to reach the subsistence target, may now relax a little bit more, thus a decline in labour inputs. For the same reason the investments will also increase in the subsistence case.

An increase in the discount factor (decrease in the discount rate) implies putting more weight on life as old. This provides an incentive for conserving more of the resource stock, hence the labour input will decrease and the resource investments increase. There is no difference here between the two cases.

5 A simplified model with exogenous labour

The analytical complexity of the model so far prohibits any firm conclusions in the comparative statics. Moreover, the model is *not* dynamic recursive, something which makes it difficult to solve explicitly for the long term dynamics. In order to handle these two difficulties, we shall simplify the model by assuming that labour inputs are exogenous in the model, which make the model dynamic recursive.

This will reduce the flexibility of the model, as there is only one choice variable left (investments). This implies, for example, that it is not possible to both increase present consumption and the resource stock, the decision maker now faces a hard choice between higher consumption now or later. However, the basic concern for the decision maker in the model is not consumption but utility, and in this respect there is no difference between the models -- there is in both a hard choice between welfare in the two periods. Thus even with labour kept exogenous, the basic structure of the decision problem remains the same: the balance between present and future welfare through the resource stock carried over between the periods.

An alternative would be to keep labour endogenous, and make the investments exogenous. One analytical problem with this is that the model would not be dynamic recursive: the labour input decisions in period $t+1$, *and* thereby the period $t+1$ consumption of generation t, would depend on the decisions in period t. If we disregard this effect ($s_r = 0$), it can be shown that this alternative (i_t exogenous) will give the same qualitative results of the comparative statics as the ones presented below.

5.1 Decisions in period t

We set the labour input in all periods to a fixed level;

(19) $$l_j = \hat{l};\ j = t, t+1, ...$$

The optimality condition is now a modified version of the previous model;

$$-U_1 + U_3 a f_{r_{t+1}} g_i = 0$$

The optimal investment level is where the welfare loss in period t equals the welfare gain in period $t+1$, where the latter takes into account the resource augmenting effect of investments, the marginal productivity of the resource stock and the output share people receive as old. The FOC can be rewritten as;

(20) $$CRI = a f_{r_{t+1}} g_i - 1$$

This is the simplified version of (18): in optimum the consumption rate of interest should equal the net return on investments. The optimal investments are illustrated graphically in Figure 1. *CRI* is increasing with increasing i_t as c_t is reduced and c_{t+1} is increased. The net return on investments is falling with i_t, both due to decreasing marginal productivity of natural resources in production, and decreasing return on resource investments.

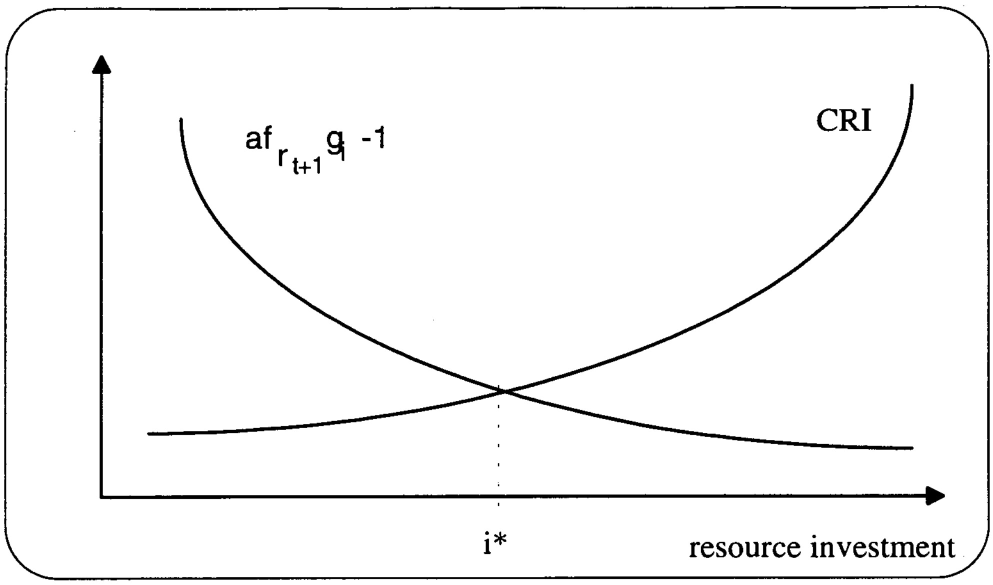

Figure 1. The optimal resource investment (i).*

Even though there are incentives for generation t to conserve the resource base, the incentives are not perfect: they enjoy only a share a of the increase in output due to resource conservation. The structure of the problem in our model has strong parallels to the sharecropping theory (or principal-agent theory more generally), and the Marshallian inefficiency created by such contracts: those who take the decisions and bear the costs receive only a fraction of the total benefits. Thus, we still have a market failure in the sense that there is a difference between the private and social valuation of the marginal benefits of resource conservation.

5.2 Comparative statics

The investments in period t, and thereby total production (period $t+1$), consumption (periods t and $t+1$), and the resource stock (period $t+1$), are determined by several variables and parameters:

- The utility function, i.e., the subsistence limit, and the elasticity of marginal utility wrt. surplus consumption: c^s, $\alpha-1$.
- The production technology, i.e., the technology parameter and the input elasticities: A, γ.
- The natural resource system, i.e., the intrinsic growth rate and the carrying capacity: k, r^c
- The resource degradation and investment technology, i.e., the effect on resource degradation of production intensity (labour) and investments: m, ε, n, τ.
- The initial resource stock: r_t.
- The amount of exogenous labour input: $\hat{l}$.
- The sharing rule: a.
- The discount factor: b.

Thus we have a total of 14 exogenous parameters or variables in the model, which impact on the optimal investment level can be studied. We shall, however, limit the analysis of changes in what is considered the most interesting variables: r_t, r^c, A, a and b.

The full derivation of the comparative static results is presented in appendix 3, and only the main results are presented here. We shall clearly distinguish between the farm firm and subsistence effects, cf. section 3.4. Generally, the farm firm effect refers to changes in *physical consumption* units (i.e., keeping *CRI* constant), whereas the subsistence effect refers to changes in the *marginal valuation* of consumption in the two periods, as expressed through changes in *CRI*. Related to Figure 1, the farm firm effect refers to changes in the downward sloping curve, whereas the subsistence effect refers to changes in the upward sloping curve.

(21) $\frac{di_t}{dr_t} = \frac{1}{H}(CRI+1)(1-\alpha)\left[\frac{af_{r_{t+1}}g_{r_t}}{c_{t+1}-c^s} - \frac{(1-a)f_{r_t}}{c_t-c^s} - \frac{f_{r_{t+1}r_{t+1}}g_{r_t}}{(1-\alpha)f_{r_{t+1}}}\right]\begin{cases} >0 \ (poor) \\ <0 \ (rich) \end{cases}$; *H < 0*, see appendix 3

A key aspect in the long term (steady state) analysis of the next section is the effect on investments of higher resource stock. The first two elements in [ ] in (21) give the subsistence effect, whereas the last one expresses the farm firm effect. The latter effect is negative. The marginal return on investment declines because of higher resource stock in period *t+1* and diminishing marginal return in production ($f_{rr} < 0$). Moreover, by using the functional forms for the production and resource growth functions we find that this expression is *increasing* for the resource stock within realistic ranges of the resource stock (see appendix 3).

The subsistence effect is more complicated. Higher resource stock increases production and consumption in both periods, thus it has contradicting effects on *CRI*, as reflected in the opposite signs of the first two elements in [ ]. These two expressions can be rewritten and given an intuitive interpretation. The numerator of the two fractions refer to the direct effects (keeping investments constant) of an increase in the resource stock. The condition for the subsistence effect being positive is then;

(22) $\frac{af_{r_{t+1}}g_{r_t}}{c_{t+1}-c^s} < \frac{(1-a)f_{r_t}}{c_t-c^s} \Leftrightarrow \frac{dc_{t+1}/dr_t}{c_{t+1}-c^s} < \frac{dc_t/dr_t}{c_t-c^s}$

The sign of the subsistence effects depends on the *relative increase in surplus consumption in the two periods:* if the relative increase is higher in the first period, then higher resource stock reduces *CRI* and pushes investments upwards. The logic behind this result is seen from the definition of *CRI* in (6), and the intuition is straightforward: if consumption increases relatively more in the present period, the young generation wants to smooth the consumption by investing more. If the increase is relatively higher in the future, they will want to reduce the investments.

Whereas one cannot generally say that the condition in (22) will be met, we shall argue that it will under plausible assumptions. First, we recall from (5) the effect on the resource stock in period *t+1* of a increase in the present resource stock: $g_{r_t} = 1 + k\left(1 - \frac{2r_t}{r^c}\right)$. g_{r_t} will for realistic values of the intrinsic growth rate (k) and the resource stock (r_t) be close to one. Consider then a situation where the resource stock is the same in both periods, the surplus consumption is also the same, and there are positive investments. This implies that $a < 0.5$, and the condition will hold. More generally, it is realistic to assume that $a < 0.5$ because the young generation is responsible for the investments (which is subtracted from their share of the output) and also the labour input, cf. section 8. Thus, even in situations when there is some decline in the resource stock and consumption from period t to $t+1$, the condition will hold.

One should note two elements which are *not* included directly in the condition in (22). First, only the relative change in consumption between the two periods matters. The absolute level of consumption or changes in that level have no *direct* impact. This should be understood in light of the basics of the model, which is based on balancing consumption in the two periods of life through resource investments. Second, the pure time preferences as reflected in b does not have a direct bearing on the sign (but is obviously important for the investment levels, as seen below).

A common argument in the literature is that poverty leads to high discount rates. In our model it is the relative consumption level that is important for *CRI*, in addition to the pure time preference (b). If we had made b dependent on the consumption level in the present period, then we would have an *additional* argument for a positive subsistence effect on resource investments, and for this effect being stronger for low consumption levels.

Whereas the sign of the subsistence effect in the model is not directly affected by the consumption levels, the size of this effect is: the closer the consumption level in either period is to the subsistence level, the stronger the effect will be, and it goes to infinity as the consumption level approaches the subsistence level. Recalling from (6) that *CRI* goes towards infinity when c_t approaches c^s, it follows that a given increase in the resource stock and consumption will have a large impact on the *CRI*. Thus, the lower the resource stock is, the greater will be the subsistence effect. Similarly, the effect is weakened as the resource stock increases, as both f_{r_t} and $\frac{1}{c_t-c^s}$ decline, and the effect approaches zero as r_t goes towards infinity.

In summary, we have two opposite effects of a higher resource stock on investments: a positive subsistence effect declining with increasing resource stock, and a negative farm firm effect increasing with the resource stock. Thus for low resource stocks (and consumption level close to the subsistence level) the subsistence effect will be strong and dominate, whereas it will be weaker and dominated by the farm firm effect for larger resource stocks.

$$(23) \qquad \frac{di_t}{dr^c} = \frac{1}{H}(CRI+1)(1-\alpha)\left[\frac{\alpha f_{r_{t+1}} g_{r^c}}{c_{t+1}-c^s} - \frac{f_{r_{t+1} r_{t+1}} g_{r^c}}{(1-\alpha) f_{r_{t+1}}}\right] < 0; \quad H<0$$

Higher carrying capacity (r^c), which also could be interpreted as a smaller population, will unambiguously lead to a reduction in the investments. Higher carrying capacity increases the resource growth and resource stock in the next period, which reduces the marginal return on resource investment. This is the farm firm effect, which is similar to the case when r_t changes. The subsistence effect here is only to increase consumption next period; the present resource stock is unchanged. This implies higher *CRI* and lower investments. Thus there is no ambiguity as it was in the case of r_t.

Even though changes in r_t and r^c have some similarities, one should note the fundamental difference. A change in the carrying capacity represents a fundamental change in the resource system, which will have an effect on the long term equilibrium outcome. Changes in the resource stock, for whatever reason, represent a temporary fluctuation, which has an effect on the behaviour in that and the near future periods, but does not alter the underlying structure of the long term analysis. As strong modification is, however, needed: the level of the initial resource stock is critical for which long term state one ends up in, as seen in the next section.

$$(24) \quad \frac{di_t}{dA} = \frac{1}{H}(CRI+1)(1-\alpha)\left[\frac{ay_{t+1}}{A(c_{t+1}-c^s)} - \frac{(1-a)y_t}{A(c_t-c^s)} - \frac{1}{A(1-\alpha)}\right] > 0; \quad H<0$$

Improved technology in term of an increase in A (a once and for all technological leap rather than a steady technological progress) will affect resource investments both through farm firm and subsistence effects. Higher return on investments, because the marginal productivity of the resource stock has increased, will push towards higher investments. This is the farm firm effect, as reflected in the last element in [ ].

The expression for the subsistence effect is similar to the case of a change in r_t. Technical progress will have a direct impact on consumption in both periods, as reflected in the first two elements in []. The condition for the subsistence effect being positive is that the relative increase in period t consumption is larger than the relative increase in period $t+1$, cf. (22). Based on a similar reasoning as for the change in r_t, we shall take this condition to be fulfilled. Thus, both the subsistence and farm firm effects pull in the direction of increased resource investments following a positive shift in the technology parameter.[18]

$$(25) \quad \frac{di_t}{da} = \frac{1}{H}(CRI+1)(1-\alpha)\left[\frac{y_{t+1}}{c_{t+1}-c^s} + \frac{y_t}{c_t-c^s} - \frac{1}{a(1-\alpha)}\right]\begin{cases} <0 & (poor) \\ ? & (rich) \end{cases}; H<0$$

A higher output share to the old generation means that they will receive higher return on investments in consumption units, thus the farm firm effect pulls towards higher investments. An increase in a gives lower consumption in period t and higher in period $t+1$, which implies a higher CRI and therefore lower investment (subsistence effect). In this case there is no ambiguity involved for the sign of this effect.

Again, the subsistence effect will be large for low consumption levels. It is readily seen from (25) that for low resource stocks and consumption levels (in either period) the subsistence effect dominates. The reverse is, however, less obvious. Taking the limit of the expression in [] as y_t and y_{t+1} go toward infinity, and using (2) and (3), we find that the condition for [] being negative is $a < \alpha$.[19] We have earlier argued that a should realistically be below 0.5 (cf. section 8), whereas

[18] The effect of technical progress in only one period can also be analyzed. Technical progress only in the second period will have to opposite effects on investments: the subsistence effect is negative, whereas the farm firm effect is positive, hence the net effect is ambiguous.

[19] The expression for $[\ ] < 0$ when y_t and y_{t+1} go toward infinity is: $1/a + 1/(1-a) - 1/(a(1-\alpha)) < 0$. Solving this yields: $a < \alpha$.

the value of α is more uncertain. A typical characteristic of many traditional agrarian societies is that consumption above the subsistence level is given relatively little value, which suggests that α is well below one. Thus we are not able to determine *a priori* which effect will dominate for large resource stocks.

(26) $\frac{di_t}{db} = -\frac{1}{H}(CRI+1)\left[\frac{1}{b(c_t-c^s)^{1-\alpha}}\right] > 0; \quad H<0$

Finally, a higher discount factor (lower discount rate) will, as expected, unambiguously increase the resource investments as more weight is put on next period consumption.

We summarize the results in Table 1, and in the reduced form model;

(27) $i_t^* = i(r_t, r^c, A, a, b); \; i_{r_t} \gtrless 0, i_{r^c} < 0, i_A > 0, i_a \lessgtr 0, i_b > 0$

Exogenous variables:	*Effect on resource investments:*	
	Farm firm effect	*Subsistence effect*
Initial resource stock (r_t)	-	+
Carrying capacity (r^c)	-	-
Technical progress (A)	+	+
Share to old (a)	+	-
Discount factor (b)	0	+

Table 1. Summary of comparative statics.

To summarize, the effect on the resource investment of changes in the initial resource stock and the share to the old depends on the existence of poverty, whereas the effect of changes in the carrying capacity, technological level and the rate of pure time preferences does not. The poverty conditioned response to changes in the resource stock is a key element in the analysis of long term resource dynamics, which is examined in the next section.

6 Long term bioeconomic equilibrium

6.1 Possible steady state solutions

The long term bioeconomic equilibrium or steady state is defined as a situation where the resource stock remains constant over time. This is illustrated graphically by the 45° line in the phase diagram.

(28) $r_{t+1} = r_t$

Using (5) and (27) we have;

(29) $r_{t+1} = r_t + h(r_t; k, r^c) - m\hat{l}_t^{\varepsilon} + n[i(r_t, r^c, A, a, b)]^{\tau}$

This is a first-order nonlinear difference equation in r, which gives the resource locus (phase line). In the discussion of the long term behaviour of the resource stock, we distinguish between, first, the location of the curve above or below the 45° line, that is, if $(r_{t+1} - r_t)$ from (29) is positive or negative; and second (and related), the slope of the curve, given by;

$$(30) \quad \frac{dr_{t+1}}{dr_t} = 1 + k\left(1 - \frac{2r_t}{r^c}\right) + \tau n i_t^{\tau-1} \frac{di_t}{dr_t}$$

where $\frac{di_t}{dr_t}$ is given by (21). The net resource change from period t to $t+1$ $(r_{t+1} - r_t)$ depends on three factors, as shown in (29). As the labour input is given in this version of the model, the resource depreciation resulting from the intensity of production is exogenous. The natural growth is represented by a logistic growth function, which yields high growth for medium sized resource stocks (around $r_t = r^c/2$), whereas it is smaller as the stock moves in either direction towards zero and r^c. For stocks above the carrying capacity the growth is negative, cf. (5).

The final component is growth due to resource investments. As argued above, the investments will be low in *poor* economies (poor in terms of present resource stocks and thereby consumption). Starting in a situation with small resource stock, the investments will be increasing with increasing resource stocks, but eventually higher resource stocks will have a negative effect on resource investments, cf. (21). We have an inverted U-shaped curve also in the investment-stock diagramme.

Combining these three effects, the resource locus will look as follows. For low resource stocks, both the natural growth and the resource investments will be small, thus the resource depletion due to production dominates and the net growth is negative. As the resource stock increases, both natural growth and resource investments will increase, and the net growth will eventually be positive. For larger resource stocks, higher resource stocks will have a negative impact on both the natural resource growth and resource investments (the turning point will generally be different for the two). For sufficiently large resource stocks the net change in the stock from period t to $t+1$ will again be negative. Thus we get a S-shaped resource locus, as illustrated in Figure 2. The shape is identical to what Clark (1990: 17) labels a critical depensation curve.

There are two possible long term equilibria; $r = 0$ and $r = r^s$. Which equilibrium will be achieved depends critically on the initial resource stock. If the initial resource stock is below the minimum viable resource stock - $r^{critical}$, then a "vicious circle of poverty" is at work: low resource investments due to poverty, combined with low natural resource growth will make the stock decline over time, until the resource has been completely exhausted (zero stock). If, on the other hand, the initial resource stock is larger than the critical one, the long term solution will be r^s. There is, of course, also the possibility that no segment of the resource locus will be above the 45° line, thus the only steady state solution is zero stock. [20]

[20] We should add that strictly speaking the model does not say what happens when the resource stock is below the level where the subsistence requirement cannot be met.

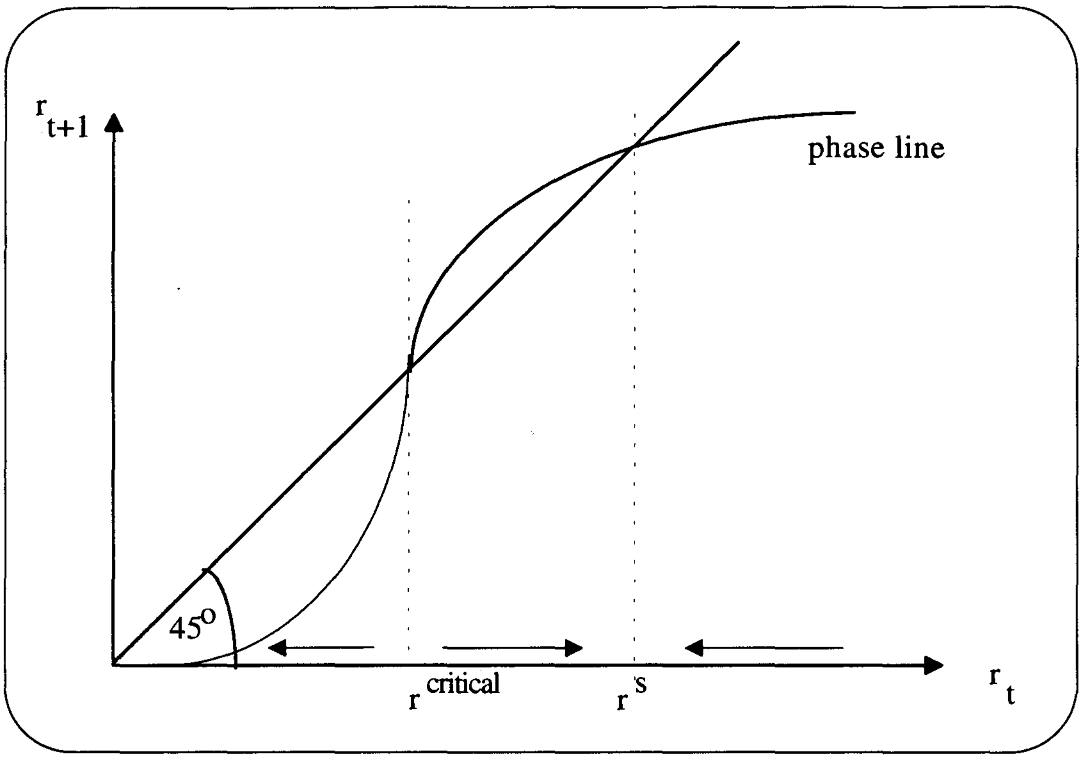

Figure 2. Phase diagram for the resource stock.

This model provides a number of variables, which could more or less easily be related to real world phenomena, to explain why some resource based societies may be trapped in a vicious circle of poverty and resource degradation. Note that there are two mechanisms in the model which generates a critical resource stock, and the possibility for complete exhaustion of the resource if the stock comes below that level. First, the stock dependent natural resource growth, and second, the poverty (resource stock) dependent investments. But unlike many "pure" models for renewable resource growth, e.g., Clark (1990), it is *not* a minimum viable level of the resource which generates the threshold, but rather the fact that production depletes the resource and sufficient compensatory investments will not be undertaken when the consumption level among the resource users is close to their subsistence requirement. The mechanisms appear similar, but the thresholds are determined by entirely different reasons in the conventional renewable resource economics models and the present model.

6.2 Comparative statics of long term equilibria

The location of the resource locus, and thereby $r^{critical}$ and r^s, depends on the exogenous factors in the model. The effect on the long term equilibria of exogenous changes can be studied by differentiation of (29).

(31) $\frac{dr_{t+1}}{dr^c} = h_{r^c} + \tau n i_t^{\tau-1} \frac{di_t}{dr^c} > 0$

A higher carrying capacity (r^c) has two opposite effects on the resource stock. Natural growth is boosted, whereas resource investment is reduced. However, the investment effect is a secondary effect, derived from the increase in the resource stock in next period, cf. the discussion in relation to (23). Thus we can conclude that higher carrying capacity, in line with expectations, will augment the resource stock in next period. Related to Figure 2, this implies an upward shift in the resource locus, which increases the steady state and reduces the level of the critical resource stock.

A lower carrying capacity, for example, an appropriation of parts of the resource (land) by external agents, will increase the level of the critical resource stock. Indeed, it is possible that the only steady state would be the zero stock solution. In this way the model can be used to describe a phenomenon that is observed in developing countries today: local communities lose their resources to state (sponsored) projects, and a self-reenforcing process of resource degradation is initiated because the actual resource stock is lower than the critical level.

(32) $\frac{dr_{t+1}}{dA} = \tau n i_t^{\tau-1} \frac{di_t}{dA} > 0$

Technical progress will increase the resource investments, and shift the resource locus upwards. This implies a steady state solution at a higher level for the resource stock, and a lower critical stock. Thus, policies which promote technical progress will both increase the equilibrium resource stock, and reduce the possibilities for a process of accelerating resource degradation.

(33) $\frac{dr_{t+1}}{da} = \tau n i_t^{\tau-1} \frac{di_t}{da} \begin{cases} < 0 & \text{(small resource stocks)} \\ ? & \text{(large resource stocks)} \end{cases}$

We found in (25) that $\frac{di_t}{da}$ was negative for small resource stocks, whereas the sign is ambiguous for larger ones. Thus we could expect the resource locus to shift downwards for resource stocks around (and below) the critical level, which implies that the $r^{critical}$ is increased. The effect for larger stocks, and therefore on the level of the steady state solution is, however, uncertain; the steady state resource stock may either increase or decrease.

(34) $\frac{dr_{t+1}}{db} = \tau n i_t^{\tau-1} \frac{di_t}{db} > 0$

The effect of a higher discount rate (lower b) will, as expected, be to shift the resource locus downwards, and thereby reduce the equilibrium resource stock and increase the critical stock level.

In summary, a higher carrying capacity of the resource stock (e.g., lower population density), technical progress, a higher share to the young, or a lower discount rate will reduce the critical stock level, and thereby the chances to be trapped in a vicious circle of poverty and resource degradation. These changes will also (with a question mark for lower a) result in a higher long term equilibrium level for the resource stock.

The unambiguous positive effect of technical progress on resource conservation should be noted. The result of this model is typical for resource economic models studying the management of resources to which the users have full property rights, and where the conservation problem is modelled as an investment. As discussed in Angelsen (1996), models of resource appropriation, e.g., deforestation, could yield the opposite conclusions.

7 Introducing alternative retirement savings opportunities

One aim of the paper is to explore the effects of the particular system for retirement savings in our traditional agrarian economy, compared to the standard OLG approach where a financial market for savings and/or government retirement programmes exist. What is the effect in our model of introducing the possibility for alternative retirement savings?

The optimizing problem can now be written as maximizing (1) given (4), (5), (19) and the modified version of (2) and (3);

(35) $c_{t,t} = (1-a)y_t - i_t - x_t$

(36) $c_{t,t+1} = ay_{t+1} + (1+z)x_t$

(37) $x_t \geq 0$

where x_t is the amount of savings (in consumption units), and z is the interest rate. Only positive savings are allowed, i.e., borrowing is excluded. In discussing the solution, we distinguish between two cases, depending on whether the initial *CRI* is lower than z or not.

Case A: Initial CRI < z (interior solution: $x_t > 0$)

The optimality condition in this case is summarized as;

(38) $CRI = af_{r_{t+1}g_i} - 1 = z$

The consumption rate of interest should equal the interest rate on retirement savings, which again should equal the net return on resource investments. This is illustrated as situation 2 in Figure 3.

The introduction of a market interest rate in the economy has a fundamental impact on the logic of the model. The household's decisions are now recursive (provided the initial *CRI* is lower than z). First, the external interest rate (z) will determine the amount of resource investments, and thereby the resource stock and production in the next period. The resource investments decisions are taken without considerations to the consumption side, thus only farm firm effects are present in a comparative statics analysis. Second, the amount of savings is chosen to balance the consumption between the two periods such that *CRI* = z.

In this case the effect of the new market assumption will be to reduce the resource investments, that is, to move from i^1 to i^2 in Figure 3. The relevant discount rate is now z, and a higher discount rate will reduce resource investments.

Case B: Initial CRI > z (corner solution: $x_t = 0$)

A situation with poverty can be characterized by a high *CRI*, that is higher than *z*, and will yield a corner solution. This is illustrated as situation 1 in Figure 3. An intuitive interpretation is that consumption is so close to the subsistence level that people cannot afford to make use of the savings opportunity. The solution will in this case be as in the model in section 5, with $x_t = 0$. The introduction of the alternative savings opportunity has no effect on resource investments. This conclusion is critically dependent on the assumption that negative saving (borrowing) is not allowed.

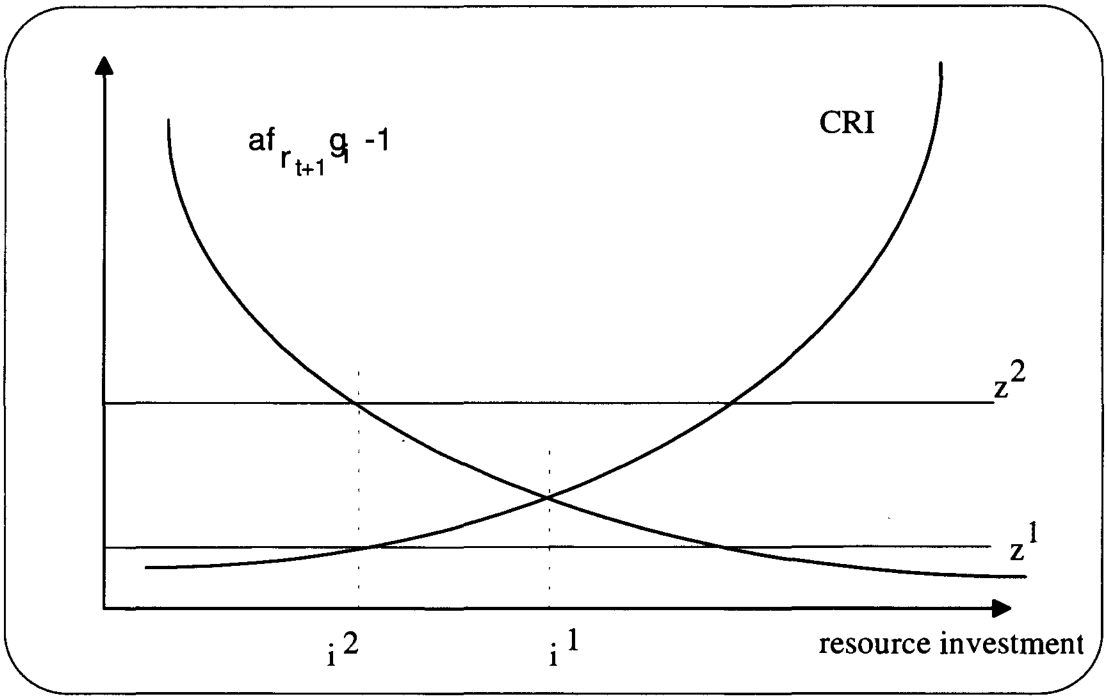

Figure 3. The effect of alternative retirement savings opportunities.

In a real world context, the introduction of retirement savings may be associated with a reduction in the share that the old receive (*a*).[21] Again we must distinguish between the two cases; $x_t > 0$ and $x_t = 0$. In the latter one (situation 1 in Figure 3), the level of investment is determined within the household, i.e., by the intersection of the net return and *CRI* curves.[22] The effect of reduced *a* has already been discussed under the comparative statics in sections 5.2 and 6.2: in the wealthy economy case a lower *a reduces* the resource stock carried over to the next period. If , however, the consumption in either period is close to subsistence, the effect will be increased investments and thereby higher resource stock.

[21] This may be explained through some evolutionary processes, where external retirement savings gradually increases its importance. The opportunity to save for retirement in other assets than natural resources may not instantaneously remove the traditional mechanisms for caring for the old, but one may argue that there will be a downward pressure on *a*.

[22] If the downward shift in the net return curve ($af_{r\,t+1}\, g_i - 1$) is sufficiently large it will cause the young generation to start saving.

The more relevant case for a lowering of a is when people actually make use of the alternative retirement savings, that is, the case when $x_t > 0$. In this case the resource investments are determined by the intersection of the net return and the z^2 curves. A lower a will shift the net return curve downwards, and cause the resource investments to decrease.

To summarize, does the introduction of alternative retirement savings opportunities lead to lower resource investments and resource degradation? In a poor society, it is unlikely that *CRI* is lower than z, thus it will have no effect on resource investments. If this is accompanied by a reduction in a -- although unlikely to happen -- the effect of a higher share to the young was found to increase resource investments.

In the case where the initial $CRI < z$, then introducing this savings opportunity will reduce the resource investments. The effect of a lower a on investments was positive in a poor economy and ambiguous in a richer economy. One could, intuitively, expect the first (discounting) effect to dominate. In both cases (z below/above CRI), what seemed to be an obvious argument on how the lack of alternative ways to secure one's life as old promotes resource conservation in a traditional agrarian economy, is more complex than it appeared.

The introduction of alternative retirement savings opportunities is most relevant for more wealthy economies, and in this case we could argue that the lack of a capital market for retirement savings or a government retirement programme enhances resource conservation. Given that economic development often can be associated with the introduction of such markets or government programmes, our model offers a new explanation on how (why) resource degradation may be linked with economic development.

To complete the discussion about the effect on resource investments of external savings opportunities or government retirement programmes, we must add that an important argument is left out of the model. In a more complete model, the decision of how many children to get should be endogenous. And the incentives for having many children would be reduced in the presence of other means to secure the welfare as old. Lower population will ha a positive effect on the equilibrium resource stock, as shown under the comparative statics in section 6.2.

8 The optimal resource allocation between generations (a)

To explore the optimal sharing rule between the two generations (a), that is, the share that maximizes lifetime utility, we define the value function;

(39) $V_t(a) = \max_{i_t} \{U_t\}$

Using the envelope theorem, we find that the value of a which maximizes V_t is such that the following condition is met;

(40) $\frac{\partial V_t}{\partial a} = 0 \Leftrightarrow CRI = \frac{y_{t+1} - y_t}{y_t}$

The consumption rate of interest should equal the growth rate of production. In steady state, when the resource stock is constant, the production will also be constant, which means that *CRI* is zero. This may appear to be a strange result, but makes good economic sense when the definition of *CRI* in (6) is manipulated to yield;

(41) $CRI = 0 \Leftrightarrow \frac{c_{t+1}-c^s}{c_t-c^s} = b^\theta \leq 1; \theta = -\frac{1}{\alpha-1}$

In steady state the optimal a is chosen such that consumption is lower in the second period. How much lower the consumption will be depends on the parameters b and θ. A high value of b (low discount rate) will give a relatively small decrease in consumption.

The parameter θ is the inverse of the negative of the elasticity of marginal utility with respect to surplus consumption. It can be shown that this is equal to the elasticity of substitution between consumption in the two periods, when the two periods converge in time (see Blanchard and Fisher, 1989: 40).[23] A high θ implies that α is such that the relative decrease in consumption from period t to $t+1$ is relatively large.

The condition can also be solved for a. Using the explicit functional forms, we can rewrite (40) as;

(42) $\frac{(ay_{t+1}-c^s)^{1-\alpha}}{b((1-a)y_t-i_t-c^s)^{1-\alpha}} = \frac{y_{t+1}}{y_t}$

$\Leftrightarrow \frac{ay_{t+1}-c^s}{(1-a)y_t-i_t-c^s} = \frac{y_{t+1}^\theta b^\theta}{y_t^\theta}$

$\Leftrightarrow ay_{t+1}y_t^\theta - c^s y_t^\theta = y_{t+1}^\theta b^\theta y_t - y_{t+1}^\theta b^\theta a y_t - y_{t+1}^\theta b^\theta i_t - y_{t+1}^\theta b^\theta c^s$

$\Leftrightarrow a = \frac{y_t - i_t - c^s + c^s y_t^\theta y_{t+1}^{-\theta} b^{-\theta}}{y_t + y_t^\theta y_{t+1}^{1-\theta} b^{-\theta}}$

Whereas the exact solution for a may not be easily interpreted, the influence of the various parameters on the level of a is in accord with intuition. For example, a high investment level (i_t) will make a relatively small, i.e., a relatively high share to the generation undertaking the investments. A high discount rate for utility (low b) also tends to make a relatively low, as relatively large weight is put on first period consumption.

In a long term steady state where the resource stock and thereby production are constant ($y_t = y_{t+1} = y$), the expression for a is reduced to;

(43) $a = \frac{y-i-c^s(1-b^{-\theta})}{y(1+b^{-\theta})}$

The effect of, for example, a high level of production (that is, a high resource stock) is ambiguous, it depends on the sign of the expression $(i + c^s(1-b^{-\theta}))$. The level of a is decreasing

[23] This result is readily understood when we note that the welfare function used, when discounting is disregarded as will happen when the two periods converge in time, is actually equivalent to using a CES function, and the elasticity of substitution in that function is given by $1/(1-\alpha)$.

with an increase in the factor $b^{-\theta}$. A low discount rate (high b) will make this factor small (relatively close to one), and therefore the share to the first period relatively small. $b^{-\theta}$ will also be small, and a relatively high, if θ is high, that is, if α and the elasticity of surplus consumption (α - *1*) is small. This corresponds with the general definition of *CRI;* a high *CRI* may be due to either a high pure time preferences or a high elasticity of marginal utility of consumption above subsistence.

To get an impression of the actual levels of an optimal a, assume that $c^s = 10$, $y = 30$, $i = 3$, $b = 0.9$, and $\theta = 2$ ($\alpha = 0.5$). The optimal share to the old is then approximately *0.438*.

An interesting case is when the pure time preference is zero, i.e., $b = 1$. The expression for a then reduces to $a = \frac{y-i}{2y}$. Inserting this in the expression for the consumption in the two periods, we find:

$$(44) \qquad c_t = \left(1 - \left(\tfrac{y-i}{2y}\right)\right)y - i = \tfrac{y}{2} - \tfrac{i}{2}$$

$$(45) \qquad c_{t+1} = \left(\tfrac{y-i}{2y}\right)y = \tfrac{y}{2} - \tfrac{i}{2}$$

Thus in the case when there is no discounting due to pure time preferences, and we are in steady state, the a which maximizes lifetime welfare is such that the consumption level will be the same in both periods, and the burden of the investments are shared equally by the generations. In our numerical illustration the optimal a is *0.45*. Note that such an equal sharing of the investment costs depends critically on the rate of pure time preferences being zero.

9 Moral partnership or selfish generations?

We have assumed no altruism in the model. This is not to deny that altruism and concern for future generations may be an important aspect of resource use decisions in traditional agrarian societies in developing countries. Such intergenerational altruism is in line with the Burkian notion of society as a moral partnership, "between those who are living, those who are dead and those who are yet to be born" (Lemarchand, 1992: 178). Lemarchand and others argue that many traditional societies in developing countries come close to such a description. If individuals in these societies, for example, through resource management institutions or social norms, act according to such a moral partnership perspective, then the RS model could be more appropriate as a descriptive model for such economies.[24]

This romantic view on traditional, pre-capitalist societies is controversial. Whereas one should not overlook the potential importance of such a collective and moral partnership oriented aspect

[24] On the basis of the same arguments, it is not obvious that the OLG model represents a superior framework for *normative* analysis. On the contrary, one can argue that parts of the underlying ethic in the sustainability debate is more in accord with the immortal representative individual approach of the RS models: we should be concerned with the long-term welfare of *mankind* rather than of mortal men.

of the decision making in many traditional societies, some critical questions must be asked, as done in Baland and Platteau (1996: chap. 10). First, the conservationist thesis is mostly concerned with societies operating in a static environment, for example, little population growth, no technical change, and no radically new trade opportunities. Second, traditional conservation practices may be unintentional. The technology may be so primitive and/or the population density so low that people cannot exhaust the resource base.

A major aim of this paper has been to explore the outcome of interactions among actors who pursue their self-interests in a rational (consistent) manner. If we are able to show that the outcome in a model with selfish generations resembles the outcome we get in a model with altruism, we have a basis for critically asking if altruism is as important as sometimes presumed.

This issue relates to a broader debate about "green primitivism": "Part of the mythology of late-twentieth-century environmentalism is that certain 'traditional' peoples are uniquely adapted in ways which ensure that their material and spiritual resources are held in balance. ... [and] have cosmologies which stress environmental harmony" (Ellen, 1993: 126). This is part of a modern world's need for a "primitive, exotic Other". In this perspective, this paper can be seen as an attempt to provide a somewhat less romantic explanation of the resource conservation practices commonly found in traditional agrarian societies. We are not, of course, able to say something about the relative empirical importance of these alternative explanations based on the model of this paper.

10 Summary and some policy conclusions

This paper has shown that the OLG framework may provide a useful tool for the study of resource allocation problems in developing economies. The main argument in favour of the OLG models over conventional RS models is the more realistic description given of intergenerational allocation problems. This paper has developed an OLG model for a traditional agrarian economy, which gives each generation strong incentives for resource conservation. As in principal-agent theory in general, these incentives are not perfect, as the old generation only enjoys a *share* of the fruits of their resource investments as young.

This broad conclusion will be significantly modified in situations where consumption is close to the subsistence level. Poverty may make the resource investments too low to keep the resource non-decreasing over time. A vicious circle of poverty is created. The overriding concern for the survival may suppress the incentive for resource conservation that otherwise is present in this structure of the economy.

The introduction of alternative retirement savings opportunities is most relevant for more wealthy economies, and where the consumption rate of interest is lower than the external interest rate. In this case we could argue that the lack of a capital market for retirement savings or a government retirement programme enhances resource conservation. In a poor society with *CRI* above the external interest rate, it will have no effect on resource investments.

The model also provides a basis for the discussion of different policy measures. First, imbalance between the population (overall subsistence needs) and the carrying capacity of the resource system may initiate an accelerating process of resource degradation. Policies which reduce the population pressure, and conserve or augment the resource base will reduce the risk of this situation. We also find that technical progress will unambiguously increase resource investment as well as the equilibrium resource stock. This result does not depend on the consumption level, and appears to be a robust one in the model.

Appendix 1: Risk aversion and consumption level

The proof of the results in (9) is as follows:

$$\Delta_3 = U_{11}U_{22}U_{33} = \alpha^2(\alpha-1)^2(c_t - c^s)^{\alpha-2}\beta(\beta-1)(l^m - l_t)^{\beta-2}b(c_{t+1} - c^s)^{\alpha-2} < 0$$

$$\begin{aligned}\Delta_3^b &= -U_{11}U_{22}U_3^2 - U_{11}U_{33}U_2^2 - U_{22}U_{33}U_1^2 \\ &= -\Delta_3\left[b\alpha(\alpha-1)^{-1}(c_{t+1} - c^s)^{\alpha} + \beta(\beta-1)^{-1}(l^m - l_t)^{\beta} + \alpha(\alpha-1)^{-1}(c_t - c^s)^{\alpha}\right] \\ &= -\Delta_3\Omega < 0\end{aligned}$$

Inserting this in the formula for R_A gives;

$$(46) \qquad R_A = \frac{-\Delta_3}{\left(-\Delta_3^b\right)^{\frac{3}{4}}} = \frac{-\Delta_3}{(\Delta_3\Omega)^{\frac{3}{4}}} = \frac{(-\Delta_3)^{\frac{1}{4}}}{(-\Omega)^{\frac{3}{4}}} > 0$$

By studying the expressions for Δ_3 and Ω we see that the results of (9) hold. If, for example, c_t approaches c^s, the expression $(c_t - c^s)^{\alpha-2}$ increases and goes towards infinity, and so will Δ_3. It is also seen that Ω will decline, thus R_A will increase and go towards infinity as c_t approaches c^s. The same reasoning gives the other results in (9).

Appendix 2: Comparative statics of end period in the two period model

The FOC is given by;

(47) $(1-a)f_{l_{t+1}} - w = 0$

$$w \equiv -\frac{U_2}{U_1} = \frac{v\beta(l^m - l_{t+1})^{\beta-1}}{\alpha[(1-a)f(l_{t+1}, r_{t+1}) - c^s]^{\alpha-1}}$$

Differentiation yields;

(48) $\left[(1-a)f_{l_{t+1}r_{t+1}} - \frac{dw}{dr_{t+1}}\right]dr_{t+1} + \left[-f_{l_{t+1}} - \frac{dw}{da}\right]da = H\,dl_{t+1}$

$$H \equiv -\left[(1-a)f_{l_{t+1}l_{t+1}} - \frac{dw}{dl_{t+1}}\right] > 0$$

$$\frac{dw}{dl_{t+1}} = \frac{-v\beta(\beta-1)(l^m-l_{t+1})^{\beta-2}\alpha[c_{t+1}-c^s]^{\alpha-1} - v\beta(l^m-l_{t+1})^{\beta-1}\alpha(\alpha-1)[c_{t+1}-c^s]^{\alpha-2}(1-a)f_{l_{t+1}}}{\left[\alpha(c_{t+1}-c^s)^{\alpha-1}\right]^2} > 0$$

$$\frac{dw}{dr_{t+1}} = \frac{-v\beta(l^m-l_{t+1})^{\beta-1}\alpha(\alpha-1)[c_{t+1}-c^s]^{\alpha-2}(1-a)f_{r_{t+1}}}{\left[\alpha(c_{t+1}-c^s)^{\alpha-1}\right]^2} = \frac{-(1-a)^2 f_{l_{t+1}}(\alpha-1)f_{r_{t+1}}}{c_{t+1}-c^s} > 0$$

$$\frac{dw}{da} = \frac{v\beta(l^m-l_{t+1})^{\beta-1}\alpha(\alpha-1)[c_{t+1}-c^s]^{\alpha-2}y_{t+1}}{\left[\alpha(c_{t+1}-c^s)^{\alpha-1}\right]^2} = \frac{(1-a)f_{l_{t+1}}(\alpha-1)y_{t+1}}{c_{t+1}-c^s} < 0$$

The effect on labour input of changes in the share and the resource stock is then, using the specific production function;

(49) $$\frac{dl_{t+1}}{dr_{t+1}} = \frac{1}{H}\left[(1-a)f_{l_{t+1}r_{t+1}} + \frac{(1-a)^2 f_{l_{t+1}}(\alpha-1)f_{r_{t+1}}}{c_{t+1}-c^s}\right]$$

$$= \frac{1}{H}\left[\frac{(1-a)\gamma(1-\gamma)y_{t+1}}{r_{t+1}l_{t+1}} + \frac{(1-a)^2(\alpha-1)\gamma(1-\gamma)y_{t+1}^2}{(c_{t+1}-c^s)r_{t+1}l_{t+1}}\right]$$

$$= \frac{1}{H}\left[\frac{(1-a)\gamma(1-\gamma)y_{t+1}}{r_{t+1}l_{t+1}}\left(1 + \frac{(\alpha-1)c_{t+1}}{c_{t+1}-c^s}\right)\right] \gtrless 0 \Leftrightarrow c_{t+1} \gtrless \frac{c^s}{\alpha}$$

(50) $$\frac{dl_{t+1}}{da} = -\frac{1}{H}\left[f_{l_{t+1}} + \frac{(1-a)f_{l_{t+1}}(\alpha-1)y_{t+1}}{c_{t+1}-c^s}\right]$$

$$= -\frac{f_{l_{t+1}}}{H}\left[1 + \frac{(\alpha-1)c_{t+1}}{c_{t+1}-c^s}\right] \lessgtr 0 \Leftrightarrow c_{t+1} \gtrless \frac{c^s}{\alpha}$$

Appendix 3: Comparative statics in the simplified model

The FOC is;

$$(20)\quad CRI+1-af_{r_{t+1}}g_i=\frac{[af(g(.))-c^s]^{1-\alpha}}{b[(1-a)f(r_t)-i_t-c^s]^{1-\alpha}}-af_{r_{t+1}}g_i=0$$

Differentiation yields:

$$(51)\quad \left[\tfrac{\partial CRI}{\partial r_t}-ag_if_{r_{t+1}r_{t+1}}g_{r_t}\right]dr_t+\left[\tfrac{\partial CRI}{\partial r^c}-ag_if_{r_{t+1}r_{t+1}}g_{r^c}\right]dr^c+\left[\tfrac{\partial CRI}{\partial A}-ag_if_{r_{t+1}}A^{-1}\right]dA$$

$$+\left[\tfrac{\partial CRI}{\partial a}-f_{r_{t+1}}g_i\right]da+\left[\tfrac{\partial CRI}{\partial b}\right]db=H\ di_t$$

$$H=-\left[\tfrac{\partial CRI}{\partial i}-af_{r_{t+1}}g_{ii}\right]$$

$$(52)\quad \tfrac{\partial CRI}{\partial i}=\tfrac{1}{Q}\left[(1-\alpha)(c_{t+1}-c^s)^{-\alpha}af_{r_{t+1}}g_ib(c_t-c^s)^{1-\alpha}+(c_{t+1}-c^s)^{1-\alpha}b(1-\alpha)(c_t-c^s)^{-\alpha}\right]$$

$$=\tfrac{K}{Q}[af_{r_{t+1}}g_i(c_t-c^s)+(c_{t+1}-c^s)]>0$$

$$K\equiv(1-\alpha)b(c_{t+1}-c^s)^{-\alpha}(c_t-c^s)^{-\alpha}>0$$

$$Q\equiv b^2(c_t-c^s)^{2-2\alpha}>0$$

$$\tfrac{K}{Q}=(1-\alpha)b^{-1}(c_{t+1}-c^s)^{-\alpha}(c_t-c^s)^{\alpha-2}>0$$

Thus we have $H<0$.

The change in *CRI* (subsistence effect) of a change in the resource stock is given by;

$$(53)\quad \tfrac{\partial CRI}{\partial r_t}=\tfrac{K}{Q}[af_{r_{t+1}}g_{r_t}(c_t-c^s)-(1-a)f_{r_t}(c_{t+1}-c^s)]\gtrless 0$$

$$\Leftrightarrow \frac{c_t-c^s}{c_{t+1}-c^s}\gtrless\frac{(1-a)f_{r_t}}{af_{r_{t+1}}g_{r_t}}$$

We define the *direct* effects of increased resource stock in period t on consumption in the two periods;

$$\tfrac{dc_t}{dr_t}=(1-a)f_{r_t};\quad \tfrac{dc_{t+1}}{dr_t}=af_{r_{t+1}}g_{r_t}$$

The condition can then be rewritten as;

$$\tfrac{\partial CRI}{\partial r_t}\gtrless 0\Leftrightarrow\frac{dc_{t+1}/dr_t}{c_{t+1}-c^s}\gtrless\frac{dc_t/dr_t}{c_t-c^s}$$

To see that the element for the farm firm effect in [] in (21) is increasing with r_t, we use the specific functional forms to get;

$$(54)\quad \frac{f_{r_{t+1}r_{t+1}}g_{r_t}}{(1-\alpha)f_{r_{t+1}}}=\frac{1}{(1-\alpha)(\gamma-1)}\left(r_t+kr_t-\frac{2kr_t^2}{r^c}\right)$$

This expression will be increasing in r_t for $r_t < \frac{(1+k)r^c}{4k}$. If, for example, $k = 0.02$, the critical stock size is $12.75\ r^c$. For a very high value of k of 0.1 the critical value is $2.75\ r^c$.

(55) $\frac{\partial CRI}{\partial r^c} = \frac{K}{Q}(c_t - c^s)af_{r_{t+1}}g_{r^c} > 0$

(56) $\frac{\partial CRI}{\partial A} = \frac{K}{Q}[ay_{t+1}A^{-1}(c_t - c^s) - (1-a)y_tA^{-1}(c_{t+1} - c^s)] \gtrless 0$

$\Leftrightarrow \frac{c_t - c^s}{c_{t+1} - c^s} \gtrless \frac{(1-a)y_t}{ay_{t+1}}$

$\Leftrightarrow \frac{dc_{t+1}/dA}{c_{t+1} - c^s} \gtrless \frac{dc_t/dA}{c_t - c^s}$

(57) $\frac{\partial CRI}{\partial a} = \frac{K}{Q}[y_{t+1}(c_t - c^s) + y_t(c_{t+1} - c^s)] > 0$

(58) $\frac{\partial CRI}{\partial b} = -\frac{1}{Q}[(c_{t+1} - c^s)(c_t - c^s)]^{1-\alpha} < 0$

The total effect on investments of exogenous changes is then, using the FOC and definition of *CRI*, as given in (21) - (26).

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