Policies for reduced deforestation and their impact on agricultural production

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Edited by Ruth S. DeFries, Columbia University, New York, NY, and approved June 18, 2010 (received for review October 22, 2009)

Policies to effectively reduce deforestation are discussed within a land rent (von Thünen) framework. The first set of policies attempts to reduce the rent of extensive agriculture, either by neglecting extension, marketing, and infrastructure, generating alternative income opportunities, stimulating intensive agricultural production or by reforming land tenure. The second set aims to increase either extractive or protective forest rent and—more importantly—create institutions (community forest management) or markets (payment for environmental services) that enable land users to capture a larger share of the protective forest rent. The third set aims to limit forest conversion directly by establishing protected areas. Many of these policy options present local win–lose scenarios between forest conservation and agricultural production. Local yield increases tend to stimulate agricultural encroachment, contrary to the logic of the global food equation that suggests yield increases take pressure off forests. At national and global scales, however, policy makers are presented with a more pleasant scenario. Agricultural production in developing countries has increased by 3.3–3.4% annually over the last 2 decades, whereas gross deforestation has increased agricultural area by only 0.3%, suggesting a minor role of forest conversion in overall agricultural production. A spatial delinking of remaining forests and intensive production areas should also help reconcile conservation and production goals in the future.

climate | Reducing Emissions from Deforestation and Forest Degradation | tropical forests | protected areas | yield

Most tropical deforestation results from trees being chopped down to generate space for crops and cattle (1). Reducing deforestation therefore means slowing down the expansion of agricultural land into forests. At the same time, the world needs to increase its agricultural output to feed the 923 million people who go to sleep hungry every evening (2), keep pace with a still growing population, and meet increased food demand arising from higher incomes and concomitant changes in eating habits. Are we then facing an unpleasant choice between "conserving the forests" and "feeding the hungry"?

This article approaches this question from two different angles. First, we take a land rent (von Thünen) approach and ask what policies are effective to halt deforestation and how these will affect agricultural yield and thereby total output. Second, we use a modified global food equation and ask if yield-enhancing policies will reduce deforestation or make forest conversion more attractive.

Causes of deforestation at different levels can be distinguished (3). First, the deforestation *agents* (individuals, households, or companies) and their characteristics and activities must be identified. Second, agents' choices are influenced by external factors (decision parameters) such as prices, market outlets, technologies, and agroecological conditions—the *immediate causes.* Third, these parameters are in turn affected by broader national and international macrolevel and policy instruments—the *underlying causes*. A different set of explanations concerns why particular policies are pursued, i.e., the political economy of deforestation. This article focuses on the policies rather than the politics, but poor governance and corruption will make even the best-intended policies ineffective.

The microeconomics of land use, dealing with the first two levels, takes as its starting point that land is allocated to the use with the highest land rent (surplus). A key determinant of land rents is location and distance to markets, which is the original von Thünen approach (4). We consider a simple model where land has two uses: agriculture and forest (5). The real world presents a continuum of land uses between agriculture and forest, e.g., agroforestry and silvopastoral systems, and including those in more disaggregated, empirical studies is important to capture their different provision of environmental services. Our dual model is therefore an analytical simplification, but sufficient to capture key policy issues.

Agricultural Rent

Agricultural rent can be defined as: $r^a = p^a y^a - wl^a - qk^a - v^a d$. Agricultural production per hectare (yield) is given (y^a). The produce is sold in a central market at a given price (p^a). The labor (l^a) and capital (k^a) required per hectare are fixed, with input prices being the wage (w) and annual costs of capital (q). The fixed wage assumption implies that labor can move freely in and out of agriculture. Transport costs are the product of costs per kilometer (v^a) and distance from the center (d). The rent declines with distance, and the agricultural frontier is where agricultural expansion is not profitable anymore: $r^a = 0$. Thus the frontier is defined at $d = (p^a y^a - wl^a - qk^a)/v^a$.

This model, illustrated in Fig. 1, yields several key insights into *the immediate causes* of deforestation. Temporarily ignoring the forest rent, deforestation will take place up to the distance A. Higher output prices and technologies that increase yield or reduce cost make expansion more attractive; i.e., they move the agricultural rent curve to the right. Lower costs of capital in the form of better access to credit and lower interest rates pull in the same direction. Higher wages, reflecting the costs of hiring labor or the best alternative use of family labor, work in the opposite direction. Reduced access cost (v^a), for example, new or better roads, also provides a stimulus for deforestation.

This simple framework served as the basis for a number of empirical investigations. A survey of >140 economic models of deforestation finds a broad consensus on three immediate causes of deforestation: higher agricultural prices, more and better roads, and low wages and shortage of off-farm employment opportunities (3, 6).

The basic model can be extended in several directions, for example, to allow farmers to be capital and/or labor constrained, to allow some markets to be missing or imperfect, to include uncertain tenure, to permit market feedback, to include the temporal dimension, and to account for multiple production systems and their interactions (7, 8).

Forest Rent

Forest rent is more complex, reflecting the different nature of products and services generated by standing forests. We distinguish between three main types: first, private forest products, such as timber and a large number of nontimber forest products (NTFP); second, local public goods, such as water catchment and pollination services; and third, global public goods, such as carbon sequestration and storage and biodiversity maintenance. We

Author contributions: A.A. designed research, performed research, analyzed data, and wrote the paper.

The author declares no conflict of interest.

This article is a PNAS Direct Submission.

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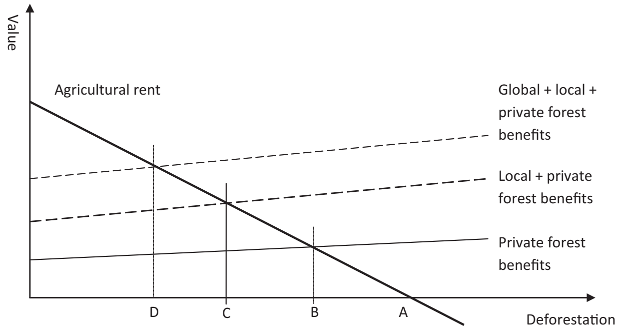

Fig. 1. Agricultural and forest rents and forest rent capture.

refer to the first type as *extractive* forest rent and the latter two as *protective* forest rent. Total forest rent is given by $r^f = (p^t y^t - wl^t - qk^t - v^t d) + p^l y^l + p^g y^g$.

The extractive rent increases due to higher timber and NTFP prices (p^t); technological progress (y^t, l^t, k^t); and lower labor (w), capital (q), and transport (v^t) costs. Higher values of local (p^l) and global (p^g) forest public goods increase the overall forest rent further and should lead to less forest being put under agricultural use. However, such an outcome depends critically on that rent being captured by the actual land users, as returned to below.

Agricultural Policies

Reducing Overall Agricultural Rent. Understanding variation in agricultural rent is key to understanding differences in forest cover and deforestation rates across the tropics. Keeping agricultural rents low can be very effective in saving forests. Wunder (9) refers to this as "the 'improved Gabonese recipe' for forest conservation," where central ingredients are heavy taxation of export agriculture, neglect of rural roads, and limited support to smallholders. The oil rent that Gabon enjoyed was concentrated in urban areas, resulting in massive urbanization and forests being left alone to grow.

Such policies run counter to mainstream policy recommendation for agricultural and rural development (10) and are in conflict with objectives of reducing poverty and boosting agricultural production (11). As a general conservation policy recommendation a discrimination against agriculture is politically unacceptable, although policies for decades have had a strong antirural and antiagriculture bias in many poor countries (12).

Economic Development. Agricultural rent can be lowered by raising the opportunity cost of labor. A country's forest cover over time might follow a pattern known as the forest transition (FT) (13, 14). FT describes a sequence where forest cover first declines and reaches a minimum before it slowly increases and eventually stabilizes. A major FT driver is higher off-farm wages and better employment opportunities that pull labor out of agriculture and forested areas (out-migration), referred to as "the economic development path" (15).

Economic development is, however, not a policy instrument but the aggregate outcome resulting from, *inter alia*, a constellation of policies. Targeted policies can be used to stimulate nonfarm employment in rural areas, but they do not guarantee forest conservation outcomes. Higher nonagricultural incomes might be deployed to invest in foresting-depleting activities such as cattle ranching (16). A win–win outcome seems more likely in labor-intensive agricultural systems than in capital-intensive ones (17). In the latter, any stimulus to the local economy will help relax capital constraints that currently slow down an otherwise profitable forest conversion.

Targeting Intensive Agriculture. An important extension of the simple von Thünen model is to distinguish between intensive (lowland) and extensive (upland or frontier) agriculture, where "intensive" is understood to mean intensive in productive inputs other than land. Spatially targeted policies to stimulate intensive agriculture can be an effective forest conservation policy. Improved small-scale irrigation systems in the lowlands of the Philippines pushed up labor demand and wages and pulled labor out of a more extensive agricultural sector in the uplands, reducing forest clearing by almost 50% (18, 19). Additionally, an output market effect might pull in the same direction: Increased supply from the intensive sector exerts downward pressure on domestic agricultural prices, further reducing the rent of extensive agriculture (20). Policies aimed at such targeted agricultural intensification have been dubbed reduced emissions agricultural policy (REAP) by Rudel (21) and can include credit programs, subsidized fertilizers and seeds, assistance in marketing, and agricultural extension programs.

Although a favorable forest outcome might be the most likely scenario, it is not guaranteed. If the dominant crop in intensive agriculture is traded internationally, a supply increase will have small effects on the price (for the benefit of farmers in that sector). If policies promote labor-saving technological change, the labor pull effect may be weak or even reversed (17). In addition, the higher profit in intensive agriculture can be used to clear new land for extensive crops and cattle production. These conditions were met in Sulawesi, Indonesia in the 1990s: Mechanization of lowland rice cultivation freed up labor, and profits were used to expand cocoa cultivation in the forested uplands (22).

Ignoring Frontier Agriculture? The above policies can be accused of ignoring agriculture in remote forested areas, where poverty rates typically are higher (23). Is it possible to raise productivity, increase output prices by better market access, and provide input support to extensive agriculture without increasing the pressure on natural forests? A summary of more than a dozen studies on the impact of technological changes on tropical deforestation (17) concluded that "trade-offs and win–lose between forest conservation and technological progress in agriculture in areas near forests appear to be the rule rather than the exception" (page 9).

Nevertheless, potential win–win opportunities exist for certain technologies and market conditions. As most farmers face labor and/or capital constraints, new labor/capital-*intensive* technologies may slow rates of deforestation, even if they simultaneously increase profitability. However, precisely because farmers are labor/capital constrained, we can—as a rule—expect them to prefer labor/capital *saving* technologies. Thus, with some important exceptions, we are *not* likely to get the type of technological change that would save the forests (17). For example, pasture intensification is technically possible throughout Latin America, but is not typically adopted before forests have been depleted (24). This finding confirms Boserup's hypothesis, namely that farmers will exploit the extensive margin before the intensive one (25).

A more probable win–win route to assist remote farmers would be in situations where they are involved in both intensive and extensive production systems, the extensive system being the principal source of deforestation. In Zambia, high-yielding maize varieties introduced in the 1970s discouraged extensive shifting cultivation and slowed down deforestation (26).

Roads. Establishing new or improving existing roads opens up new areas, reduces transport costs, provides market access, and thereby makes deforesting activities more profitable. Roads are among the most powerful factors contributing to deforestation across the tropics (27). In the Brazilian Amazon, 95% of all deforestation occurs within 50 km from highways or roads (28). This fact led Eneas Salati, a respected Brazilian scientist, to conclude that "the best thing you could do for the Amazon is to bomb all the roads" (29).

Although roads are critical, some caveats are in order. First, some early studies establishing a negative correlation between distance to roads and rate of deforestation tended to overstate causality. Some roads are built precisely because an area has been cleared and settled, rather than vice versa. Second, roads are particularly important at the early stages in the FT to open up new areas for human activity (30). At later stages, roads can assist in agricultural intensification and economic development that lessen the pressure on forests and provide incentives and increase the capacity for better forest management. Third, the role of state-run road building (together with other large-scale projects such as colonization programs) has weakened since the 1980s (31). Yet, no forest conservation policy can be considered comprehensive unless it provides clear guidelines on investments in transportation infrastructure.

Property Rights. The analysis of the deforestation impacts of property rights must distinguish between exogenous and endogenous tenure insecurity (5). If exogenous, the relevant question is, What is the impact of tenure insecurity on deforestation? If endogenous, the relevant question is, How do land users' actions to increase tenure security affect deforestation?

The impact of exogenous tenure insecurity in an extended von Thünen model is straightforward, but opposite of what is commonly assumed: Land reforms that give higher tenure security increase the net present value of land clearing and therefore spur deforestation (7, 32). This effect can be modified by the "land degradation–deforestation hypothesis" (17): Insecure tenure might 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. The net impact of higher tenure security is therefore context specific.

Tenure is also endogenous, and land users take actions to increase tenure security (33). Forest conversion often, according to both customary and statutory law, establishes or strengthens existing land rights. Deforestation therefore becomes a strategy for establishing title. This might lead to a "land race" or a "race to the frontier," which refers to forest being cleared prematurely to establish property rights. The deforestation push has been discussed particularly in relation to the Amazon (32, 34, 35), e.g., where forest clearing is used to strengthen claims in conflicts between landowners and squatters (32). In Ecuador, forest land was so quickly converted to pasture to secure rights that farmers could not stock the land with cattle (36).

Impacts on Agricultural Production. For any given yield, the more successful the policy is in halting agricultural expansion and reducing deforestation, the larger the reduction in production. The central question is therefore what happens to yield under different policies (Table 1). Policies that depress agricultural rent present the strongest trade-off between conservation and production. The negative impact is smaller if discrimination can be geographically limited to frontier agriculture or to typical deforesting crops. Positive stimulus to intensive agriculture should increase yield and possibly also expand intensive production and lead to a contraction of extensive agriculture. Intensive agriculture can, however, also expand into forested areas (e.g., oil palm in Indonesia).

Selective support to extensive agriculture, *if* successful in reducing deforestation, also has the potential to yield win–win outcomes. Higher agricultural production in itself can help to achieve both objectives as it puts downward pressure on local or domestic output prices and makes agricultural expansion less profitable. Reforms to enhance tenure security should contribute to higher yield, as farmers are more willing to invest in the land (37). This could therefore, again if successful in forest conservation, yield win–win outcomes.

Increase and Capture of Forest Rent

Increasing forest rent over time is the second route to protect forest, "the forest scarcity path" of the FT (15). Higher demand for and limited supply of forest products stimulate forest cover stabilization and regrowth. This extractive forest rent can be influenced in similar ways to the agricultural rent, e.g., through tax policies and marketing arrangements that affect prices of timber and other forest products or through promotion of new technologies.

Large tracts of tropical forests are, however, characterized by weak, unclear, and contested property rights, making them de facto open access (38). Land users then have no incentives to include any forest rent in their decisions. If private property rights to the forests are established, we move from point A to point B in Fig. 1. Higher forest extractive rent then implies more forest will remain as forest. Factoring in degradation, the effects are more complicated. According to the standard Faustmann model, higher timber prices will shorten the rotation period and thereby reduce the average forest carbon stock (39).

Whereas the forest scarcity path historically has been linked to higher *extractive* forest rent, in the future it could be driven by increases in the *protective* forest rent. Because of its public goods nature, an increase in the protective rent has no impact on deforestation unless land users can capture some share if it. There are two principal ways of "internalizing the externalities": (*i*) moving decisions to a higher scale and (*ii*) creating a market for the public goods.

In the popular debate assigning individual property rights to forest is commonly put forward as a solution to excessive deforestation. This reform in itself will not solve the problem of local and global public goods (externalities), but clear and secure property rights—either at the individual or at the community level—are a necessary step toward establishing systems for payments of environmental services (PES). It will also encourage more sustainable management of forests compared with an open access regime, with positive effects on degradation and carbon fluxes.

Community Forest Management (CFM). Within our framework, CFM is an attempt to move decisions from the individual level to the community level to incorporate community-level negative exter-

Table 1. Overview of forest conservation policy options

Policy	Effectiveness (forest conservation)	Direct costs of policy (efficiency)	Effect on inequality/poverty	Agricultural yield (not production)	Political viability
1. Reduce (extensive) agriculture rent					
Depressing agriculture prices	High	Negative	Negative	Very negative	Very low
Creating off-farm opportunities	High	Medium/high	Neutral/positive	Uncertain	High
Support to intensive agriculture sector	Moderate/high	High	Uncertain	Positive	High
Selective support to extensive agriculture	Uncertain/moderate	High	Positive	Positive	Moderate
Ignore extensive road building	High	Negative	Negative	Negative	Low/moderate
More secure property rights	Uncertain	Medium	Uncertain	Positive	Moderate/high
2. Increase forest rent and its capture					
Higher price of forest products	Moderate	Low	Positive/uncertain	Small	Moderate
CFM: Capture local public goods	Moderate	Low/medium	Positive	Small	Moderate
PES: Capture global public goods	Potentially high	Medium/high	Uncertain/positive	Small	Moderate/high
3. Protected areas	Moderate/high	Medium	Uncertain	Small	Moderate

nalities from deforestation (point C in Fig. 1). The CFM experience is mixed. In a metaanalysis of 69 cases of CFM (40), 58% were considered successful on the basis of ecological sustainability criteria (the most typical measure was "improved forest condition"). Another large comparative study of 80 forest commons in 10 countries found that greater rule-making autonomy at the local level is positively correlated with high forest carbon levels (41). However, an analysis of the central Himalaya in India finds no difference in forest cover between village- and state-managed forest, although the costs per hectare are seven times higher for the latter (42).

Nobel laureate Elinor Ostrom has for the past 2 decades been demonstrating how different attributes of users, institutions, resources, and context may or may not facilitate local cooperation (43, 44). There are several reasons why communities might be effective managers. They have better knowledge about the local forest and its users and uses compared with the state, making policing easier. Communities may also apply a different set of sanctions, as resource management is embedded in larger social systems (45, 46). However, achieving collective outcomes is difficult, particularly when the user group is large, heterogeneous, and poor and the forest benefit flow and economic environment are unstable (47). In addition, central government policies often have not been supportive, and the most valuable forest resources tend to remain outside community control (48).

Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) and PES. The current international debate focuses on REDD as the main vehicle for forest conservation. The key idea of REDD is to create a multilevel (global–national–local) PES system for the carbon sequestration and storage services of forests (49). Whereas REDD promises to offer significant, cheap, and quick reductions of greenhouse gas emissions from forests (50), a number of obstacles must be overcome to have a significant impact on the ground. At the international level and in global climate negotiations, questions of funding and carbon market integration; reference levels (including developing country responsibilities); and standards for monitoring, reporting, and verification (MRV) must be agreed on (51). Similarly, at the national level effective institutions must be established and policies implemented to channel payments to effectively incentivize and compensate forest users for opportunity and transaction costs (52).

Many actors will be seeking REDD rents, and "rent seeking" is the root cause of corruption (53). Governance problems and widespread corruption will limit the effectiveness and the scope of possible actions for REDD, as it will for the other policies discussed. Implementing effective PES schemes also assumes that the land and carbon rights have been settled. At least in the short to medium term, using PES as an instrument to achieve REDD will be more difficult than commonly assumed among policy makers (52). National REDD strategies will have to rely heavily on non-PES policies (such as those discussed in this article).

Impacts on Agricultural Production. Policies to increase forest rent are likely to have negligible direct effects on yield from existing agricultural land. But the supply effect from less land being available for agriculture may partly be offset as prices can be pushed up and encourage intensification. Further, *average* yield can be expected to increase because the least productive land areas are taken out of production (or not included through continued deforestation). Such a search for the most productive land has played an important role in forest transition in Europe (14).

Protected Areas (PAs)

Forest protected areas (PAs) within International Union for Conservation of Nature (IUCN) categories I–VI make up 13.5% of the world's forests (54), the share being significantly higher (20.8%) for rainforests (tropical lowland evergreen broadleaf forests). There is a broad consensus in the literature that (*i*) the degree of protection is <100%, but (*ii*) rates of deforestation within PAs are lower than outside them, also after controlling for "passive protection" (PAs are often located in remote areas with lower deforestation pressure) (55, 56).

A study of PAs in Costa Rica found substantial passive protection: Without controlling for observable covariates, PAs reduce deforestation by 65%; the degree of protection drops to 10% after controlling for differences in location and other characteristics (57). A methodologically similar study from Sumatra finds the difference between deforestation rates in PAs and wider areas during the 1990s to be 58.6%; this difference falls to 24% after propensity score matching (58). None of the studies finds any significant leakage (deforestation activities shift from inside to outside PAs), although the methods required to estimate leakage are complex and go beyond simple comparison of the (adjusted) deforestation rates inside and outside PAs.

Various types of PAs have also significantly reduced deforestation in the Amazon. Indigenous lands occupy one-fifth of the Brazilian Amazon, and Nepstad and coauthors (59) find the inhibitory effect for the period 1997–2000 to be 8.2 (the deforestation ratio between 10-km-wide strips of land outside and inside the PA border). These and other results led a World Bank forest policy review (60) to suggest that "protected areas may be more effective than is commonly thought" (page 126).

There is less consensus on other aspects related to PAs, e.g., the livelihood benefits and to what extent an inclusive or an exclusive approach of local communities is more effective when it comes to conservation effectiveness (61). This lack of consensus also holds for the integrated community development programs (ICDPs), which can be seen as a mix of a traditional "park and fence" approach and an attempt to provide alternative income opportunities to reduce agricultural rent and nonsustainable forest extraction. One study (62) concludes that "it is not that the principle of linking protected area management with local social and economic development is flawed, [but] the expectations and implementation that have been problematic" (page 514). The alternative livelihoods created were often small compared with the income from deforestation and forest degradation, and the benefits were not made conditional on forest conservation (as they are in a PES system).

Successful PAs can be expected to have similar effects on agricultural yield as policies to increase and capture forest rent. However, one can hypothesize that a PA approach will lead to higher loss of agricultural production per hectare forest saved, because there is less assurance that the least productive land is saved from agriculture.

The Global Food Equation

The global food equation (GFE) is a simple identity that links population and food consumption per capita with agricultural yield and land area:

$$\text{Pop} \times (\text{Food}/\text{Pop}) \equiv (\text{Food}/\text{Ag land}) \times \text{Ag land}.$$

Put simply, without an increase in yield, agricultural area must expand to feed a growing population and meet higher per capita food consumption. GFE has been used to draw conclusions about the need for higher yield to spare forests (63). Waggoner and Ausubel (64) refer to it as "the popular image of farming's encroachment on forests" (page 241). This line of reasoning also underlies the Borlaug hypothesis (17), which suggests that the Green Revolution has had a positive effect on forest cover.

Using the GFE logic, Balmford and coauthors (65) predict that the agricultural land area in developing countries will increase by 2–49% between 2000 and 2050, depending on assumptions of population growth (23% being the medium variant scenario). This scenario assumes an extrapolation of current yield trends (with a mean of 1.13% per year). A more optimistic scenario with an annual yield increase of 1.53% virtually eliminates the agricultural area increase.

The GFE provides no direct link between agricultural and forest areas, nor does it account for two facts: Much agricultural production is not food and countries trade. Moving to the national level and further decomposition gives a national deforestation equation (NDE):

$$\mathrm{Pop} \times (\mathrm{Food\ cons/Pop}) \equiv (\mathrm{Food\ cons/Food\ prod}) \times (\mathrm{Food\ prod/Ag\ prod}) \times (\mathrm{Ag\ prod/Ag\ land}) \times (\mathrm{Ag\ land/Forest}) \times \mathrm{Forest}$$

or

$$\mathrm{deforestation} \approx \mathrm{pop\ growth} + \Delta\ \mathrm{food\ cons\ per\ capita} - \Delta\ \mathrm{self\text{-}sufficiency\ ratio\ (inverse)} - \Delta\ \mathrm{food\ share} - \Delta\ \mathrm{ag\ yield} - \Delta\ \mathrm{ag/forest\ ratio}.$$

Agricultural yield is just one of many factors affecting deforestation, and changes in yield have indirect effects on these factors. First, countries increasingly trade in agricultural products. The trade intensity (trade/GDP ratio) has increased from 60 to >100% since the early 1970s (66). Developing countries as a group have over the same period moved from being net agricultural exporters to net importers. Higher yield boosts the competitiveness of domestic agriculture and raises self-sufficiency.

Second, a lower share of agricultural output being for foodstuffs (Δ food share) can boost deforestation, as illustrated by the boom in biofuel crops. Oil palm expanded by 1.9 and 3.0 million ha in Malaysia and Indonesia, respectively, during the period 1990–2005 (67). Most of the smallholder crops on forests cleared in Indonesia, following the economic crisis in the late 1990s, were not food crops (e.g., rubber) or not staples (e.g., cocoa, pepper, and coffee) (68). Higher yield can reduce the food share, as food demand is typically more price inelastic than demand for nonfood commodities.

Third, forest, cropland, and pasture are not the only land uses; large areas of fallow, savannah, bush, and other land categories are available for agricultural expansion (Δ ag/forest ratio is not stable). Waggoner and Ausubel (64) find changes in cropland and forest area to be uncorrelated in the period 1900–1995, although this might partly be due to poor data for many countries. Their average "encroachment factor" (share of agricultural expansion into forests) is assumed to be 1/3, but is also highly variable across crops and countries. Fifty-five to 60% of the recent oil palm expansion in Indonesia and Malaysia was at the expense of forests (67).

Other potential impacts of higher yield include a price effect on food consumption per capita (inelastic food demand suggests this effect will be small) and a Malthusian effect (higher population growth due to increased food consumption).

The GFE, NDE, and similar identities are useful in providing a consistent accounting framework, but are also potentially dangerous to use as predictive models and for policy analysis if they do not factor in how a yield change impacts the other factors through behavioral and market changes. This change by moving from a mechanical simulation to empirical analysis using a regression model is illustrated by the results of Ewers and coauthors (69), using country-level data for the period 1980–2000. If "perfect land-sparing" yield change were occurring, the land-yield elasticity should be −1; i.e., all other factors in NDE remain constant. The authors find a much lower elasticity: −0.152 (t = −1.78) for developing and −0.089 (t = −0.57) for developed countries due to effects such as those discussed. The impact on forests (not included in their analysis) would be even smaller as long as the encroachment factor is below unity.

Discussion and Conclusion

The starting point of the von Thünen model is the plot level, and deforestation is framed as a contest between agricultural and forest rents. The GFE starts at the other end of the scale and asks how much land we need to feed the global population. The von Thünen model is at one extreme where demand is perfectly elastic (prices fixed), whereas the GFE assumes demand to be perfectly inelastic (quantities fixed). They present two contrasting views on the forest impact of higher agricultural yield, but they converge when modified to include behavioral and market effects. Whereas overall food demand may not respond much to price changes, this does not necessarily hold for particular crops or for nonfood agricultural products where substitutes are available.

The demand elasticity and thereby the forests impact of higher yield also depend critically on the scale of analysis. Angelsen and Kaimowitz (17) conclude that "situations that are win–lose [agricultural production and forest conservation] at the local level may be win–win at the global level" (page 400).

An illustration of the limited trade-off between production and conservation at higher scales is given by comparing recent agricultural production and area increases in developing countries. Crop and livestock production grew by 3.3–3.4% per year during the period 1985–2004 (66). Gross annual deforestation (1990–2005) for agricultural uses represents ~0.3% of the total agricultural area (66, 70, 71). Because productivity of cleared forest land can be expected to be well below average productivity (production is less intensive, and most productive land is already cleared), these numbers suggest that only a small share (<<10%) of the agricultural output increase has come from deforestation.

REDD is currently being promoted as a low-cost climate mitigation option. The report that underlies the Stern review (50) and the Eliasch report (72) finds the opportunity costs (foregone agricultural rent and logging revenue) of completely eliminating deforestation in eight countries (accounting for 6.2 million ha of annual deforestation, about half the global number) to be approximately USD 6.5 billion per year (73). Due to increasing marginal costs, spreading a 50% reduction across all deforesting countries is significantly cheaper. Other studies such as Kindermann and coauthors (74) have cost estimates in the range of USD 17–28 billion for a 50% global reduction. These numbers include REDD rents to developing countries, which are not true economic costs but transfers and typically inflate cost numbers by a factor of ≥3 (51). Yet, the relatively low opportunity costs of avoided deforestation, particularly for the initial reductions, suggest the conflict between production and conservation is modest.

At the national level, higher volumes of agricultural trade have delinked domestic and local consumption from production and deforestation. Moreover, high rates of deforestation for several decades have made forested areas recede, frequently into relatively inaccessible areas. The issues of forest conservation and agricultural production are therefore becoming increasingly spatially delinked.

In summary, at global and national levels policy makers are only to a limited degree presented with a trade-off between conserving the forests and feeding the hungry. Potential conflicts between production and conserving forests do, however, exist at the forest margins. Stimulating agriculture in forest-rich areas through, for example, better technologies, improved roads, and more secure tenure to "reduce the need for new agricultural land" is a highly risky conservation strategy. Agricultural policies that target low-forest areas, or crops and production systems that are unsuitable at the agricultural frontier, are more likely to reduce pressure on forests. Such policies are complementary to, and will increase the effectiveness of, efforts that more directly target forest conservation: protected areas and institutional arrangements and payment mechanisms that enable land users to capture a higher share of the local and global benefits provided by tropical forests.

Materials and Methods

This article is based on an extensive review of the deforestation literature, in particular several metaanalyses and comparative studies. These studies include a review of economic deforestation models by Angelsen and Kaimowitz (3, 6), two comprehensive metaanalyses of deforestation studies by Geist and Lambin (27) and Rudel (31, 75), a policy analysis by Chomitz and coauthors (60), and a comparative study on the impact of agricultural technologies on deforestation by Angelsen and Kaimowitz (17).

ACKNOWLEDGMENTS. I thank Arun Agrawal, David Kaimowitz, Tom Rudel, Gerald Shively, Louis Verchot, two referees, and the editor for their valuable comments on earlier drafts of this article. This article is based on research I have done in cooperation with the Center for International Forestry Research in Indonesia.

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