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Forest Cover Change in Space and Time:

Combining the von Thünen and Forest Transition Theories

By

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Abstract

This paper presents a framework for analyzing tropical deforestation and reforestation, using the von Thünen model as its starting point: land is allocated to the use which yields the highest rent, and the rents of various land uses are determined by location. Forest cover change therefore becomes a question of changes in rent of forest *vs.* non-forest uses.

While this is a simple and powerful starting point, more intriguing issues arise when this is applied to analyze real cases. An initial shift in the rent of one particular land use generates feedbacks which affect the rent of all land uses. For example, a new technology in extensive agriculture should make this land use more profitable and lead to more forest clearing, but general equilibrium effects (changes in prices and local wages) can modify or even reverse this conclusion. Another challenging issue is how a policy change or a shift in broader market, technological and institutional forces will affect various land use rents. The paper deals with three such areas: technological progress in agriculture, land tenure regimes, and community forest management.

The second part of the paper links the von Thünen framework to the forest transition (FT) theory. The FT theory describes a sequence over time where a forested region goes through a period of deforestation before the forest cover eventually stabilizes and starts to increase. This sequence can be seen as a systematic pattern of change in the agricultural and forest land rents over time. Increasing agricultural rent leads to high rates of deforestation. The slow-down of deforestation and eventual reforestation is due to lower agricultural rents (the economic development path) and/or higher forest rent (the forest scarcity path). Various forces leading to these changes are discussed, and supported by empirical evidence from different tropical regions.

Keywords: deforestation, von Thünen, forest transition, technological change, tenure, community forest management

1 Introduction[2]

The aim of this paper is to present a conceptual framework to analyze the processes of tropical deforestation and reforestation. The von Thünen model provides an appropriate starting point. First, the model focuses on *land rent*, based on an assumption that land is allocated to the use generating the highest land rent (surplus). Changes in the land rent of different uses therefore become the key to explain changes in land uses and land cover. Second, the von Thünen approach deals with the *spatial determinants* of the rent of different land uses, which is a strong empirical characteristic of forest cover change.

The von Thünen model provides a general framework for understanding forest cover change, but does not provide an explanation of why land rents change, nor does it contain a theory of feedbacks from changes in land rent curves or interactions between the curves. Within this conceptual framework one therefore needs to incorporate theories of land users' behavior and how markets for commodities, labor, capital and land operate.

While the von Thünen approach has a *spatial* focus, the forest transition (FT) has a *temporal* one. The FT describes a sequence where a forested region goes through four stages: (1) initially high forest cover and low deforestation, (2) accelerating and high deforestation, (3) slow-down of deforestation and forest cover stabilization, and (4) a period of reforestation. Unlike the von Thünen model, the FT is an attempt to synthesise empirical regularities without any coherent underlying theory. This paper argues, however, that the FT can be related to a systematic pattern of change in the agricultural and forest land rents over time. In short, a period of increasing agricultural land rent and therefore high rates of deforestation (stage 2) is followed by lower agricultural rent (the economic development path) and/or higher forest rent (the forest scarcity path) leading to the eventual reversal of the forest cover decline (stage 3-4). The von Thünen and FT approaches are therefore complementary: the von Thünen approach provides a static theory on how land rent determines land use and an empirical proposition on how land use is determined by location, while the FT provides an empirical proposition on how land use changes over time.

The paper is organized in two main sections: section 2 presents the basic von Thünen model and discusses how changes in prices and technologies directly influence land rent. We then look at various feedbacks and interactions between agricultural and forest rent curves. The last part of this section discusses three complex and contentious topics within a von Thünen framework: technological progress in agriculture, land tenure, and community forest management. Section 3 discusses the forest transition, and relates it to the discussion of land rent in section 2. The main drivers and stages in the FT are elaborated, and related to some broad forces observed at regional (sub-continental) scales across the tropics.

The main focus throughout the paper is on agriculture rather than forestry. This is justified by the fact that conversion to agriculture (crops and pasture) is the main source of tropical deforestation, and therefore the most important sector to study to understand the process of deforestation (and reforestation). It should also be noted that the organization of the paper is theoretical rather than empirical, in the sense that it attempts to sort out a number of the causes and mechanisms of forest cover change in a systemic and theoretically consistent manner. This is illustrated with a few

[2] The paper is one of two papers for a World Bank commissioned project to CIFOR on "Synthetic and analytic work on deforestation and forest-related poverty". An accompanying report, Sunderlin et al. (2006), has a more specific poverty focus, while the present one focuses on deforestation and reforestation. The TOR of this report states that: "The goal of this paper is to present one (or more) stylized conceptual model(s) of landholders' decisions on forest conversion, maintenance, and re-establishment. … Here the emphasis is on understanding the effect of geographic and socioeconomic contextual factors – agroclimate and topography, security of land tenure, remoteness and market access – on landholder decisions of whether or not to deforest."

empirical case studies and examples, but the list of empirical work cited does not in any way do justice to the rich deforestation literature that exists.[3] By extension, the paper does not aim to provide a comprehensive list of policy recommendations, although any policy prescriptions should be based on a clear understanding of the causes of deforestation. Finally, the discussion on causes of deforestation is primarily at the level of *intermediate* rather than *underlying* causes. Thus important topics, such as the impact of trade liberalization and globalization, are only touched superficially. This is partly due to space constraints and partly because the links between underlying causes and deforestation are highly context specific and therefore requires a more empirical and case-based approach (Angelsen and Kaimowitz, 1999; Scrieciu, 2006).

2 The von Thünen model and beyond

The economics of land use takes as its starting point that *land is allocated to the use with the highest land rent (surplus or profit).* In fact, this principle extends beyond economics, and land use science is built around this principle (e.g., Lambin et al., 1999). Applied to the conversion of forests to other land uses (deforestation), the key tenet is that farmers, companies or other land users deforest because non-forest land uses are more profitable than forest land uses (= yield higher land rent).

The rent of alternative land uses is determined by a number of factors such as crop prices, input costs, available technologies, agroecological conditions, etc. Many of these depend directly or indirectly on the location of the land. A key aspect of the location is the remoteness, as measured by the distance to markets or cities. This approach was proposed by Johann von Thünen in 1826 in his seminal work *The Isolated State.* The von Thünen's approach concerns how *land rent* – determined by distance from a commercial center (the city) – shapes land uses. Or in the words of von Thünen: "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?"

Thus the original von Thünen approach was to study how the height and slope of rent curves of different land uses depends on the distance from the center. The "utmost rationality" assumption simply implies that the land use yielding the highest rent is chosen. Today the von Thünen approach has got a somewhat wider interpretation in the literature, that is, the study of locational aspects of land uses as determined by the land rent.

The structure of this section of the paper is as follows: The simple von Thünen model as applied to deforestation is presented, first with only two land uses (agriculture and forest), and then with sub-sectors within agriculture and forestry. Next, the factors determining the location of the rent curves are discussed rather briefly, as the results are pretty straightforward from an analytical point of view. More complex issues arise when one moves beyond these first order explanations and look into the issues of interaction between rent curves, and possible feedbacks from shifts in a rent curve. One type of feedback and interaction is general equilibrium effects, i.e., changes in market prices. Finally the impacts of technological progress in agriculture, land tenure security, and community forestry are discussed. These topics are selected for two reasons. First, the forest cover impacts are not straightforward, at least for the first two, and they remain contentious issues with limited and inconclusive evidence.[4] Second, all three topics have high policy relevance.

[3] Three comprehensive reviews of this literature are: Kaimowitz and Angelsen (1998), Geist and Lambin (2001), and Rudel (2005).

[4] A small historical note: When David Kaimowitz and I did the deforestation model review, cf. Kaimowitz and Angelsen (1998), we identified technological change and tenure as two areas of high policy relevance yet limited or inconclusive empirical evidence. We chose to look further into the issue of technological change, partly because more case studies were available. This effort resulted in an edited volume: Angelsen

2.1 Land rents in the von Thünen model

2.1.1 The basic model of two land uses

Consider a model where land only has two uses: agriculture and forest, e.g., Angelsen et al. (2001). Agricultural production per ha (yield) of the homogenous land is given (*y*), and the produce is sold in a central market at a given price (*p*). The labor and capital required per ha are *l* and *k*, with inputs prices *w* (wage) and *q* (annual costs of capital). The cost of enforcing property rights is given as *c*. Finally, transport costs per km are denoted *v* and the distance from the center *d*. This defines the land rent or profit from agriculture as a declining function of distance:

$$r(d) = py - wl - qk - c - vd \tag{1}$$

Assuming for the time being that forest has zero value, the agricultural frontier is defined as the distance at which agricultural cultivation is not profitable anymore, i.e., $r(d) = 0$. Combining the zero rent definition of the frontier with equation (1) gives:

$$d^{frontier} = \frac{py - wl - qk - c}{v} \tag{2}$$

This simple model yields several key insights on *the immediate causes* of deforestation, cf. the terminology introduced by Kaimowitz and Angelsen (1998) where this refers to changes in the land users' *decision parameters*. Higher output prices (*p*) and technologies that increase yield (*y*) or reduce input costs (*l*, *k*) make agricultural expansion more attractive. Lower costs of capital (*q*) in the form of better access to credit and lower interest rates pull in the same direction. Higher wages (*w*), reflecting the costs of hiring labor or the best alternative use of family labor, work in the opposite direction, as do high costs of defending property rights (*c*). Reduced access costs (*v*) - new or better roads - also provide a great stimulus for deforestation.

Having laid the micro-foundations for the deforestation analysis, the next question is how the land rent – and the land users' means – is determined by broader societal and policy factors: local institutions, national economic policies, international markets, and so on. These form *the underlying causes* of deforestation, and their impacts are much more complex and context specific than the immediate ones. But any credible story about their impact must explain how these broad forces alter the rent of different land uses and thereby the rate of deforestation.

The above von Thünen model is based on a number of simplifying assumptions, many of which will be modified in the following sub-sections:

(a) We assume no conversion costs between alternative land uses. Adding this would yield a certain degree of stability in land use, and would be important in studies particularly at the household/farm level. The conversion costs are highly asymmetric, i.e., it costs a lot to convert forests to agriculture than vice versa.

(b) Related to this, we assume that all land will be converted to the land use with the highest probability (a deterministic approach). An alternative is to use (Markov) transition probabilities, i.e., a particular parcel of land is more likely to be transformed to a particular land use the higher the rent of that land use.

(c) We assume – like von Thünen – the featureless homogenous plain. Adding topographical and other spatial features such as differences in slope, altitude, soil quality, rainfall, etc. would obviously be important in empirical investigations. In a conceptual model "distance" may be interpreted as "cost adjusted distance", taking into account not just physical distance but also

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and Kaimowitz (2001). A similar comparative study has, to my knowledge, not been done for the impact of tenure regimes on deforestation.

accessibility. Differences in, for example, soil quality would affect yield and thereby land rent directly.

(d) We have simplified the problem by assuming fixed intensity of production within all the different classes of land use (but obviously not between them). Thus there is no optimization of input use, and an output price increase in, say, intensive agriculture does not lead to intensification but only an area expansion of that land use.[5]

(e) Distance is included as an additive cost, and not, as a factor reducing output and reducing input prices, as done in, for example, Chomitz and Gray (1996). Given the assumption about fixed intensity, it does not matter which way we model distance costs.[6]

(f) The time dimension is often ignored in the von Thünen model, including whether the rent curves should be interpreted as current value (annual rent) or discounted values (net present value (NPV) of rent), in which case expectations of annual rent over time become important. "Rent" refers to annual values (in the Ricardian world: the maximum annual amount a land manager could pay per year to the land owner for using his land). But in many cases it would be more relevant to look at NPV. We return to this in the discussion of tenure in section 2.4.

(g) The model implicitly assumes that there either is an omnipotent central planner, a rational owner of all land, or well functioning land markets that ensure that land actually is allocated to the land use with the highest rent (the "utmost rationality" assumption). This is again modified in the discussion of land tenure.

(h) There are important interactions among the rent curves, an aspect which can be illustrated but not analyzed directly within the von Thünen model. We also return to this at length in section 2.2.

2.1.2 Two agricultural sectors and three forest uses

The von Thünen model can be extended to several different land uses. We consider five different (and mutually exclusive) land uses:

I = intensive agriculture
E = extensive agriculture
M = managed forests
O = open access forests ($c^O = 0$)
G = old growth (virgin) forest

Land rent of the different land uses (denoted by superscript *i*) is then:

(3) $$r^i(d) = p^i y^i - wl^i - qk^i - c^i - v^i d; \quad i = I,E,M,O,G$$

These generic land use categories correspond to many situations found across the tropics. In the Amazon, one typically finds a combination of intensive cropping, extensive pasture, and managed forests for timber production. In Southeast Asia, a major distinction is between the more intensive lowland (rice) cultivation and extensive upland agriculture (often of some cash crops), surrounded by forests where *de facto* open access logging is practiced. In Southern Africa, one may find an intensive agricultural sector growing, for example, maize or cash crops, and an extensive shifting cultivation system, with managed or open access forests (woodlands) in the next zone.

[5] Intensification is here defined as higher input use (and therefore output) per hectare.

[6] An alternative formulation of the land rent would be:
$$r^i(\underset{-}{d}) = p^i(\underset{-}{d}) f^i(\underset{+}{l^i}, \underset{+}{k^i}) - w(\underset{-}{d}) l^i - q(\underset{+}{d}) k^i - c^i(\underset{?}{d})$$

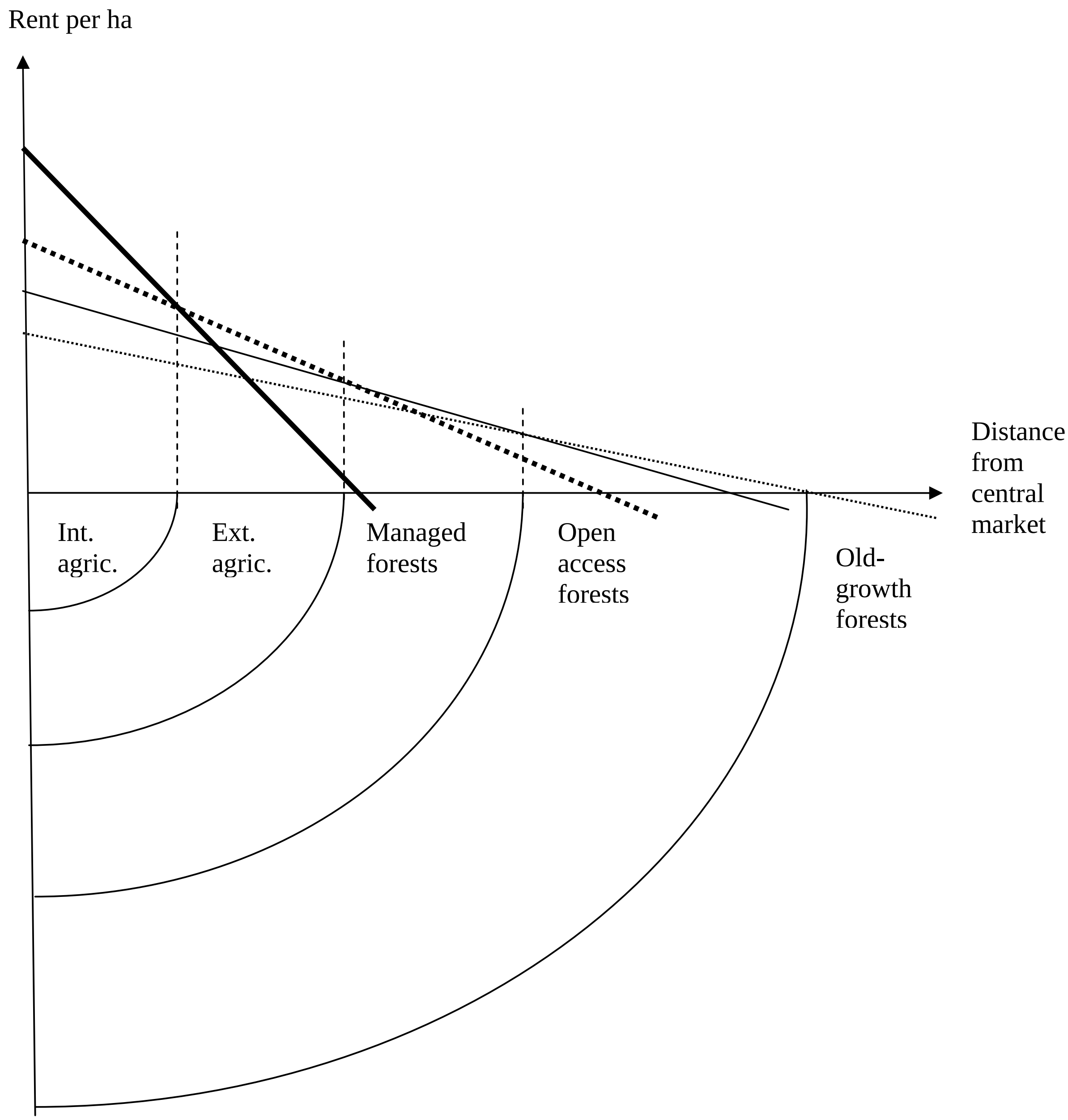

Figure 1. The von Thünen model with five alternative land uses.
Note: The four rent curves are designated by different lines: fat-solid = intensive agriculture; fat-dotted = extensive agriculture; thin-solid = managed forestry; thin-dotted = open access forestry.

The various rent curves and the associated land use zones – von Thünen's concentric circles – are shown in Figure 1. Note that it is by no means sure that all land rent curves will surface as one moves from the center, thus all the five land use zones may not necessarily exist in the area.

The border between intensive and extensive agriculture defines the *intensive margin*, while the border between extensive agriculture and forests gives the *extensive margin* (the agriculture-forest interface or the agricultural frontier). From a deforestation viewpoint, the changes in the extensive margin should be the main focus as that is where the forest-non-forest border is, although the interface in some cases could be between intensive agriculture and forest. Also, the intensive margin indirectly will affect the extensive one, cf. section 2.2.

The difference between managed and open access forestry should also be noted. Managed forestry implies certain costs in terms of defining and enforcing property rights (*c*). Beyond a certain distance the rent is too low to defend these costs. Open access forestry takes over, i.e., a system where logging on a "cut-and-leave" basis is practiced.

Rudel (2005) notes this center-periphery pattern of forestry in South Asia. Institutions of forest management exist in the more central areas, but not in the more remote ones, leading to more unsustainable forest uses of *de facto* open access forest. The presence of good institutions can be directly linked to the higher value forests have in areas closer to urban centers. In other contexts there may be no managed forests at all because of tenure problems. That would make it easier for agriculture to encroach on open access forests, as there are no managed forests to act as buffers.

As for the simple von Thünen model, a number of underlying assumptions and caveats should be kept in mind for Figure 1:

(a) Logging covers a range of practices, from selective logging under a Sustainable Forest Management (SFM) regime to clear-cutting and no re-growth. The latter implies deforestation, the former not. In the following we assume that logging does not in itself lead to deforestation (although it may imply forest degradation).

(b) We do not consider trade-offs between extraction of forest products (e.g., logging) and provision of environmental services from standing forests. We simply assume that both can increase the forest land rent in the competition with agricultural land uses. But environmental services are often public goods. Unless there are appropriate institutional arrangements (e.g., community forestry – see section 2.5 – or payment for these environmental services), their social value of such services does *not* enter the decision-making calculus of the individual land users.

(c) We still maintain the assumption of no interdependency among the curves. For example, logging often provides roads and other infrastructure and works, increasing agricultural land rent, generating a logging-agriculture tandem (Geist and Lambin, 2001).

(d) The factors which increase the rent of a particular land use also tend to increase the intensity of that land use. Thus the expansion of one particular land use and its intensity tend to move in tandem.

(e) Related to the above, the intensity is likely to vary within each land use zone, with more intensive uses closer to the center. Thus the border between intensive and extensive agriculture is likely to be rather fluid. Similarly, the forest-agricultural interface may consist of mixed forest-agricultural land uses, e.g., agroforestry or silvipasture.

(f) The sequence of the extensive agriculture and the managed forest may be reversed, i.e., (intensively) managed forests may be found closer to the center than extensive agriculture.

In the following sections we are – for analytical clarity – not maintaining all the five land categories discussed above, although the distinction intensive-extensive agriculture will remain central. But we shall mainly be treating forest as one category, which is – admittedly – a big simplification.[7] This is partly justified by the chosen focus of the paper, which is on agriculture and agricultural encroachment on forests rather than forestry.

2.1.3 What determines land rents?

In the von Thünen approach, deforestation is caused by any changes that increase rents of agricultural land uses and/or reduce rents of forest land uses. The key question is therefore what determines land rents, particularly those at the extensive margin. The previous sub-section showed how the location (height and slope) of the rent curves depends on the values of the decision parameters of the land rent equations. This sub-section provides a brief discussion of these and how

[7] For an insightful analytical discussion where this distinction is maintained, see Amsberg (1998).

they are in turn determined by a number of underlying factors. Note that the same underlying factors commonly impact both the agricultural and forest rent, making the net effect the critical issue. This is not pursued further here, but we return to the issue in section 3.2.

Shifts in agricultural rent

A number of factors will tend to increase the agricultural land rent and thereby push the agricultural frontier outwards. These are summarized in Table 1 and elaborated below.[8]

(a) Higher output prices: This can be caused by an increased demand for the output (due to, for example, higher income, changes in preferences, opening-up for international trade, or devaluation), increased competition and market efficiency, or lower taxes.

(b) Good agroecological conditions: Land suitable for agriculture (good soils, enough rainfall, etc.) is expected to lead to more deforestation.

(c) Technological progress: The impact of technological progress (higher productivity) is a complex issue, and discussed in section 2.3. The impact on land rent of the sector enjoying technological progress, without considering any market feedbacks and interaction among sectors, is nevertheless to increase the land rent unambiguously.

(d) Lower off-farm wages: Poorer off-farm employment opportunities, reducing the opportunity cost of using labor in extensive agriculture, can be due to, for example, economic stagnation and low economic growth.

(e) Lower interest rates: Access to cheap credit provides an incentive for agricultural expansion, but the strength depends on how capital intensive extensive agriculture is. While low labor cost may be associated with economic stagnation, it may be the opposite for credit cost (capital).

(f) Lower input prices: In the basic agricultural land rent equation, lower input prices provide a stimulus for deforestation. There are, however, important interactions between intensive and extensive agriculture that may reverse this conclusion, as discussed in section 2.2.

(g) Better roads and transport infrastructure: Reduced transport costs (alternatively expressed as higher output prices) provide a strong push for expansion of agriculture.

(h) Lower costs of property rights enforcement: This can be interpreted as higher tenure security, and should lead to agricultural expansion. But again, the issue is more complex than is suggested here and is discussed in greater depth in section 2.4.

Parameter	**Determinants**
p	Market demand, taxes/subsidies, export/import regulations, marketing efficiency (competition)
w	Off-farm employment opportunities, migration, economic development
q	Access to credit, interest rates
y	Technology, intensification, agroecological conditions: soil quality, rainfall, temperature
l, k	Technologies applied (labor or capital intensive: l or k high)
c	Property regime, law enforcement/corruption, land competition
v	Roads (extent and quality), rivers, general infrastructure

Table 1. Determinants of the decision parameters in the agricultural land rent equations.

[8] Much of this discussion is based on Angelsen and Kaimowitz (1999),.

Shifts in forest rent

In general, the following factors will increase forest land rent:

(a) Higher price of forest products: While the impact of changes in forest product prices are straightforward, sometimes the same forces leading to higher forest prices may also raise agricultural prices, making the question of relative increases in the two rent curves critical.

(b) Lower wages: In capital intensive logging operations wage rates play a less important role than in agriculture due to its capital intensity, while it is important for the typically very labor intensive collection of non-timber forest products (NTFPs).

(c) Technological progress: New and improved technologies in logging operations (and downstream activities) should increase forest rent, unless there are strong general equilibrium effects which significantly reduce timber prices, cf. section 2.2.1.

(d) Payment for environmental services (PES) related to standing forests: A critical aspect is that the payment is directly to those making the decisions about the agricultural *vs.* forest land uses, such that they factor the payment into their forest rent equation.

(e) Community forest management (CFM): Some of the environmental services are local public goods, and the collection of NTFPs is often from common pool resources. Individual farmers, who can convert forest to agriculture without restrictions, will ignore these forest values. CFM intends to transfer the forest use decisions from the individual (or state) to the community level, and is therefore also more likely to include these forest values in their decisions (see section 2.5 for a further discussion).

2.2 Feedbacks and interactions between rent curves

2.2.1 General equilibrium effects in output markets

General equilibrium effects in this section refer to how changes in the supply of an output can lead to changes in its price.[9] We split the analysis in two, first considering just one agricultural sector, and then the interaction between two sectors producing the same product and competing in the same market.[10]

One agricultural sector

Consider an expansion of the agricultural land use due to, for example, technological progress or lower input costs. This increases the market supply, with possible repercussions on the market price. In economic theory this is analyzed using the price elasticity of demand (or just: *demand elasticity*) defined as the percentage change in quantity (x) demanded when the price (p) changes with one percent:

(4) $$e = \frac{\partial x}{\partial p}\frac{p}{x}; \quad \frac{1}{e} = \frac{\partial p}{\partial x}\frac{x}{p}$$

[9] Another important general equilibrium effect not considered here is how changes in aggregate incomes affects demand for agricultural and forest products, and thereby prices, land rents and land uses. Further, we do not consider general equilibrium effects in markets for non-labor inputs.

[10] The discussion of general equilibrium effects focuses on the demand side. In a complete analysis of general equilibrium effects, the supply side elasticities also have to be taken into account. Our focus is justified by the fact that the differences in effects observed are primarily due to differences on the demand rather than the supply side.

Elastic demand refers to a situation where the demand is relatively sensitive to price changes, i.e., we have a relatively flat demand curve ($e > 1$). In the extreme case, when demand is perfectly elastic, the demand curve is horizontal ($e = \infty$). Similarly, *inelastic demand* means the demand is relative insensitive to price changes ($e < 1$), with perfectly inelastic demand giving a vertical demands curve ($e = 0$).

For our purposes, however, it is more convenient to look at the inverse of e ($1/e$) to answer the question: how much will a supply increase reduce the price? Further, we need to take into account that the commodity is produced by different sectors and/or regions. Let x_1 be the supply from the sector or region we are studying, while x_2 is the supply from all other sectors (and $x = x_1 + x_2$). The question is then: how much will a supply increase from the focal sector/district reduce the price? The answer is given by:

$$\frac{1}{e_1} = \frac{\partial p}{\partial x_1}\frac{x_1}{p} = \frac{\partial p}{\partial x_1}\frac{x_1}{p}\frac{x}{x} = \frac{\partial p}{\partial x}\frac{x}{p}\frac{x_1}{x} = \frac{1}{e}\frac{x_1}{x} \tag{5}$$

The reduction in price following a supply increase in sector 1 depends on two factors: the demand elasticity in the market (e), and the market share of that sector (x_1/x). Thus a sector can face a relatively flat demand curve, either because the total market demand is inelastic, or because its market share is low, or both.

It is commonly argued that demand for food is relatively inelastic ("you need food irrespective of the price"). This means that a given change in the supply will lead to a relatively large change in the market price. One should, however, remember that many agricultural products are not food stuff (e.g., cotton and rubber), or they are not the *basic* food stuff (e.g., cocoa and coffee). In general such products should be expected to display a more elastic demand.

In Figure 2 we consider three typical demand situations a sector can face, reflecting the market share of the sector.

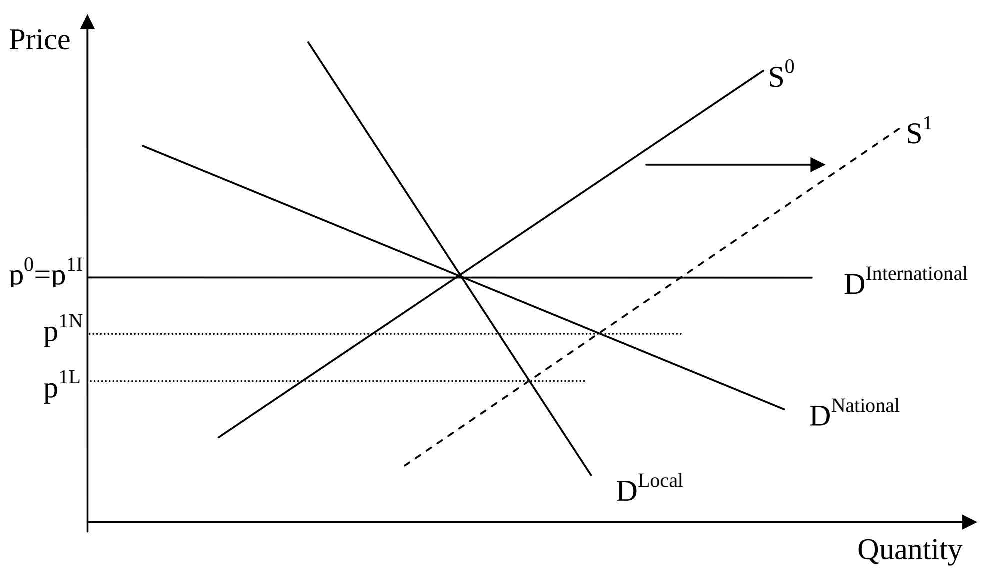

Figure 2. Three different market situations and the price effect of a supply increase.

In the first case, when the sector produces for a large market, e.g., for export, an increase in the supply will have negligible price effects. Rubber producers in a district of Sumatra expanding their supply through forest clearing will not affect the world market price of rubber much. This is represented by a horizontal demand curve in the figure (demand is perfectly elastic).

In the other extreme case, the producers are selling their output in a small local market. A given supply increase may imply a major drop in the price (demand is inelastic). Increased production of plantain in an isolated community of West Africa is likely to cause a drop in the local market price. An intermediate case is when producing for larger regional or national markets.

Two agricultural sectors

Consider next the situation with an intensive and an extensive agricultural sector (land use) producing the same commodity sold in the same market. Suppose the supply from the intensive sector increases, e.g., due to technological progress. How will that affect the land rent of the extensive one, and thereby the agricultural frontier and deforestation?

We have, in fact, already answered that question. In equation (5), let x_1 be the output from the intensive, and x_2 from the extensive sector. Except for the case with perfectly elastic demand, the result will be a drop in the price, and therefore a contraction of the extensive sector. The magnitude of the price decline is again given by two factors: the market's demand elasticity, and the share of the intensive sector in overall production.

This line of reasoning has been used to argue that Green Revolution technologies have saved tropical forests, sometimes referred to as the Borlaug hypothesis. In Asia, these technologies were more suited for the lowlands, irrigated rice production, whereas upland (dryland) rice cultivation has maintained old technologies. There are two reasons why this effect could be strong: the lowlands have a high share of total production, and rice demand is inelastic. There are, nevertheless, a few counter-effects which are considered in section 2.3.2.

Summary

Two general equilibrium effects in the output market are important for the deforestation outcome. First, any expansion of a particular land use will be dampened when producers face a downward sloping demand curve. This price-dampening effect is negligible when land users face an elastic demand (relatively flat demand curve). Unsurprisingly, the most spectacular stories of deforestation stories are related to commodity booms: farmers clear land for a particular crop (e.g., rubber, cocoa, banana, and soy bean) sold in a large international market (Angelsen and Kaimowitz, 2001: 386). The phenomenon is further strengthened if these goods are income elastic such that global demand increases with economic growth.

Second, there are important interactions among sectors, e.g., an expansion of intensive agriculture can lead to an agricultural price decline which lowers the rent of extensive agriculture and thereby a contraction of the extensive margin.

2.2.2 General equilibrium effects in labor markets

The general equilibrium effects in the labor market refer to both changes in market wage rates, and the impact such changes have on migration. As for the discussion of the agricultural output market effects, it is useful to distinguish between the one and two sector cases.

One agricultural sector

Consider an upward shift in the rent curve of extensive agriculture. The immediate effect is an expansion of the extensive margin. This may cause an increase in the demand for labor, raising the wages, and therefore dampening the expansion. The strength of this effect depends on two factors:

First, the magnitude of the change in labor demand is critical, and is the product of two factors: the change in labor intensity (labor inputs per ha), and the area expansion. The latter effect is normally sufficient to increase overall labor demand and this is taken to be the typical case in the following. However, if the shift in land rent is due to an adoption of a labor saving technology (e.g., mechanization) and the area effect is small, total labor demand may drop.

Second, the change in wages following an increase in labor demand is conditioned on the supply elasticity in the labor market, as well as the market share of extensive agriculture. If the extensive sector is relatively small, it can pull labor from other non-agricultural sectors with only small increases in the wage rate. In the medium term, higher profitability in the extensive sector can also attract labor beyond the local labor market. Thus the medium-/long-term supply curve will be flatter than the short term one.

Two agricultural sectors

Consider next the situation with an intensive and extensive agricultural sector, competing for the same labor. The situation is illustrated in Figure 3. We further distinguish between two situations: without and with a (perfect) off-farm labor market.

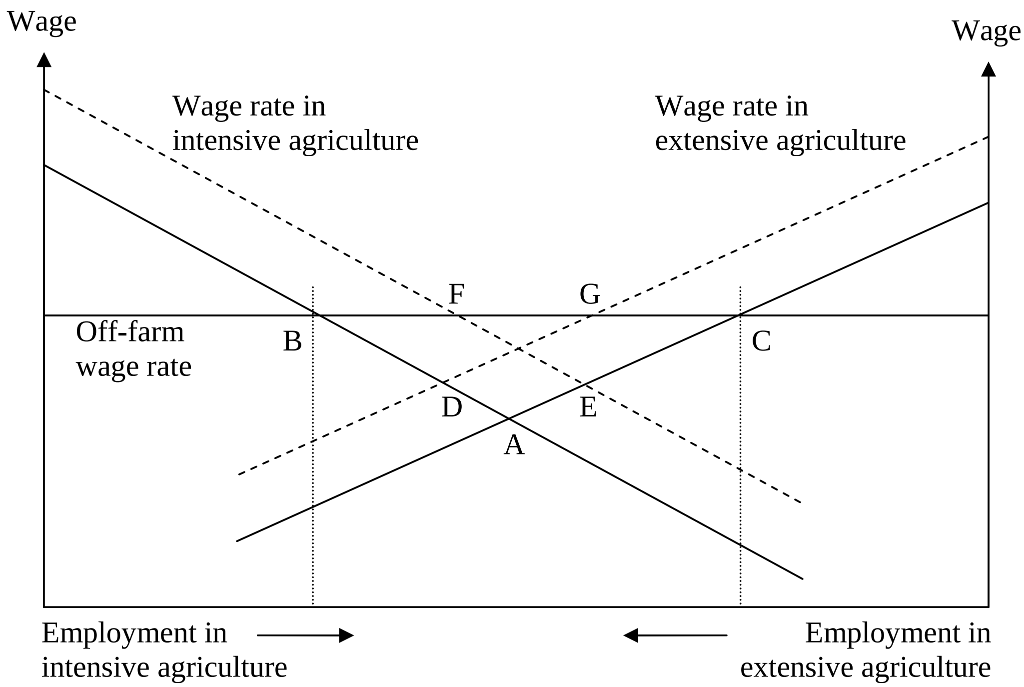

Figure 3. The labor market interaction between intensive and extensive agriculture.

When no off-farm labor market exists, the allocation of labor between the two sectors is found at point A. A shift in the rent curve of intensive agriculture, increasing the demand for labor, will move the equilibrium from A to E, and thereby reduce the extensive land use. Similarly, higher labor demand from extensive agriculture results in a move from A to D. The two sectors interact by bidding up wages to attract labor from the other sector. The magnitude of the wage increase depends on the relative size of the two sectors and the supply elasticities, as expressed in the slope of the curves. (Note that the labor supply curve of one sector is, in fact, the demand curve of the other one.)

What happens if we introduce an off-farm labor market? This is represented by the horizontal line in the figure.[11] Higher labor demand from intensive agriculture is depicted by a move from B to F, while higher demand from extensive agriculture is given by the move from C to G. In either case, there is no reduction in the other sectors' labor use. The market wage rate is given by the off-farm labor market, and therefore no labor market interactions between the two sectors.

[11] We assume that the market wage rate is above the wage rate in A. If not, we are back to the situation without an off-farm labor market.

Most real-world cases are in-between these two extremes: an off-farm labor market exists, but the market is imperfect. Thus we may expect some interactions, but the magnitude depends on the size and functioning of the off-farm labor market. The interaction will be miniscule if the off-farm market is large compared with the agricultural sectors. Moreover, the existence of an off-farm labor market with an almost perfectly elastic supply of labor is a more realistic description of the long term effects when people move between regions and sectors based on the wages and incomes they can obtain.

Summary

Similar to the general equilibrium effects in the output market, there are two key points to consider for the labor market effects. Higher demand can bid up local wages – particularly in the short term – and therefore put a brake on the expansion of the land use. And, an expansion of one land use may raise wages and lower the rent of other land uses.

Again, the question of magnitude of these effects is important, and this depends on a number of factors: First, there will be a marked difference between short and long term effects, with wage-dampening effects playing a much smaller role in the long term when differences among sectors and regions is levelled out though migration (Cattaneo, 2001).

Second, the size of the agricultural sectors relative to the rest of the economy matters: the smaller the size, the smaller the wage increases. A key structural change during economic growth is agriculture's shrinking share of GDP and employment. Thus we can expect the labor market effect to be small in middle-income Asian countries like Malaysia and the Philippines, while it will be much more important in low income African countries, particularly those with large extensive agricultural sectors.

Third, the less integrated the local (labor) markets are in the larger economy, the stronger the wage increase effects. An interesting comparison can be made between rubber expansion in West Kalimantan and Riau/Jambi provinces of Indonesia. In Riau/Jambi large influx of migrants provided a steady labor supply for expansion. In the more isolated West Kalimantan, rubber adoption lead to a much smaller expansion due to shortage of labor (Jong, 2001).

Fourth, the labor intensity of the land use in question and the *change in* that intensity is critical. If, for example, intensive agriculture expands due to mechanization (labor saving), the result may be reduced demand for labor, lowering the wage rate and leading to expansion of extensive agriculture (Ruf, 2001).

2.2.3 Capital markets

If labor markets are imperfect, capital markets in rural areas tend to be even more so. Farmers are typically severely credit constrained. Yet we need to consider two potentially important effects.

First, to the extent a rural credit market exists, the discussion is parallel to the one on labor market effects. Higher demand for capital (credit) will raise interest rates, and therefore dampen the agricultural expansion. Larger farmers and companies may have access to credit from non-local sources, and such dampening effects are therefore much less likely to apply to them (Cattaneo, 2001).

Second, due to capital markets imperfection, much of the capital needed is raised by the farmers or companies themselves. Farmers save and accumulate capital, and they can easily transfer it between sectors they are involved in. This point is discussed in the next sub-section.

2.2.4 *Interactions at the household level*

If farmers are integrated into well-functioning markets for output, labor, credit and land, there are no direct household effects to consider.[12] When they are not, the household characteristics and household level feedbacks and interaction have to be brought into the discussion, cf. Singh et al. (1986) and Janvry et al. (1991).[13] Changes in one of the land rent curves will have household level repercussions that affect that and the other rent curves.

There is a significant literature on farm household and deforestation, both theoretical models and empirical studies.[14] Related to our discussion of changes in land rent curves, there are three important effects to consider when the perfect markets assumption does not hold:

First, increased agricultural land rent – together with an accompanying expansion of agricultural land use – will raise income and consumption. If limited opportunities exist for selling the produce, there will be a *saturation effect* which limits further agricultural expansion. This can be modelled as the household balancing the utility of higher consumption with the disutility of work, referred to as the Chayanovian model of agricultural economics. In the extreme case, the "full belly" model, the farm households seek a given subsistence level of consumption and prefer leisure beyond that point. The relevance of saturation effects depends, *inter alia*, on how isolated the community is, both in geographical (market access) and cultural terms.[15]

Second, when labor markets are imperfect or missing, a key decision by the households is how to allocate scarce family labor among different farm activities. The effect resembles the general equilibrium effect in the labor market; the household can be seen as miniature labor market, with its own "shadow wage rate" or "subjective equilibrium wage rate", reflecting the households' opportunity costs of labor.

Consider an increase in the land rent of extensive agriculture. The household would like to expand its land use, but is constrained by labor shortage. If also involved in intensive agriculture, labor can be allocated from that sector to ease the labor constraint. Alternatively, higher rent in intensive agriculture will raise the households' shadow wage rate, and pull labor from the extensive land use, thereby reducing forest clearing.

Third, the households also allocate scarce capital to farm activities. An expansion following higher land rent in, say, extensive agriculture may be constrained by the availability of capital (in the same way as for labor). And, an increase in rent of intensive agriculture can pull capital from extensive agriculture. But, there are crucial additional effects to consider. Higher land rent in either sector will raise farm income and ease capital constraints. Consider the following situation. Capital constraints prevent farmers from expanding the extensive land use, which would otherwise be profitable to do. Intensive agriculture then enjoys technological progress or a higher output price, leading to higher farm income. This may well be used for an expansion of the extensive agriculture rather than the

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[12] The household effects would then be limited to study how the aggregate household demand for commodities and capital and supply of labor affect the market equilibria in the various markets.

[13] Generally, if the farmers are integrated in perfect markets, the decisions related to land use are separable, that is, they can be analyzed as a profit maximization problem without paying any attention to household characteristics such as the households' labor endowment (labor can be hired). In a general equilibrium framework, however, some household effects should be considered, for example, the changes in their *aggregate* demand for agricultural products which affect market prices and thereby production.

[14] An aging review of such models is Kaimowitz and Angelsen (1998). Later contributions include Pendleton and Howe (2002), Soest et al. (2002), Merry et al. (2002) and Shively (2006). See also the special issue of *Land Economics*, 77 (2), 2001.

[15] See Angelsen (1999) for a further theoretical discussion of this, and Angelsen and Luckert (2004) for a critical discussion on their empirical relevance.

intensive. Similarly, higher wages – which increase the opportunity cost of labor and thereby reduce agricultural land rent – may in such a situation ease the capital constraint.

This argument is illustrated in Figure 4, where we for simplicity only draw the rent curve of the extensive agricultural sector. Due to capital constraints, the extensive land use stops at d^1. Next, the household gets higher market wage rates or an increase in the land rent of intensive agriculture. This shifts the extensive land rent downwards due to an increase in the household's opportunity cost of labor, but also provides capital for extensive agriculture. Since the latter is the determining factor, the frontier moves from d^1 to d^2. The ease in the capital constraint gets the farmer closer to the optimal non-constrained solution, and changes in these constraints are more important than the optimal unconstrained levels of forest clearing.

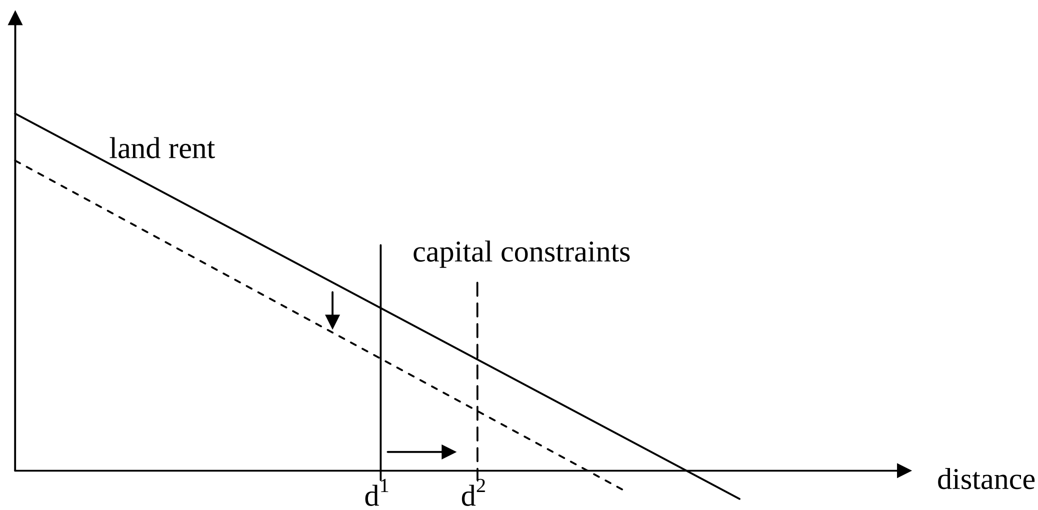

Figure 4. The impact of a simultaneous change in land rents and capital constraints.

This effect has been observed in several areas of South America, where the extensive land use typically is pasture for cattle production (e.g., Vosti et al., 2002). The system is capital intensive and its expansion is constrained by the access to capital, at least for the small and medium sized farmer. Higher off-farm wages, for example, can be used to invest in more cattle, outweighing the effect that labor has become more expensive.

Merry et al. (2002) find a similar effect in their study of forestry-pasture interactions in the Bolivian Lowlands. Higher stumpage values will not, as a simple unconstrained analysis suggests, lead to a shift from pasture to sustainable forestry. Instead it will provide capital-constrained farmers the capital needed to convert forest land to pasture.

2.2.5 Increasing return to scale: infrastructure, public services, and processing

Two key concepts in economic geography or geographical economics are *transport costs* and *increasing returns to scale (IRS) or economics of scale*, cf. Brakman et al. (2001). The former is the key variable determining land use in the von Thünen model. The concept of IRS is of more recent date, has partly been inspired by the new (endogenous) growth theory.[16] It is, nevertheless, only to a very limited extent included in economics models of deforestation. The omission of IRS is partly to do with the complexity it entails, which also should limit the expectations about how far one can get in this direction. Related to this, non-linearities normally imply multiple equilibria and small initial

[16] IRS is defined as decreasing average costs as output increases. It may refer to the production at the level of an individual producer, a sector, a region, or the whole economy.

differences having major impacts on the outcomes ("butterfly effects"). Thus the predictive power of such models is limited by their very nature.

Yet, in empirical studies IRS effects can be strong, and need to be considered. There is a dangerous "fallacy of average" (Verburg et al., 2002), i.e., there are threshold effects and non-linearities which sometimes give surprising outcomes. Many of the deforestation stories observed can only be understood by considering IRS effects, e.g., the recent soybean expansion in Brazil and Bolivia (Kaimowitz and Smith, 2001).

Consider an exogenous increase in rent land of the extensive agricultural sector. The sector expands: output increase and people move to the region. This may have several reinforcing effects that further increase the land rent, of which two are particularly important.

First, a larger population leads to the development of better infrastructure (e.g., feeder roads), local markets and public services. This can boost the (absolute) farm-gate prices of agricultural commodities, both by reducing transport costs and increasing local demand. Lower prices of *imported* consumer goods can also be expected due to lower transport costs and higher competition, further increasing the *relative* price of agricultural commodities.

Second, higher output can lead to the development of downstream activities in both agriculture and forestry, e.g., food processing, slaughterhouses, dairies, and mills. Such activities are characterized by IRS: a minimum supply of raw materials and products are needed to make them profitable. Similarly, the establishment of marketing and transport systems, inputs supplies, and extension services are also characterized by IRS.

In short, an exogenous increase in the land rent initiates processes which further increase profitability by increasing output prices and reducing input costs. We discuss further such reinforcing loops and their role in the forest transition in section 3.2.

2.2.6 Forest scarcity feedbacks

An increase in agricultural land rent is the key driving force behind deforestation. This will reduce forest area in the early stages of the forest transition, and most likely also the supply of forest products and forest-based environmental services. We briefly discuss two major feedbacks the reduction in each of these may generate.

Reduced supply of forest products might lead to an increase in their prices. This is a type of general equilibrium effect discussed in section 2.2.1. The magnitude depends on the actual reduction in the supply (e.g., to what extent is logging moving to new areas as the agricultural frontier expands), the demand elasticity, and the market share. As will be discussed further in section 3 on the forest transition, such increases in forest product prices provide a very important feedback that helps to stabilize forest cover.

Reduced supply of forest-based environmental services should also increase the value of such services. Due to their public goods nature, most of these do not have any market and therefore no market mechanisms that will raise forest rent (unlike for forest *products*). There are exceptions, such as forest based tourism and emerging markets for environmental services related to particularly water catchment services.[17]

In the absence of markets for a number of forest products, the main response is, therefore, likely to be political in the form of efforts to protect forests to maintain the services provided. Programs for tree planting, forest conservation areas, and devolution of forest management to local communities

[17] For reviews of PES markets, see Landell-Mills and Porras (2002), and Wunder (2005) for a didactic introduction to PES and more references.

can all be seen as political responses to shrinking forest areas. It can also be in the form of local institutional responses, as discussed further in section 3.2.3.

2.2.7 Land degradation (soil exhaustion)

Agricultural yields are not constant over time, but benefit from good land management practices and deteriorate from bad ones. In the event of bad practices, the land rent curve shifts down, and this may lead to an abandonment of agricultural land. Mather (1992) and Mather and Needle (1998) argue that such trial and error patterns were important in the forest transition in Europe, and it also plays an important role in many poor, tropical countries today. Over time there is learning process leading to a concentration of agricultural production on the more fertile land, while poorer land is left for reforestation.

Land degradation and exhaustion of soils is a function of not only land management practices but also of natural conditions. Tropical soils with forest cover are often not able to sustain yields for prolonged periods without nutrients being replaced by fertilizers or through sufficiently long fallow periods that allow for soil recuperation. Cultivation on steep slopes makes the land more susceptible to soil erosion. Thus agricultural expansion into marginal land areas is more likely to suffer from low and declining yields.

2.2.8 Summary

This subsection has looked at a number of feedback and interactions from changes in (mainly agricultural) land rent curves. Some of these effects tend to dampen an initial increase in the rent, while others magnify it. Similarly, an upward shift in one land rent curve can push other curves up or down, depending on which effect we are looking at and the context in which it operates.

We summarize the first five effects discussed above in two categories. Assume an increase in rent in an agricultural sector. The following effects will *tend to* dampen the initial increase in land rent of that sector, and also reduce the land rent in other agricultural sectors:

(a) General equilibrium effects in the output, labor and capital markets.

(b) Consumption and labor scarcity effects at the household level.

The following effects will *tend to* magnify the initial increase in the land rent, and also increase the land rent in other agricultural sectors:

(a) Capital accumulation effects at the household level.

(b) Increasing returns to scale in infrastructure, public services and downstream processing.

2.3 Technological progress in agriculture[18]

"Technological progress" is in economics defined as an increase in *total factor productivity*, which simply means getting more physical output with the same amount of inputs (or the same output with less inputs). Thus technological progress, defined this way, has a broader meaning than it does typically. It does not only result from the adoption of new high-yielding varieties, physical inputs or capital goods (*embodied* technological change), but can also result from better management practices and information (*disembodied* technological change).

The question of how technological progress impacts the rate of deforestation is contested. Part of the reason is that it covers a wide range of phenomena occurring in very different contexts, and the

[18] This section draws on the edited volume by Angelsen and Kaimowitz (2001), which contains both a unifying theoretical and conceptual framework as well as a number of case studies.

different participants in this debate refer to different things.[19] Below we argue that the deforestation impact of technological progress depends critically on three sets of factors:

(a) The sector in which technological progress is occurring;

(b) The market context;

(c) The type of technological progress.

We first discuss technological progress when considering only one agricultural sector, and then interactions between two sectors. The different market contexts are discussed under each of them: the perfect market case, and then effects at the farm household level and at the market level (general equilibrium effects).

The impact of technological changes is in most contexts greatly conditioned by the nature of technological change, a key element being the factor intensities. Table 2 provides a classification of technologies based on that.

Type of technology	Yield (y)	Labor per ha (l)	Capital per ha (k)
Labor intensive	+	+	?
Labor saving	?	–	?
Capital intensive	+	?	+
Capital saving	?	?	–
Pure yield increasing (Hicks neutral)	+	0	0
Yield increasing and input intensive ('land saving')	+	+	+

Table 2. Classification of technologies based on change in yield and factor intensities.
Source: Angelsen et al. (2001).

2.3.1 One agricultural sector

Perfect markets

The perfect market case, as used in this paper, refers to a situation where all relevant prices are given and does not change following changes in the agricultural sector (output demand and input supplies are perfectly elastic). Thus farmers can sell any amount of the produce at a given price, they can hire or sell labor in any amount at a given market wage rate, and they can get as much credit as they want at a given interest rate to buy any inputs they want at a given price. While unrealistic if taken literally, it may give a reasonable approximation of a situation where the sector experiencing technological progress is relatively small (low market share), and the farmers are well integrated into markets.

The impact of technological progress is pretty straightforward in this case: it boosts agricultural land rent, and therefore forest conversion. This can be read directly out of the basic land rent equation: higher yield (y) and/or reduced input use (l and k) will lift up the agricultural rent curve. The effect does *not* depend on the type of technological progress.

While simple and straightforward, this conclusion is an important one and is present in all cases discussed below. Technological progress in agriculture at the forest margin increases the

[19] See Angelsen and Kaimowitz (2001) for a general overview of this debate. Angelsen and Kaimowitz (2004) discusses this with particular reference to agroforestry, while Kaimowitz and Angelsen (2006, forthcoming) reviews this debate with reference to livestock intensification in Latin America.

profitability of converting forest to agriculture, and will lead to more deforestation, unless counteracted by strong household or general equilibrium effects.

Imperfect markets and farm household effects

Rural areas are often characterized by imperfect (thin or missing) markets and by limited participation of farmers in the markets due to high transaction costs. In this situation farmers' own stocks of labor and capital are critical. Also, the impact is strongly modified if there is no market outlet for increased production. We put forward two hypotheses:

First, labor (capital) constrained farm households that adopt labor (capital) *intensive* technologies will reduce their forest clearing.[20] The reason is simple: if the households only have a limited amount of labor (capital) to their disposal, the only way they can adopt a new labor (capital) intensive technology is to reduce their cultivated area. On the other land, labor (capital) *saving* technological progress should greatly enhance deforestation. In addition to the increased profitability that is implied by technological progress, the new technology will free up labor (capital) that can be used for cultivating more land.

Second, if farmers have limited outlets for surplus production and therefore mainly produce for family consumption, higher yield may reduce total agricultural area. In the extreme case, dubbed the "full belly model", the target is to reach a subsistence target at minimum cost, thus any yield increase will reduce agricultural land area.[21]

General equilibrium effects

General equilibrium effects in the markets for agricultural output and for labor will serve to enlarge, modify or possibly reverse the effects of technological progress compared with the perfect market case. It all depends on the factor intensities of the technologies and the market characteristics, as discussed in section 2.2.1-2. As shown there, the strength of the general equilibrium effects depends on the demand/supply elasticities and the market share of the sector enjoying technological progress.

The output market effect depends also on the magnitude of the supply increase, which again is determined by yield increase and area increase. Some technologies do not affect yield much. They only reduce costs. Mechanization of agricultural operations is an example, and the price-dampening effects of such technological changes will therefore be smaller.

The change in labor demand similarly depends on change in the labor intensity following technological change. Labor saving technologies such as mechanization may reduce overall labor demand, putting downward pressure on wages which would lift the agricultural land rent curve even higher. Labor intensive technologies, on the other hand, will increase labor demand and put upward pressure on wages, and therefore serve to constrain agricultural expansion. Such technologies are therefore identified as being the most promising for win-win outcomes: higher wages will both limit deforestation and increase rural incomes (Kaimowitz and Angelsen, 2001).

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[20] One might legitimately ask why labor (capital) constrained households will adopt labor (capital) intensive technologies. In general they would prefer labor (capital) saving technologies, but farmers cannot freely design their technological packages. Thus, labor (capital) intensive technologies may still be attractive because of their profitability or reduction in risk, as argued by Pichón (1997) in a study of Ecuador.

[21] This assumes, in addition to farmers having full-belly preferences, also that agriculture is the only income source. If not, it would be beneficial to switch from non-farm activities into agriculture, and the impact on deforestation of a yield increase is ambiguous.

2.3.2 *Interactions between two agricultural sectors*

Perfect markets

We now turn to the case with two agricultural sectors. Technological progress can take place in the intensive sector, in the extensive, or in both. In the case of perfect markets, there is no interaction. All relevant prices are given, and a change in one sector does not affect the other. Thus technological progress in the intensive sector has no effect on the extensive margin. Technological progress in the extensive sector is similar to what was discussed above in the one sector case with perfect markets.

Imperfect markets and farm household effects

Consider first technological progress in extensive agricultural sector only. The effects discussed for the one sector case still hold, but with one important addition: Labor and capital constraints are "softer" as the farmer can move resources from the intensive to the extensive land use. Thus we are less likely to see a contraction of the extensive margin when farmers adopt a labor (capital) intensive technology.

Consider then the impact when the farmer adopts new technologies in intensive agriculture. Adoption of labor (capital) intensive technologies will pull resources from the extensive sector and reduce deforestation. Labor saving technological progress makes a more challenging case, as it both frees up farm labor and also makes the intensive sector more profitable relative to the extensive one. Angelsen (2006) demonstrates in an analytical two-sector farm household (Chayanovian) model that the latter effect always dominates: new labor saving technologies in intensive agriculture will *not* lead to an expansion of the extensive margin. This suggests that the sector that experiences technological progress may be more important than the nature (i.e., factor intensity) of the new technology.

General equilibrium effects

We first consider the effect of technological progress in extensive agriculture. Compared with the one sector case, the introduction of an intensive agricultural sector is likely to weaken any dampening general equilibrium effects. Thus it becomes more likely that technological progress results in more deforestation.

A pure yield-increasing technological change may be dampened by lower output prices, but the magnitude depends on the size of the extensive sector relative to the intensive one. If small, as often is the case, the dampening effect is limited or negligible. Coxhead et al. (2001) find this to be the case among upland farmers in their study area in the Philippines. Supply shocks had no effect on prices in broader corn markets; the farmers were price-takers in these markets.

Labor saving technological progress leads to more forest conversion compared with the perfect market case. The effect of labor intensive technological progress is indeterminate: reduced labor inputs per ha increase land rent, but higher wages push in the other direction. Again, the relative size of the two sectors and the demand elasticity determine the net effect.

Technological progress in the intensive sector will affect the extensive margin indirectly though changes in the output price, wage rate, and/or capital costs. The output market effect of any yield-increasing technological change is to depress prices and therefore lead to a contraction of the extensive margin. Labor intensive technologies have a similar effect though bidding up wages, while labor saving ones have the opposite effect. Thus a yield increasing and labor saving technological change will have contradictory effects on the extensive margin.

The Green Revolution is often portrayed as a form of technological progress in intensive agriculture which has saved large amounts of forests. The effect works principally through the output markets by keeping the prices of rice, maize and other food crops lower than they would have been without the Green Revolution.[22] Although this may be true on aggregate, Ruf (2001) notes two effects that could lead to the opposite result. In a study from Sulawesi (Indonesia), he finds that Green Revolution technologies were linked with more forest clearing in the uplands for cocoa planting: (1) the technologies implied a mechanization of lowland rice production (hand-tractors), which freed up labor, and (2) the increased profitability provided funds for investing in cocoa production in the uplands.

A third effect arising from the Green Revolution is that higher local incomes can to lead to higher population growth, as predicted by the demographic transition. Although such basic Malthusian effects are controversial, the Green Revolution has coincided with very high population growth rates in many countries. Although this to some extent seems to be an unavoidable stage in the demographic transition, it will nevertheless have significant impacts on the forest cover.

2.4 Land tenure regime

Land tenure – or the institutions regulating property rights to land – is a multi-dimensional concept. In the context of deforestation, two dimensions are critical:

(i) The degree of tenure insecurity, which is modeled below as the probability of eviction or losing land without compensation. Tenure security from this perspective is considered to be *exogenous*, and the relevant question is: *what is the impact of tenure insecurity on deforestation?*

(ii) The actions the land manager can undertake to influence tenure insecurity, including how land rights are acquired in the first place. Tenure security from this perspective is considered *endogenous*, and the relevant question is: *how do land users' actions to increase tenure security affect deforestation?*

The two dimensions are often mixed up in the literature and policy discussion. Although it may be difficult to clearly isolate the two effects in empirical work, from a conceptual view this and for the clarity of the discussion the distinction is critical. We therefore consider each of them in turn.

2.4.1 The impact of (exogenous) tenure insecurity

Consider a land user who has the option to clear one ha of forest and start cultivating crops.[23] There are certain initial costs of clearing the land (h_0), after which the land yields an annual profit or rent r. We assume for simplicity that the rent to the decision maker of keeping the land as forest is zero, alternatively, r can be interpreted as the rent above the one received if the land is kept as forest. This rent is a function of the location, as measured by distance to the center (d), $r_d' < 0$.

The rent (r) is not adjusted for the risk of losing the land. The farmer does not, however, have full tenure security, and there is a probability λ in each period of losing the land. She uses a discount rate of δ, and we assume for simplicity infinite time horizon. The forest is cleared if the net present value (NPV) is greater than zero:

$$(6) \qquad NPV_0(d) = \int_0^\infty e^{-\lambda t} e^{-\delta t} r(d)dt - h_0 = \frac{r(d)}{\lambda + \delta} - h_0 > 0$$

It is straightforward to see that higher tenure security (lower λ) increases the NPV of clearing a particular piece of forest land, thus the agricultural frontier expands. The provocative conclusion

[22] See Jayasuriya (2001) for a analytical discussion of Green Revolution impacts in Asia. Another analytical treatment (with some empirical examples) of the general equilibrium interactions between intensive and extensive agriculture is Angelsen and Kaimowitz (2001).

[23] The forest may be owned by the farmer or be an open access resource. Which of these two property regimes are assumed does not matter for our line of reasoning.

from this simple model is therefore: tenure insecurity saves the forest! The key for understanding the model's conclusion is that forest conversion is framed as an investment. Higher risk (tenure insecurity) reduces the expected return and profitability of that investment, in the same ways as a higher discount rate does. These are, in fact, nothing but standard results in financial theory.

In the popular debate and also within textbook resource and environmental economics, protecting the environment is considered an investment for the future. It may also be so from a social welfare perspective. But, to understand the forces behind deforestation, one should take the perspective of the individual land users, and to them deforestation is an investment in agricultural land. The effects of tenure insecurity (and risk more generally) and discount rates on environmental protection is therefore turned upside down. The lack of distinction between whose perspective the analysis takes is an important source of confusion and controversy in the debate on the causes of deforestation (these points are elaborated in Angelsen, 1999).

One should always be careful in drawing policy conclusions based on simple models, as the reality on the ground is much more complex. For example, in a shifting cultivation system tenure insecurity varies depending on the stage in the cultivation cycle. Farmers may have good tenure security over currently cultivated plots, but weak security for plots in fallow, and weaker the longer the plot has been in fallow. This may lead to inefficiently short fallowing, which is documented for Ghana in Goldstein and Udry (2005). Moreover, insecure tenure will lead to less land investment and more soil exhaustion, thus increasing the need and/or incentives for cutting down more forest to replace degraded land.

This line of argument can be referred to as the "land degradation-deforestation hypothesis" (Angelsen and Kaimowitz, 2001), and is normally based on either of the following assumptions:

1. The farm household has a certain subsistence target to reach, cf. the discussion in section 2.2.4 on household interactions and "full belly" models. Low productivity on existing land leads to more clearing of new land.
2. There are important general equilibrium effects in the output, labor or capital/credit markets. Insecure tenure can lead to lower investments and intensity of production (lower demand for labor and capital) and therefore productivity (lower supply). In the output market, the price of the particular crop is pushed upward, which provides a stimulus for deforestation. In the labor and capital/credit markets, wages and interest rates are pushed downward, also increasing the land rent of land converted to agriculture.

Both arguments are more applicable to situations of imperfect markets, which is typically found in more remote areas with poor infrastructure, leading to lower integration in regional and national markets. This also assumes that the only two sectors are farming on existing land and farming on newly cleared land. If, for example, other income and investment opportunities exist, the link between the two sectors will be weakened, cf. section 2.2.2.[24]

In short, these arguments suggests that the rent of new agricultural land is a function of tenure insecurity: $r = r(d,\lambda), r_\lambda > 0$. Thus our NPV formula is rewritten as:[25]

[24] Similarly, the "full belly" effect in argument 1 is weakened the higher the off-farm income is, cf. Angelsen (1999, Appendix 2).

[25] An essential part of this argument is that tenure insecurity, expressed though λ, is the same on both existing agricultural land and newly cleared land. In the NPV equation, λ in the nominator is due to tenure insecurity on existing land (changes in prices and wages), while λ in the denominator refers to the tenure insecurity on newly cleared land. In fact the argument rests on there being a link between (changes in) tenure security on existing and new agricultural land.

(7) $$NPV_0(d) = \frac{r(d,\lambda)}{\lambda+\delta} - h_0 > 0$$

Higher tenure insecurity (higher λ) has two contradictory effects on the NPV of cleared forest land. The direct effect is negative, reflecting the increased risk of losing land (the denominator). The indirect effect is positive though higher (risk-unadjusted) rent, due to higher output prices and lower wages and capital costs. We cannot on a theoretical basis determine the net effects.

The tenure insecurity may not affect all land users in the same way. Large clearings are less likely to generate a counter claim on the land compared with small clearings. The implication is that tenure insecurity will change the composition of the actors who clear land – leading to more large scale landclearing enterprises, as observed by Rudel (1995) in Ecuador. This can possibly also lead to more overall deforestation.

To summarize, insecure tenure has contradictory effects on the rate of deforestation. While tenure insecurity is often thought to automatically lead to more deforestation, the above discussion should serve as a warning against such generalized conclusion. Unfortunately, there are few comparative empirical studies that investigate the impacts of varying degrees of tenure insecurity on deforestation, although Otsuka and Place (2001) contains a few insightful case studies. But this is clearly an area where more thorough and comparative research is warranted.

2.4.2 The impact of actions to increase tenure security

Converting land from forest to agricultural uses often, both according to customary and statutory law, gives specific rights to the land. Deforestation therefore becomes a title establishment strategy.[26] In the following we discuss three fundamental reasons why insecure tenure and "deforestation as a title establishment strategy" will lead to more deforestation: land races, land speculation, and land squeezing.

That forest clearing and intensive land use give property rights is sometimes seen as an expression of misguided policies or policy failures. But, the universality of this practice suggests that it is more fundamental and at least partially unrelated to policies. This way of securing land rights is in line with the basic principle of how property rights are established, as expressed by the 17th century philosopher John Locke: property rights to an object are established by mixing something one owns, namely labor (and capital) with the object (land). And, the more you mix what you own with the object, the stronger are your rights (e.g., Rose, 1994).

1. Land races

A "land race" or "race to the frontier" refers where forest is cleared prematurely in order to establish property rights. The problem has been discussed particularly in the Amazonian deforestation context, e.g., Schneider (1995) and Alston et al. (2000).

A land race can arise in a situation with the following characteristics:

(a) *De facto* open access, i.e., no or limited (enforcement of) property rights to the existing forest.

(b) Property rights are established by forest clearing.

(c) Agricultural land rents are expected to increase over time, e.g., due to better infrastructure or higher demand for agricultural products.

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[26] Tenure security will also depend on the investments in the land, e.g., the intensity of cropping in shifting cultivation systems, or the establishment of perennials. We do not pursue that issue further here, but refer to Otsuka and Place (2001) who discuss how tenure regimes in different settings can both give incentives for deforestation and reforestation.

The last assumption is essential. In a theoretical model Angelsen (1999) demonstrates that the first two are – somewhat surprisingly - not sufficient to generate a land race. Thus land races are more prevalent in places experiencing an expansion in infrastructure because inaccessibility no longer limits access.

To see how land races are generated, compare the above tenure regime with a situation where a land user has pre-established 100% secure property rights to the forest land. The question the land user then asks is this: when should I cut a particular piece of forest and bring it into agricultural cultivation? The short answer is: when the annual land rent becomes positive. Due to the assumption of increasing land rent over time, there will be a moving frontier, and the frontier at time t_1 is characterized by:[27]

(8) $$r_{t_1}(d) = 0$$

This is illustrated by point A in Figure 5. Next, consider the land race situation. Forest clearing is now an investment, as it establishes rights to the land. The relevant criterion is therefore the net present value (NPV) the plot being converted from forest to agriculture. Land will be cleared up to the point where the NPV is zero, thus the frontier at any time t_1 is characterized by:

(9) $$NPV_{t_1}(d) = \int_{t_1}^{\infty} e^{-\delta t} r_t(d)dt = 0$$

The frontier in this case is given by point B in Figure 5. Land between distance A and B is cleared in order to secure the land rights, even though the agricultural rent for the first few years is negative (the annual rent curve at time t_1 is below the x-axis). Deforestation between point A and B is due to the land race.

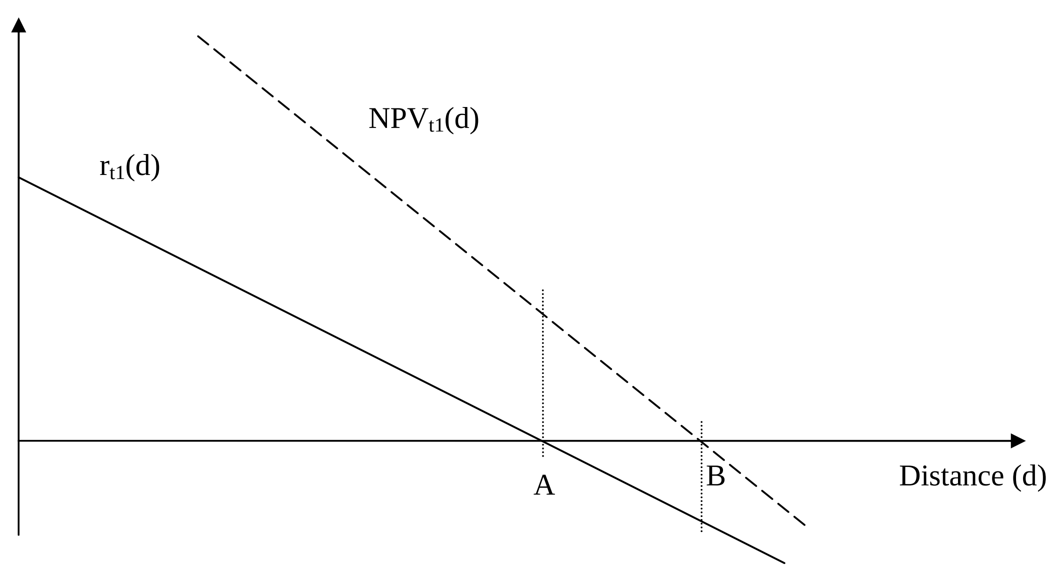

Figure 5. Land race (B) compared with pre-established property rights (A).

[27] As before, we assume that land rent is declining with distance from the center. For simplicity we ignore clearing costs.

2. Land speculation

While some may call land races a form of speculation, *land speculation* is actually a different phenomenon. It refers to a situation where land is cleared (and property rights established) to capture expected profits through later sales, and land prices are not solely a function of the land rent but also contain a speculative element.

The simple capital asset pricing theory suggests that land prices reflect the discounted value of future land rents. In booming frontier areas with active land markets, land prices may reflect the expectations about being able to sell the land at even higher land prices later. This form of "rational bubbles" is similar to what can be observed in other asset market, e.g., stock and real estate markets.

A study based on US data for the period 1910-1990 by Clark et al. (1993) suggests that land prices rose faster than land rents when both are rising. In other words, during boom periods the land prices seem to increase more than the land rent increase would dictate. Expectations created about future land price increases make farmers willing to pay a higher price. Thus the expectations become self-fulfilling, but the bubble – even if rational – will eventually bust when farmers start doubting that this can continue.

We are not aware of any quantitative studies of the importance of this phenomenon for tropical deforestation, although anecdotal evidences from booming frontiers may point in this direction. But they will typically work in tandem with other forces to expand the agricultural frontier, and the relative importance remains unknown.

3. Games and strategic squeezing

When property rights are established by converting forest to agriculture, there is a third effect termed "strategic squeezing" that can lead to deforestation beyond the outcome of the basic von Thünen model of section 2.1. The key elements of this effect are described below. A more elaborate discussion is given in Alston et al. (1999), Alston et al. (2000) and Angelsen (2001), and the following discussion is a simplified version of the game model of the latter.

Consider two competing land users: a local community and the state. Both agents derive benefits from both converting forest (to agricultural land) and – unlike what we assumed above – from maintaining forest cover. The latter could be in the form of environmental services and various forest products. Thus deforestation by one agent is costly as it reduces forest benefits to the other. Additionally, deforestation by the other agent is costly as it reduces own opportunity for forest conversion in the future.

The two players will take the others' response into account when they decide on how much land to clear, i.e., they think strategically. The normal response for both players would be to clear less land when the other increases its forest clearing for at least two reasons: the marginal costs of forest conversion has gone up (less suitable forest land for agricultural conversion), and the marginal value of the remaining forest is higher (higher forest scarcity).

In this context there are incentives for both players to try and squeeze the other: increasing own deforestation has an additional benefit beyond the agricultural rent obtained; it squeezes (reduces) the other players' forest clearing, which is costly to them.

We can formalize these arguments as follows:[28] The players get two types of benefits: agricultural income from forest conversion, and forest products and forest environmental services (e_i). The latter is a function of the forest area, i.e., they decline with the amount of forest converted by the two

[28] For simplicity, we only include the argument about benefits from standing forest in the model, and not the effect of increasing costs of conversion.

players (a_i). Thus $e_i = e_i(a_1+a_2); e_i' < 0; i = 1, 2$. Each land user will therefore convert land until the point where the agricultural rent equals the marginal loss of forest benefits:

$$(10) \qquad r_i(d) + e_i'\left(a_1 + a_2\right) = 0; \quad i = 1, 2$$

This would also be the solution in a game where the players make their moves simultaneously (a Cournot game).

Next, we define the response function, i.e., the optimal amount of forest cleared for one land user as a function of the amount cleared by the other, based on the above equation (first order condition): $a_i = s_i(a_j); s_i'<0; i,j = 1, 2; i \neq j$.

Assume now that player 1 moves first (referred to as a Stackelberg game in the game literature). The optimal forest clearing for the land user, taking into account the impact his decision will have on player 2, would be:

$$(11) \qquad r_1(d) + e_1' + s_2' e_1' = r_1(d) + e_1'(1 + s_2') = 0$$

Player 1 will now clear more forest. The element ($s_2' e_1'$) gives the additional benefit of his forest conversion: it squeezes player 2's forest clearing by an amount s_2', and the marginal benefit of this squeeze is e_1'. Angelsen (2001) suggests that such squeezing effects tend to be stronger the more scarce forest has become, but land still being allocated on a first-come-first-served basis.

Summing up

When land rights are being established by forest clearing, forest is converted beyond the point to which it would be converted in the basic von Thünen model. This clearing is also socially sub-optimal. Better tenure security will in this case boost deforestation. In a study of property rights and deforestation in Nicaragua, Liscow (2005) concludes that: "This study offers strong evidence that, contrary to many theoretical predictions, tenancy insecurity protects forests. … This result reveals the costs of creating better markets for land titling without creating any markets for the positive externalities provided by forests."

We investigated three reasons beyond the standard environmental argument of negative externalities why a substantial share of tropical deforestation may be excessive: land race, land speculation, and strategic squeezing. In the first two cases some forest with a negative agricultural rent will be cleared. As for the third case, although some costs due to forest loss (e.g., environmental benefits) are included, this solution is not socially optimal: the cost imposed on the others is ignored, thus there is a negative externality not factored into the decision making.

In empirical work it may be difficult to distinguish clearly between these, but based on earlier reviews of deforestation studies (e.g., Kaimowitz and Angelsen, 1998) one may suggest that the "land race" phenomenon is the most common strategic argument. Rudel (1993) gives a good illustration of this in his study from Ecuador. Forest land was converted to pasture so quickly to secure rights that farmers could not stock them with cattle. Some of these lands therefore reverted to secondary forest.

2.5 Community forest management

2.5.1 Introduction

Community forest management (CFM) or just community forestry refers to an institutional arrangement where a set of rights and obligations concerning forest use and management rests with the local communities.[29] It is useful to distinguish between CFM that has originated locally and

[29] A number of different labels exist are used for similar or closely related arrangements: joint forest management, forest-co-management, local forest management, community-based forest management, village

existed for some time (*traditional CFM*), and CFM which is introduced as part of devolution or decentralization process whereby rights and obligations are transferred from the state to local communities (*introduced CFM*).[30] They are, nevertheless, also linked as it is acknowledged that successful CFM requires both to build on existing institutions as well as transferring and formally recognizing community rights and obligations through decentralization reforms.

In recent policy debates the introduced CFM has received much attention as a potential means to achieve the twin objectives of forest conservation and higher local (forest) income. There are two major reasons why CFM may lead to forest conservation. First, communities may be more efficient managers of forests than the state. They have better knowledge and information about the local forest and its users, making policing easier. Communities may also apply a different set of sanctions, including social ones. In the literature on common property resource management it is widely recognized that local systems of natural resource management (NRM) are embedded in larger social systems (e.g., Ensminger, 1996). This is analyzed theoretically by Aoki (2001), who introduces the concept of *interlinked games*. The NRM game in itself is a prisoner's dilemma game, which leads to a non-cooperative solution. But non-cooperative behavior is being punished in a parallel social game. This changes the incentives in the NRM game and can lead to cooperative outcomes, i.e., successful CFM.

Second, many services provided by standing forests are local public goods. These provide an incentive for the community to conserve more forest than, for example, a system of private property (or *de facto* open access) would do. Thus CFM is a way to *internalize the externalities*, that is, to ensure that the negative externalities of forest conversion or forest overexploitation are factored into the forest decision making.[31]

Similarly, CFM is assumed to increase local forest incomes for three reasons. First, the communities or their members should get a larger share of their forest cake, although this has not always been the case. Second, improved management should increase the overall forest benefits, at least in the long term. Third, CFM can provide direct incentives to the individual households to get involved in tree establishments or (sustainable) use of forest products.[32]

2.5.2 CFM and land rents

Introducing community forest management (CFM) into our von Thünen framework is illustrated in Figure 6. We consider two types of benefits from standing forests: (1) *Local* (community level) benefits in the form of local public goods (environmental services such as watershed protection) and local common pool resources (forest products such as logs, fuelwood, poles, and various non-timber

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forestry, social forestry, forest user groups, etc. The term CFM is used to cover a broad range of arrangements, depending on the set of rights and obligations that the community have, and their management responsibilities. This management of the forest typically involve two sets of tasks: First, the establishment and/or modifications of *rules* with respect to *access*, permissible uses, sharing of joint production, and maintaining or enhancing the productive capacity of the forest. Second, implementing and enforcing the rules through policing, punishment, and organizing joint work. CFM may also involve in a number of other activities, e.g., working together on harvesting, processing and marketing of forest products.

[30] See Sunderlin et al. (2006) for a further discussion of this distinction.

[31] The key principle behind this is that the decision making should be at the same level as the benefits occur. Thus for community level public goods, the decision should be at the community level to get the internalization of externalities. For benefits that are mainly private, e.g., tree planting, a system for providing private incentives should be in place.

[32] Such privatization of forest benefits may appear contradictory to the spirit of CFM, but is often a key element to ensure the success of the CFM programs.

forest products).[33] (2) *Global* (and national) environmental benefits such as carbon storage, biodiversity conservation, and amenity. We only look at the decision whether to convert forest to agriculture or not, and not the intensity of forest product use, although the arguments would be similar.

Consider first the case of *de facto* open access. Forest would – as in the basic von Thünen model – be converted up to point d^O, i.e., where the agricultural rent is zero. There are no mechanisms for including the local or global negative externalities in the deforestation decision.

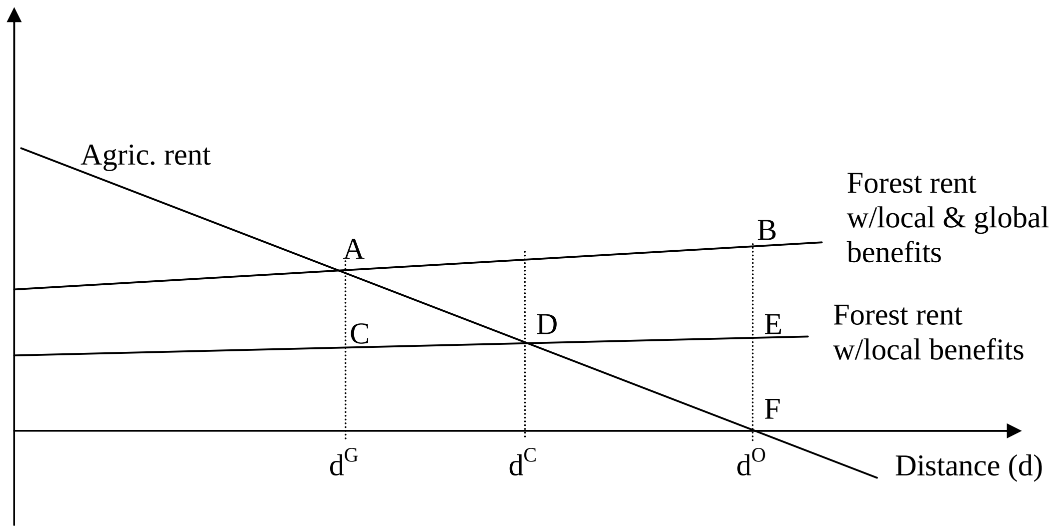

Figure 6. Land rent curves with community forestry.

Then community forestry is introduced. We discuss three stylized cases. The first one is the theoretically trivial but empirically relevant case (see below) when CFM is not working, and we remain in the d^O solution of Figure 6.

In the second case, the community has the full management responsibility to the forest, and is free to decide on how much to conserve and how much to convert to agriculture. The optimal level of forest conversion is then given by d^C, where the agricultural land rent equals the local forest benefits (local forest rent). We assume that effective mechanisms exist for decision making (establishing d^C) and implementation of that level.

CFM is in this case a way to move the land use decision from the individual farmers to the community level, and thereby internalize the local externalities. The overall net community benefit from this internalization of externalities is given by the triangle DEF (the difference between the gain in local forest benefits and the loss of agricultural rent between d^C and d^O).

Although the community will gain from CFM in this case, there are several caveats. First, there are likely to be both *losers* and *winners* within the community. The poorest with few alternative income sources may lose, as they benefited the most from the previous situation with free access and unrestricted use (Jodha, 1992). Second, there is a loss in agricultural income, thus only considering forest income gives a too narrow perspective and *overestimate* the net benefits of CFM. Third, some

[33] Both *public goods* and *common pool resources* are characterized by very high costs of exclusion. But, public goods are non-rivalry in use (consumption), while common pool resources are characterized by rivalry in use. See, for example, McKean (2000).

of the forest benefits are intangible and not easily captured by a standard household income survey. This leads to an *underestimation* of the local gains of CFM.

As a third case, the community is used by the state to implement a certain solution, e.g., to manage a given community forest area under the condition that it should remain forest. For simplicity we assume that this area is set optimally taking both the agricultural and the full forest rents into account, i.e., in the global solution (d^G). The community may capture a share of the global forest benefits, e.g., through a system for Payment of Environmental Services (PES) for carbon storage in standing forests. In the extreme (and unlikely) case when they capture 100% of the global benefits, the community's net benefits from CFM is given by the triangle ABF.

Consider then the other extreme (or maybe not?) alternative where the local community capture nothing of the global (and national) benefits generated from CFM. The net loss, compared with the situation in our second case (d^C) is given by ACD. Compared with the initial situation without CFM (d^O), the net gain or loss is the difference between the gain DEF and the loss ACD. In other words, the community gain from some forest conservation by addressing the problem of internalizing local externalities. But, conservation goes beyond that point and addresses national and global environmental concerns as well without any compensation to the community. Thus they risk losing from CFM.

2.5.3 Does CFM deliver?

The last couple of decades have witnessed a worldwide move towards decentralization/devolution of forest management, including CFM. Has this change delivered in terms of better forest management and conservation, and in providing more forest benefits to local communities, in particular the poor? What are the success factors?

The large literature on common property resource management has tried to identify under which conditions groups will successfully manage a resource held in common. Agrawal (2001) summarize this literature and list more than 30 such factors, related to the resource system and the group characteristics, the institutional arrangement and the external environments. Yet, as he notes, the literature suffers from two types of problems. First, the studies focus overly on the institutions governing the resources themselves, and neglect, for example, the external institutional and economic environment. Even in Agrawal's article the role of relative prices and markets are treated in a rather cursory way under the label "articulation with external markets". Second, the links and causal chains between the large number of variables are largely unspecified, making Agrawal to conclude that "existing work has yet to develop fully a theory of what makes for sustainable common-pool resource management" (page 1651).

Another shortcoming with many of the CFM writings is their strong normative flavour, attempting to demonstrate that this solution is superior to both individual (private property) and centralized control (Agrawal and Ostrom, 2001). In a meta-study of 69 cases of CFM by Pagdee et al. (2006), 58% (40) were considered successful based on an ecological sustainability criteria (the most typical measure was "improved forest condition"). The income, livelihoods and distributional criteria were more diverse and therefore more difficult to compare.[34]

The general picture emerging from the assessments is, nevertheless, twofold: the overall success is mixed and less than what one hoped, and the success is *relatively* better on the forest conservation side than on the income improvement side. There are also noticeable regional differences. Jumbe (2006), in another review of a number of CFM case studies, finds that the African cases tend to score low on both the conservation and income criteria (lose-lose), the Latin American cases are a mix of win/lose combinations, while the Asia (mainly South Asia) cases generally have scored well on the conservation objective but more mixed on the income objective.

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[34] See also the special issue on CFM of *Forest Policy and Economics*, 8 (4), June 2006.

What can explain this relative lack of success, particularly on the income (poverty reduction) objective? The expectations may in the first place have been too high concerning the ability and incentives of forest communities to solve the basic collective action problems. This optimism may also have included the magnitude of the forest benefits and the capacity of local communities to exploit them. Further, the drive towards decentralization and CFM by the national governments have been driven more by a forest conservation than a poverty agenda. In particular, permissible local uses of forest products are often restricted to meet domestic needs. Bringing forest products to the market is needed if it is to contribute to poverty *reduction*, not just poverty *mitigation*. Moreover, the rights to the valuable (timber) products have often remained with the state, or been part of skewed revenue sharing arrangements. Finally, with few mechanisms in place for payments of forest environmental services to communities, the income gains have been small or even negative.

To conclude, CFM can be a way to raise the forest rent curve, and thereby put a brake on deforestation. It has a number of attractive features from efficiency and distributional points of view. The mixed experience so far may to a large extent reflect that "most 'devolved' natural resources management (NRM) reflects rhetoric more than substance, and is characterised by some continuation of substantive central government control and management over natural resources rather than a genuine shift in authority to local people" (Shackleton et al., 2002: 1).

3 The forest transition

While the von Thünen framework uses *space* (distance) as its organizing principle, the *forest transition* (FT) framework uses *time*. Over time, however, roads and transport infrastructure improve and remote forest areas are being included into the regional or national economies. Economic growth and accompanying structural changes will also affect the agricultural and forest rent curves at any given location. The purpose of this section is to show how the forest transition can be generated in a von Thünen framework through a systematic pattern of change in the agricultural and forest rent curves over time. The first sub-section gives a brief introduction to the notion of a forest transition, including the key drivers and four main stages. Section 3.2 elaborates on the drivers, while section 3.3 discusses the stages and relates them to regional trends observed today. The discussion is also related to different poverty scenarios during the forest transition.

3.1 The basic notion of Forest Transition (FT)

The forest transition, a concept introduced by Mather (1992), is used to describe a sequence where forest cover first declines, and reaches a minimum before it slowly increases and eventually stabilizes. This is illustrated in Figure 7.

The FT suitably describes the pattern that has occurred in Europe and North America over the past two centuries. Signs of diminishing rates of deforestation and emerging reforestation can now also be observed in a number of tropical countries (Rudel et al., 2005), where the full transition may occur over much shorter periods (decades rather than centuries).

Returning to the complementarily between the von Thünen and the FT approaches, Figure 7 can be seen as the spatial view of an area at the national or sub-national scale. Standing at the origin of the figure is like standing in the undisturbed forest and looking towards the urban areas: the various FT stages will correspond to various von Thünen zones around the city.

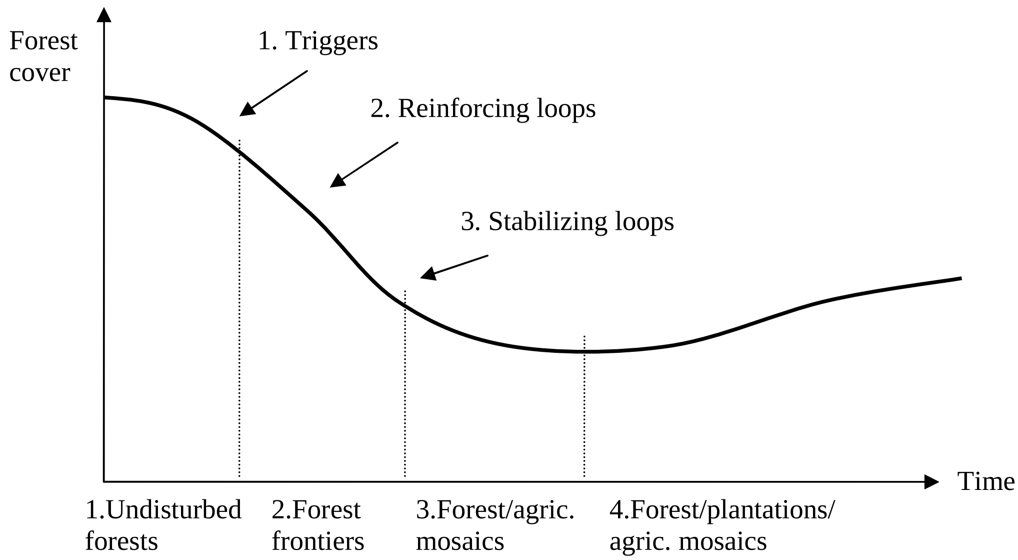

Figure 7. The stages and main drivers in the forest transition.

The forest transition theory makes two claims. First, where there is a lot of forest there will (eventually) be a lot of deforestation, while there will be limited deforestation in areas with little forest. Although this may sound trivial, it makes one pessimistic prediction: regions with high forest cover will eventually lose a large proportion of their forest (e.g., the outer islands of Indonesia, the Congo basin, and the North-western Amazon).

Second, the FT claims that forest cover eventually will be partly restored. Thus there are forces (discussed below) that put a lower threshold on the amount of forest cover and will initiate a period of reforestation, either through natural re-growth or plantations or both. The available evidence suggest that on average about half of the initial loss is gained during the recovery phase (Rudel, 1998).

The FT hypothesis predicts that there is a broad universal pattern in the forest cover change. There are, nevertheless, a few caveats that one should keep in mind:

(a) The FT hypothesis is sufficiently broad to include *local and regional differences*. Both the slopes (speed for deforestation and reforestation) and the turning point (minimum forest cover) will vary. Thus the lack of signs of slowdown in deforestation rates observed in some regions today does not necessarily disqualify the FT hypothesis; the minimum forest cover can just be very low.

(b) The FT can be seen as a synthesis of the historical experience, and, as such, incorporates fundamental demographic and economic forces. But, the role of *policies* in shaping the slope and turning points should not be underestimated. Rather, the analysis of the FT should help to understand the basic forces at work and thereby design appropriate policy measures according to the stage in the transition and the forces at work.

(c) FT analysis has been applied to different *scales*, from rather small forest areas of a few thousand square km, to districts/regions at the sub-national level, countries and even sub-continents (as in Rudel, 2005). While the following discussion may apply to different scales (and obviously depends on the size of the country), our main point of reference is districts/regions at the sub-national level.

(d) The term "forest cover" – the y-axis of the figure – includes very different types of forest, and the eventual increase in forest cover does not necessarily imply more natural forests. Rather, the natural forest cover may continue declining in stage 4, but the loss being more than compensated for by the increase in plantations.

(e) The notion of the FT is sometimes used interchangeably with the Environmental Kuznets Curve (EKC) for deforestation – the theory predicting a bell-shaped relationship between deforestation and income. Although some of the underlying ideas are related, they should not be equated. First, EKC uses income (GDP) per capita on the x-axis, while FT normally uses time. (These are of course related with positive economic growth, but the explanations used for FT tend to be broader.) Second, EKC implies accelerating deforestation at early stages, a stronger assumption than contained in FT, which simply suggests a period of deforestation. Third, EKC does not necessarily imply a period of reforestation as FT predicts.[35]

3.2 Driving forces in the FT

In Figure 7 four distinct phases are distinguished (discussed in more details in section 3.3), as well as three key sets of drivers. Borrowing concepts from systems analysis, the movement along the forest transition curve can be seen as the result of three sets of forces.

The first stage, of relatively *undisturbed forest*, is characterized by *passive protection:* the forest area has poor infrastructure and market access, and is therefore inaccessible for commercial exploitation. A set of *triggers* (force 1) starts the deforestation process, which accelerates through a set of *reinforcing loops* (force 2) leading into the second stage, the *forest frontier*. High levels of deforestation lead to forest scarcity, which – together with other socio-economic and political forces - initiate and/or strengthen a set of *stabilizing loops* (force 3), leading into the third stage of *forest/agricultural mosaics*. These stabilizing loops will eventually dominate, taking us into the fourth stage of reforestation termed the *forest/plantation/agricultural mosaics*.

These forces can be clearly related to shifts in the land rent curves. Using a von Thünen model with only agriculture and forest, the stages can be described as done in Figure 8. The first stage (undisturbed forest) is characterized by low agricultural rents and therefore limited conversion from forest to agriculture. Then both the triggers and the reinforcing loops increase agricultural land rent, leading to a period of high deforestation during the second stage (forest frontier). A weakening of theses forces and a set of destabilizing loops will take us into the third stage, where deforestation slows down and eventually is reversed. This can take the form of reduced agricultural land rent, increased forest rent, or both. In the following we elaborate on these three sets of forces.

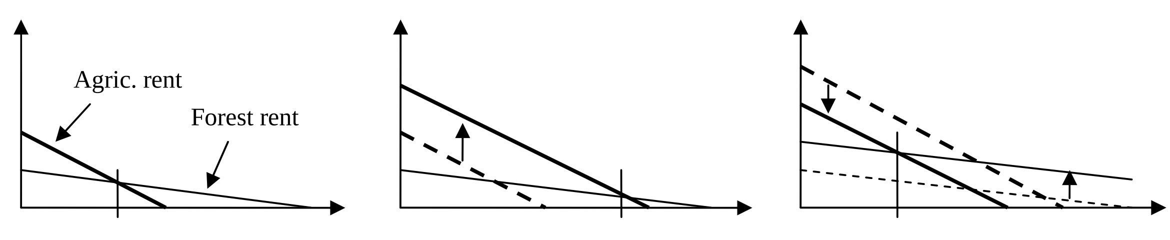

Figure 8. Changes in agricultural and forest rent curves during the forest transition.

3.2.1 Triggers

The triggers refer to the initial shift in the agricultural land rent. The single most important physical, on-site trigger of deforestation is the construction of new and better *roads.* Previously inaccessible areas open-up for both in-migration of people (and capital), and also creates a market outlet for

[35] See Mather et al. (1999) and Angelsen and Mikkonen (2005).

agricultural (and timber) products. In important cases such as Indonesia and Brazil, road construction has also been combined with orchestrated movement of people in the form of resettlement programs.

Road construction primarily takes place for two different reasons. First, road construction is necessary to get access to rents in forested areas. These rent seeking activities can be in form of logging, mining, hydropower, or growing particular export crops on deforested land. The rent seeking opportunities can be created by (i) *new market opportunities*, resulting in large price shifts of specific agricultural commodities or timber, or (ii) *technological change*, which can make the cultivation of new crops in forested areas more profitable. When these price or technological changes are combined with reduced transport costs, they provide a powerful force for forest clearing.

Second, road construction into previously inaccessible areas can be seen as the result of (geo)political considerations: "state-making" (get state control over the national territory), military control (in border conflicts or domestic ones), political stabilization, and cultural dominance. Elite interests and corruption also play a role, often in conjunction with rent *seeking* activities as well as "rent *creating* activities", cf. Ross (2001).

Natural population growth in forested areas is also a potential trigger, particularly when working in tandem with the above ones. Within the von Thünen framework, population growth can be seen as pushing down wages and increasing demand for agricultural products, both which will push up the agricultural rent curve.

3.2.2 Reinforcing loops

Reinforcing loops are generally defined as positive feedbacks which enlarge the initial effect. The triggers set in motion a process of deforestation which is driven in part by the continued effect of the triggers, and in part by a set of reinforcing loops initiated by the increase in agricultural rent and deforestation.

We discussed some reinforcing loops under the heading of increasing return to scale (IRS) in section 2.2.5. Most of them are related to *population and economic growth* in the area. They increase agricultural land rent by driving up agricultural prices, by making agricultural inputs cheaper and/or more available, or by reducing transport costs.

Agricultural prices (and rent) can be increased by at least two forces:

(a) Increased local demand: Population and economic growth increases the local demand for agricultural products. Demand for forest products will also increase, but we assume that – at least during the early phase of the second stage – forest products are still readily available, or at least the effect of higher scarcity and forest product prices does not outweigh that of higher agricultural prices.

(b) Development of downstream processing activities for agricultural products, e.g., slaughterhouses, dairies and mills. These activities are characterized by economics of scale. Thus, an initial boom in agricultural production may be further stimulated by the development of processing activities, creating a strong reinforcing loop.

The costs of and access to agricultural inputs may also boost agricultural rents in two different ways:

(a) Capital accumulation, in the sense of traditional capitalism at work. While outside capital may have played a relatively more important role in the early stages, profits generated and reinvested in forest degrading or removing activities play an increasingly important role.

(b) Population dynamics: In-migration will be stimulated by the new economic opportunities, and provides a steady supply of labor which dampens local wages. This is further strengthened by high natural population growth due to the fact that in-migrants are generally young (families).

Population and economic growth also stimulates the development of better infrastructure and transport facilities, further reducing transport costs and increasing agricultural rents.

Frontier areas often operate in an "institutional vacuum": customary land tenure systems are ineffective in regulating the increased pressure, while formal state-backed systems are not yet developed, cf. Bromley (1991). Forest land can then be claimed on a "first-come-first-served" basis, leading to land excessive deforestation as discussed at some length in section 2.4.2: land races, land speculation, and squeezing.

The Brazilian Amazon provides an important illustration of the first two stages in the forest transition. Deforestation in the 1970s and 1980s were largely driven by government policies, including road building and subsidies (initial triggers), while the deforestation process in the 1990s has gradually became autonomous (reinforcing loops), cf. Margulis (2004) and Rudel (2005).

3.2.3 Stabilizing loops

Eventually, some of the reinforcing loops may change character and turn into stabilizing loops, or new stabilization mechanisms may kick in. Related to the von Thünen model and Figure 8, this can take two forms: a downward shift in the agricultural rent curve, and/or an upward shift in the forest rent curve.[36] We discuss these in turn, as they relate to quite different mechanisms at work.

Downward pressure on the agricultural rent

A process of declining agricultural rent will in large part be the effect of forces not directly linked to the decline in forest cover. Rudel et al. (2005) refer to this as *the economic development path:* better off-farm wages and employment opportunities pulls labor out of agriculture, and reduces conversion of forest to agricultural land. This has historically characterized the transition in the currently rich countries, but examples are also found in developing countries today. High economic growth in Venezuela, for example, made possible by its oil wealth, stimulated urbanization and reduced agricultural competitiveness, resulting in low deforestation rates (Wunder, 2003).

General equilibrium effects in the output market (section 2.2.1) – increased agricultural supply dampening agricultural prices – may also put a downward pressure on agricultural rents and take the steam out of further expansion.

Land degradation through the exhaustion of soils can lead to the abandonment of agriculture. Abandoned land in current shifting cultivation will - given the right conditions - revert back to forest.

Finally, the forest transition may be linked to a *demographic transition*, which reduces the (increase in) the supply of labor and therefore tends to drive up wages. Although one should be careful in arguing that they are parallel transitions, the classical demographic transition - with stages of low-high-low population growth - corresponds well with the forest transition. But, the relative timing of these transitions is complicated by, among other things, migration and urbanization, with rural to urban migration triggering both transitions.

Increasing forest rent

Forest scarcity induces higher prices of forest products, which encourages both better forest management and the establishment of woodlots and plantations. Rudel et al. (2005) refer to this as *the forest scarcity path*, which forms the other main route towards a forest transition. The success story of Machakos in Kenya provides an example (Tiffen et al., 1994). While the forest scarcity

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[36] Strictly speaking, what is needed to get a slowdown and eventual reversal of forest cover loss is that the upward shift in the forest rent curve is larger than the any upward shift in the agricultural rent curve, i.e., the agricultural rent does not have to decline to generate this process.

path normally refers to wood and timber, it may also be applied to Non-Timber Forest Products (NTFP). This effect of forest scarcity generating higher forest rent is found in the world's most populous countries China and India, assisted by government policies and large-scale development aid programs in tree planting.

One of the most thorough studies of the rise of forest through the rise of forest rent is the study of India by Foster and Rosenzweig (2003). They argue strongly that the increase in forest cover observed in India over the past five decades are due to higher demand for forest products. The higher prices of forest products – fuelwood in particular – have provided a strong incentive for forest conservation and tree planting. Their analysis also rejects the Borlaug hypothesis – higher agricultural productivity has *not* increased local forest cover. Neither did higher wages lead to reforestation (the economic development path discussed above).

The forest recovery is not only due to scarcity of forest products. Loss of forest ecological functions (real or perceived) may result in policy changes to promote forest conservation. Institutional and policy changes may be initiated at national levels based on national and international pressure from environmental groups, or initiated at local levels based on visible effects on the local environment or from significant local dependence on forests. High local forest dependence provides, however, a dual incentive for local forest conservation efforts, as demonstrated by the contrasting experience of two forest co-management areas in Malawi (Jumbe and Angelsen, 2006).

In other contexts institutional reforms can be effective, including community forest management as discussed in section 2.5. Bray et al. (2004) argue that institutional reforms – both from above and below – in the Mayan zone in Mexico were sufficiently strong to avoid the phase of deforestation (stage 2) altogether.

The general pace of (economic) development may also create a number of changes which all contribute to forest conservation: (i) increased capacity for forest management and better enforcement of 'the rule of law', (ii) higher demand for environmental services, including raising public awareness of forest cover loss (emerging 'civil society'), (iii) more transparency and focus on, for example, illegal logging and 'forest mining'; (iv) firewood and charcoal are gradually being replaced by kerosene, gas and electricity as fuel sources. Mather (2001) argues that the latter played a significant role in the forest transition in Europe.

Policy changes can play an important role in stabilizing the forest cover. For example, geopolitics drove the creation of frontier colonization programs where distance made political controls problematic. With additional settlement and better infrastructure (and much of the forest gone), these places become closer to the center and less politically problematic, making the geopolitical rationales for expansion disappear.[37]

Finally, one should note that the type of forest recovery observed during stage 4 will be different depending on whether the economic development or the forest scarcity path is followed. In the former case relatively more land will revert to unmanaged forests through natural regrowth. Under the forest scarcity path a relatively large share is likely to be in the form of managed forests and plantations.

3.3 Stages in FT across the tropical world

Figure 7 distinguishes between four distinct phases in the forest transition. This section provides a further discussion of each of them, and relates them to regional patterns of forest cover change. It draws heavily on Rudel (2005), who gives a comprehensive overview of – as the subtitle of the books suggests – "regional paths of destruction and regeneration in the late twentieth century".

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[37] I am grateful to Tom Rudel for suggesting this link between the two approaches.

Stage 1: Undisturbed forest – low deforestation

The first stage of relatively undisturbed forest is characterized by passive protection*:* poor infrastructure and market access makes the forests inaccessible for commercial exploitation. The accompanying low population densities often found limited the local pressure on forest conversion. This describes reasonably well the core of the three main tropical forest areas of the world: the Congo basin of Central Africa, the Northwest Amazon basin, and the interior of the two largest islands of Southeast Asia: Borneo and New Guinea.

The case of Central Africa is in part a story about passive protection. Inaccessibility, poor soils and low population densities have played an important role in the low rates of deforestation. In addition, oil booms and Dutch disease effects in some of the countries pushed up wages, created jobs in urban areas, and stimulated rural-urban migration. Logging from the Western reaches of the region occurred during the 1990s, but the accompanying road building did not lead to an influx of farmers and agricultural conversion as often observed elsewhere (Rudel, 2005).

Stage 2: Forest frontiers – high deforestation

A common feature in the stories about high deforestation rates is a growing urban demand for agricultural products (and food in particular), due to both rapid urbanization and higher urban incomes. In many cases this has been complemented by booming agricultural exports. Central America has a long history of export of banana, coffee and sugar, which are keys to explain the historically high deforestation rates. West Africa also has a long history of export of particularly cocoa. The economic crisis from the 1980s did, however, eliminate much of the government support to export crops. Many farmers switched to cultivation of food crops for urban markets, often by clearing new forests areas rather than using old cocoa fields (Sunderlin et al., 2000).

The agricultural expansion is in some cases driven by smallholders, who respond spontaneously to favourable market conditions. Examples include cocoa producers in West Africa and Indonesia (Ruf, 2001), and rubber producers in Southeast Asia. A key trend is, nevertheless, that "corporate enterprises had become more salient in deforestation processes on all three continents" (Rudel, 2005: 158). Examples include the recent booms in beef exports from Brazil (Kaimowitz et al., 2004), soybean production in Brazil and Bolivia (Kaimowitz and Smith, 2001), and oil palm production in Malaysia and Indonesia (Casson, 2000).

If high agricultural demand is combined with low wages and few off-farm employment opportunities, it provides an even more fertile environment for high deforestation, as is the case for large parts of West Africa. In fact, low wages and few economic opportunities combined with high rural population densities can be sufficient to generate rapid deforestation and resource depletion. Rudel (2005: 117) argues that this characterizes the remote parts of Eastern and Southern Africa. Remote rural areas in countries such as Ethiopia and Malawi are therefore caught in "resource degrading poverty traps".

The change in poverty levels during the period of high deforestation depends, *inter alia*, on the forces behind the forest cover loss. In a scenario of declining poverty rates (*prospering deforestation*), the forest capital is used to accumulate other assets and serve as a stepping stone out of poverty. A typical pattern under this scenario will be conversion of forests for cultivation of cash crops for urban or international markets, cf. the examples given above.

A scenario of stable or even increasing poverty rates (*immiserizing deforestation*) can happen in at least two cases. In the first case, deforestation is driven primarily by *outsiders* (in-migrants, companies), with limited benefits to the local residents. The removal of forest cover and forest degradation deprives forest dwellers of their livelihoods, and the residents are the losers with few benefits and many costs of deforestation. This scenario may appropriately describe the situation of many indigenous communities of Southeast Asia where logging, plantations and colonization programs have been the main agents of deforestation, often in conflict with local populations.

In the second case of immiserizing deforestation, forest loss is driven by the *villagers* in the form of subsistence agriculture and fuelwood extraction, and poverty and high population growth as immediate causes. Short-term needs of survival dominate, and deforestation may not necessarily contribute to any improvement in human well-being. Although one may argue that the situation would have been worse without deforestation, at least in the short term, in the medium-long term this represents a vicious circle of poverty and environmental degradation, as just discussed being the situation of many remote areas of Eastern and Southern Africa.

Stage 3-4: Forest recovery – low deforestation and reforestation

The turnaround in forest cover change is, as already noted, due to two different causes: a *forest scarcity path* (higher forest rents) and an *economic development path* (higher wages and lower agricultural rent) (Rudel et al., 2005).

South Asia provides possibly the best example of the *forest scarcity path*. Several forces have been at work. First, forest scarcity has cut the supply of key forest products such as fuelwood. Combined with increasing demand from growing urban (and rural) populations, this has resulted in an upward pressure on prices of forest products. Second, institutional changes in the form on community forest management (Nepal) and joint forest management (India) have created local incentives for forest conservation. Governments, in particular of India and China, have also engaged in large scale tree planting programs. Plantations now account for about half of the forest cover in India and Bangladesh (FAO, 2001).

The combination of forest scarcity and favourable government policies is also at the core of the forest transition story of several central locations of East Africa. High urban demand for forest products, combined with relatively secure land tenure, provide incentives for reforestation. Farm forests are now on the rise in many central districts of East Africa.

The *economic development path* can be seen in parts of Central America and Caribbean. Large scale migration to the cities, or even across the borders to the United States, has initiated a forest recovery in Western Honduras, El Salvador, Puerto Rico, and Southern and Central Mexico. The demand for beef from Central America also declined after 1990, following import restrictions and decrease in consumer demand for beef in the United States. This led to some forest recovery in, for example, Northern Costa Rica, while landowners in Southern Nicaragua, who had few economic opportunities, continued to convert forests to pasture even if beef prices declined (Rudel, 2005: 45-46). Policy changes have also played an important part in the forest recovery. In El Salvador, policy reforms, such as removal of agricultural subsidies and trade liberalization, made traditional agricultural crops less profitable. Combined with a surge in international migration and a boom in remittances (now accounting for 2/3 of the foreign exchange earnings) as well as environmental conservation policies, this has led to a remarkable forest resurgence (Hecht et al., 2006).

The remote upland areas in Southeast Asia are experiencing a similar reversal of past deforestation trends. This is largely driven by the higher wage rates and off-farm opportunities generated by the high economic growth over the past decades in most countries of the region. The large-scale colonization programs, in particular the *transmigrasi* program in Indonesia, have also been on the decline since the late 1980s.

A third possibility for the slowdown and reversal of forest loss could be the environmental concern, either in the form of direct regulation (protection forest) or as payment for environmental services (PES) from forests. Central American and the Caribbean offer examples of such forces at work (Rudel, 2005: 41-47). Ecotourism in the West Indies led to the creation of parks, and labor-intensive tourist enterprises pushed up wages. Elsewhere in the region, some farmers have sought environmental certification of, for example, tree-shaded organic coffee. These efforts are, together with other schemes of PES (carbon, water, and biodiversity) still in their infancy and at too small scale to have any significant impact on regional patterns. With averted deforestation now being brought into the climate change (Kyoto) negotiations, this might change in the future.

4 Concluding remarks

The basic premise of this paper – and of the land use modelling in the von Thünen tradition – is that land use changes are determined by changes in land rents. The central question to ask in order to assess how policies affect deforestation (and reforestation) is: *how do policy changes affect the land rent of agricultural uses in comparison to forest uses at the extensive margin (the agriculture-forest interface)?* In other words, the key of any analysis of policy impact is how the basic incentives of the land users are affected.

The paper shows that while the direct effects are straightforward, they often generate feedbacks and interactions among rent curves that enlarge, modify and in some cases even reverse the initial effects. It has addressed some of the complexities involved in assessing how policy and other social changes will affect land rents and incentives, sorted out some of the key mechanisms, and put them into a von Thünen framework. This should give a more unified framework for policy analysis.

The forest transition theory suggests that there are strong forces which make forested areas lose a substantial part of their forest cover, and also – eventually – reverse this process. The period of high deforestation (forest frontier stage) is driven by an initial increase in the agricultural land rent, typically by new roads that increase demand and prices for agricultural commodities and open up for inflow of labor and capital. Self-reinforcing mechanisms further stimulate and maintain high rates of deforestation. The stabilization of forest cover is in most cases brought about by two forces: economic development, which increases the opportunity costs of labor (reduced agricultural rent), and higher demand and prices for forest products (increased forest rent).

A major problem with attempts at reducing the agricultural rent during the forest frontier stage is that they also tend to have adverse effects on rural income, e.g., reducing market access, and constraining access to capital. The mechanisms that during the next stage help to stabilize the forest cover are, on the other hand, more compatible with the aim of poverty reduction. Higher rural wages and higher prices for forest products tend to produce win-win outcomes. Thus a more acceptable strategy is to speed up the forest transition by stimulating these stabilizing forces.

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