

**Deforestation:
Population or Market Driven?**
Different Approaches in
Modelling Agricultural Expansion

Arild Angelsen

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Summary:

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.

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1 Introduction¹

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.²

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

¹ 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.

² 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.

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.

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.³

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.

$$(1) \quad X = xH$$

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.⁴ 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

³ 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.

⁴ This does not apply to model I, where transport costs are unimportant.

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

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

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;

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

The assumptions reflected in (3) are important in models I-II, where the total agricultural income plays an important role. In an open access situation, it is more reasonable 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.⁵ 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;

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

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.

⁵ 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.

<i>Model</i>	<i>Households' objective: utility maximization</i>	<i>Labour market</i>	<i>Property rights regime</i>
<i>I: Subsistence ("full belly")</i>	Minimize labour, given subsistence target (lexicographic)	No labour market	Private (or communal)
<i>II: Chayanovian</i>	Trade-off between consumption and leisure	Labour market exist, but households are quantity constrained	Private (or communal)
<i>III: Open economy, private property</i>	Maximize profit from production	Perfect labour market	Private (or communal)
<i>IV: Open economy, open access</i>	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.⁶ 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.

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

⁶ 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.

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.⁷ Including risk has the same effect as 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.

⁷ The security of land rights is also influenced by decisions made by the farmers themselves. In 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.

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" economy⁸

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;

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

Combining this with (3) gives the agricultural frontier;

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

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.^{9 10}

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 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.

⁸ 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.

⁹ 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.

¹⁰ 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.

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.¹¹ 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;

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

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;

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

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;

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

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.

¹¹ The name is taken from the Russian agricultural economist Chayanov who used this approach to study the adaptation of Russian farmers early this century.

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}).

$$(10) \quad U(C, T) = (C - c^{\min})^\alpha + \nu(T^{\max} - T)^\beta$$

$$\nu > 0; \alpha, \beta \in (0, 1); (C - c^{\min}), (T^{\max} - T) > 0;$$

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

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.¹²

¹² $(1-\alpha)$ 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,

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.

6 Model III: The small, open economy with private property¹³

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;

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

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

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.

¹³ 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.

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

or;

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

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} .

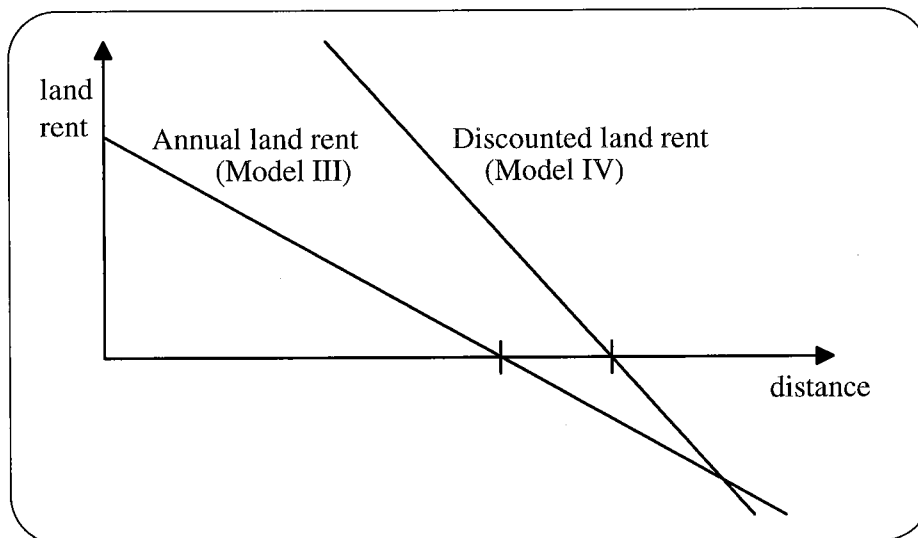


Figure 1: The determination of the agricultural frontier in the open economy cases.

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.

