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MODELING THE EFFECTS OF TRADE LIBERALIZATION ON FOREST COVER: SOME METHODOLOGICAL ISSUES

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Modeling the Effects of Trade Liberalization on Forest Cover:

Some Methodological Issues

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ABSTRACT: The environmental effects of agricultural trade liberalization are potentially large compared to the effects of manufacturing trade liberalization, and include changes in land use. The principal agents of deforestation are developing-country farm households, especially those practicing shifting cultivation, with the activity of loggers also potentially significant. There are numerous channels through which trade liberalization, by changing relative prices and incomes, can affect household land clearing decisions. CGE models with forest submodels may be useful for analyzing the effects of trade policy on deforestation.

I. Introduction[1]

Environmental quality can be profoundly affected by changes in land use. These changes in land use, which redistribute land area among forest cover, pastureland, agricultural cultivation, urbanization, and other uses, influence the environment in a number of dimensions. Of particular concern is the conversion of forested land to other uses, primarily pastures and agricultural land. Forested land, particularly in tropical forests, supports higher levels of biodiversity than other land types. Forests supply important services of carbon sequestration, acting as carbon "sinks" which may mitigate global warming, while other land types (particularly pastureland) may act as carbon sources, and are useful in erosion control and local water cycle regulation. While there are serious issues surrounding the appropriate measurement of forest land, by all accounts conversion of tropical forest cover has proceeded rapidly in a number of developing countries in recent decades. The widely cited estimates of the FAO put the annual decline in global forested area at 0.3 percent per year over 1990-95, with annual deforestation in the regions of Africa, South America, Central America and Asia supposedly running between 0.5 and 1.3 percent per year, and loss of natural (non-plantation) forest cover higher still. Temperate forests in developed countries are believed to have stabilized in aggregate, in some cases undergoing recent afforestation, but not by enough to offset tropical deforestation.

Is it likely that further trade liberalization affects the current rapid rates of deforestation, either for good or ill; and if so, by enough that anyone should pay attention? How much useful do we know about how to analyze the links between trade liberalization and land use? For example, as the Millennium Round gets underway, suppose that two relatively well-developed proposals for agricultural liberalization were to emerge, one deeper and one shallower, and each with specific details for different products and countries.

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[1]This paper relies extensively on the review of economic deforestation models in Kaimowitz and Angelsen (1998; summarized in Angelsen and Kaimowitz (1999)), which is essential reading for all researchers in this area and references most of the works cited herein.

Are economists in a position to give policymakers useful information about the consequences of each proposal for land use? If so, using what tools? If not, why not?

During the early 1990s, disputes about the relationship between trade and the environment became an increasingly important part of trade negotiations. In the run-up to the creation of NAFTA in 1994 and the WTO in 1995, economists developed a variety of tools for assessing the trade-environment nexus, perhaps anticipating a demand for such analysis by the new institutions created to address this nexus, such as the WTO Committee on Trade and Environment and the NAFTA-linked Commission for Environmental Cooperation. Popular arguments that trade liberalization led to economic growth, and that economic growth led to either (a) more pollution or (b) environmental improvements, were refined by economists in their usual manner to (c), it depends, for example on such things as whether a country has a comparative advantage in "clean" or "dirty" goods prior to trade liberalization, whether the political system responds by weakening environmental regulation in a "race to the bottom" to attract international investment or by satisfying the demands of newly enriched citizens for more environmental protection, on whether technologies stay the same or change after liberalization, on the environmental strategies of multinational corporations, and so on.

There is now a renewed stock-taking of the economists' trade-environment toolbox in the runup to the Seattle WTO ministerial and the Millennium Round. A few things have become clearer since 1994. One is that the potential issues surrounding trade, agriculture, and forestry may be relatively more important than those surrounding manufacturing. Another is that there has emerged, fairly rapidly, a more or less dominant economic paradigm for thinking about trade-environment issues, referred to variously as the Grossman/Krueger or OECD framework (Grossman and Krueger (1991)), OECD (1997)), and involving concepts such as scale effects, composition effects, technique effects, and regulatory effects. The question arises as to whether this paradigm is fully general, or whether economists thinking in terms of the paradigm have implicit pictures of factories in their minds, and something different is needed for land use issues.

As will become clear, these remarks are directed at attempts to analyze land use using simulation methods with microeconomic foundations and calibrated against observable data, such as computable general equilibrium (CGE) and partial equilibrium analysis. While such methods constitute the dominant paradigm for analysis of trade liberalization issues, there are a wide variety of other analytical methods which have been used to examine land use. Because of the need to relate trade liberalization directly to land use, I will argue that CGE and partial equilibrium methods, though possessing limitations, are at least reasonable candidates for analysis of the effects of trade liberalization on land use. Such analysis generally requires some modification to the traditional structure of trade liberalization modeling. There is no universally standard method for making such modifications, although a number of methods have been tried, which probably do not exhaust the available possibilities.

Why land use might be more important than manufacturing

Substantial analysis has been devoted to the case of trade-environment links in manufacturing.[2] The key question to be answered in such analysis is whether the potential second-best problems created by the simultaneous absence of free trade and optimal environmental regulation are of sufficient empirical magnitude to warrant the attention of policymakers. For example, if trade liberalization increases pollution in countries with inefficiently weak regulation, or inefficient differences in national regulation distort patterns of comparative advantage, there may be a case to consider environmental considerations in the design of trade policy, or trade considerations in the design of environmental regulation.

Two stylized facts drive most of the available results on trade-environment linkages in manufacturing. First, increased production costs induced by heavy environmental regulation are small, generally on the order of one percent of total cost in the dirtiest industries in the United States. Even if it is

[2] Levinson (1994) reviews much of the econometric evidence, and Beghin and Potier (1997) cover recent CGE modeling exercises, mainly pertaining to single countries. For an attempt at global CGE modeling, see Ferrantino and Linkins (1999).

assumed that these costs are completely avoided by zero regulation in developing countries, they cannot likely have much effect on the pattern of trade. Second, manufacturing tariffs have been substantially reduced in the seven previous rounds of trade negotiations, and remain high primarily in developing countries, which are the usual suspects for the status of “pollution havens” through underregulation. Trade liberalization in developing countries would likely reduce over-production in dirty industries. Thus, substantial changes in environmental policy seem empirically unlikely to alter trade outcomes by much, and substantial changes in trade policy seem unlikely to alter environmental outcomes much, with the possibility of some “win-win” situations.

In the case of land use, the possibility for measurable and important consequences running between trade policy and environmental outcomes is much greater, in both directions of causation. In terms of trade policy, levels of protection for agricultural goods remain substantially higher than for industrial goods, particularly when non-tariff barriers are taken into account. Table 1 compares estimated trade-weighted post-Uruguay round applied rates of protection on agricultural and manufacturing goods from Finger, Ingco and Reinecke (1996), using an estimate of agricultural protection designed to take into account the actual tariff equivalent of tariffs and non-tariff measures combined (Ingco (1995)). Developed countries, and many developing countries, engage in high levels of agricultural protection, while in other developing countries the combined effect of a variety of policies acts as a tax on agriculture, thus leading to negative tariff equivalents. There is thus substantial scope for future liberalization both of trade policies and of domestic agricultural policies, which is reflected in the proposals for agricultural liberalization tabled in the Millennium Round. If such liberalization were to materialize, substantial changes in global and local land use would ensue. Since deforestation largely takes the form of directly substituting agricultural and pastoral uses of land for forest cover, a large agricultural liberalization could have significant impacts both for the size and distribution of forest cover. Moreover, at a first pass, a global move of tariff equivalents of agricultural protection significantly closer to zero would appear likely to redistribute agricultural production from developed to (many) developing countries, potentially accelerating afforestation in the former and deforestation in the latter.

Moreover, it is widely recognized that policies pertaining to land use differ significantly across countries. In developed countries, land used for agriculture and commercial forestry is likely to be held in secure forms of private property, which permits both foresters and farmers to internalize at least the commercial value of future forest harvests on their lands, and gives the government someone convenient to subsidize to promote greater forest cover for positive externalities, e.g. the Conservation Reserve Program in the United States.[3]

By contrast, property rights at the extensive agricultural margin in many developing countries are relatively weak and ill-defined. with squatters engaging in shifting agriculture ("slash-and-burn"), permanent agriculture, herding, or wood gathering for fuel on wooded lands to which they have no clear title. These lands are effectively communal open-access resources, and thus subject to overutilization in a phenomenon known as the "tragedy of the commons." Clearing of land by squatters is an essential part of obtaining *de facto* right of use, and in many cases *de jure* property rights as well.[4] Thus, significant moves by developing countries to strengthen formal land title while delinking it from land clearing would be *per se* significant environmental policies, which, by altering the incentives for agriculture, pasturing, and forestry, would in turn significantly alter outcomes in merchandise trade. Stated in reverse, the current inefficient policies of land title in developing countries are probably already having substantial impacts on merchandise trade.

A study by Amelung (1991; cited in Barbier (1994)) estimates the share of deforestation during 1981-88 attributable to all agricultural activities (including pastureland, permanent crops, extension of arable land,

[3]Alig, Adams and McCarl (1998) model the comparative effects of modifying CRP, agricultural support, national-forest management and other polices on U.S. land use.

[4]Policies which grant property rights to colonists removing substantial forest cover have been widespread, both geographically and across time, and arise from governments' desire to favor settlers engaging in agricultural improvement over either land speculators or indigenous populations (Mendelsohn (1994)). Requirements of land clearing and cabin building to obtain land title were important in U.S. frontier development (Cronon (1983)).

and shifting cultivators) at 89 percent in Brazil, 80 percent in Indonesia, 100 percent in Cameroon, and 83 percent in all major tropical countries. The comparable share of deforestation attributed to forestry is 2 percent in Brazil (from logging for charcoal production), 9 percent in Indonesia, 0 in Cameroon, and 2-10 percent for all major tropical countries.[5] Indirect but perhaps more telling is the stylized fact that the numerous econometric studies directed at forest cover, some using location-specific or micro data, have produced clear evidence for a positive effect of agricultural prices on forest clearing, but weaker and more ambiguous evidence on the effects of timber prices (Angelsen and Kaimowitz (1999)). This may be because the data difficulties are greater with respect to timber prices, or because the micro-level effects of timber prices on loggers and farmers are in fact ambiguous.[6]

It is relatively unusual for trade economists to incorporate economic processes driven by agricultural households into their analysis, though such processes are familiar to economists working on topics such as fertility, education, and rural development (Singh, Squire and Strauss (1986)). The essential thing about households is that they are firms and consumers simultaneously. They can engage in a combination of household production and market production - crops grown may be eaten or sold, or both at the same time, firewood gathered may be burned or sold.

[5]Another 2-7 percent may be due to hydroelectricity productoin, mining, and related activities, with the rest accounted for in the residual.

[6]It has been suggested that high timber prices may encourage more efficient harvesting and processing techniques (Barbier et al. 1995), or may aid in efforts to prevent farmers from clearing logged areas (van Soest (1996)), both cited in Angelsen and Kaimowitz (1999).

Table 1
Post-Uruguay Round Applied Tariffs for Industrial Goods and Total Protection on Agricultural Goods
(ad-valorem equivalent)

Developed countries	***Agricultural goods***	***Industrial goods***
Australia	0.1	9.7
Austria	20.0	3.3
Canada	7.0	2.6
European Union	15.7	2.9
Finland	36.2	1.9
Japan	65.1	1.4
Norway	50.9	0.8
Singapore	8.2	0.4
Sweden	37.8	1.7
Switzerland	51.3	1.0
United States	10.8	3.1
Developing countries	***Agricultural goods***	***Industrial goods***
Argentina	- 0.7	10.6
Brazil	-21.4	11.8
Chile	- 8.4	11.0
Colombia	-17.2	10.4
India	13.4	29.0
Indonesia	23.2	11.5
Korea, Rep.	42.3	7.6
Malaysia	56.8	6.8
Mexico	3.0	11.4
Philippines	46.2	20.4
Senegal	-0.3	12.6
Sri Lanka	1.2	27.2
Thailand	33.8	26.8
Turkey	1.6	24.2
Venezuela	-16.3	12.0
Zimbabwe	-3.4	4.5
Transition economies	***Agricultural goods***	***Industrial goods***
Czech and Slovak Customs Union	-17.2	10.4
Hungary	- 1.5	6.7
Poland	1.3	6.9

Source: Finger, Ingco and Reinecke (1996). Agricultural protection is taken from the row “Agriculture, exc. Fish, estimate 1" and incorporates estimates of tariff equivalents of non-tariff barriers.

The household allocates the time of its members variously to working on the farm, working off the farm for a market wage, taking care of other productive household activities (child rearing, cooking, and other household production for own use), and leisure. The decisions made by the household in operating the farm include the full range of decisions made by a pure market farmer who sells the entire crop, including fertilizing, hiring outside labor, and clearing additional land. The household's activities are designed to maximize household utility. The arguments of the household utility function are often specified in terms of goods such as "health," "nutrition," "leisure," "children (quantity and quality)," and there are alternate technologies for producing these goods, using various mixes of market-purchased goods and household time.

Forest clearing thus appears in the household's decision-making problem as a use of household time which competes with alternate uses, and which has a joint product: firewood for consumption or sale, and a capital good, "cleared land," which increases agricultural production. There are many tradable goods whose prices enter the household's decision-making problem, including all consumer goods and producer goods for agriculture. In principle, trade liberalization could change the prices of all these goods, and since forest clearing enters on both the consumption side and the production side of the household's problem, changes in the prices of any of these goods can potentially affect the rate of forest clearing. The task then becomes to identify those traded-goods prices which are likely to have the biggest impact on forest clearing, and to devise a plausible way to introduce changes in land use into a trade modeling framework.

One device often adopted to simplify empirical work on agricultural households is to model the production, consumption, and market labor supply decisions of the household as *recursively separable*. This means that the agricultural production activity is treated as profit-maximizing, valuing household agricultural labor at the market wage, and can be planned without knowing anything about the household's consumption or labor-supply possibilities. Once production is done, though, it affects household income, and this in turn enters into consumption and labor-supply decisions through the "profit effect" (higher agricultural prices increase income, which increase consumption and may reduce wage labor supply).[7] If the household consumes the staple good, this will mean that demand for the good is less negatively sloped than it would be for an urban household which only buys, and demand may even be upward-sloping, something that non-household models of the consumer do not admit.

Recursive separability is a conclusion which is derived from several microeconomic assumptions, one of which is that the household may both freely sell labor in the marketplace and buy in labor for its own farming activities. In fact, the household's problem may not be separately recursive, and consumption and labor market decisions may affect production decisions. For example, changes in oil prices can affect demand for the substitute consumption commodity "fuelwood,"thus leading to more land clearing and increased agricultural production.[8] Barrett (forthcoming), motivated by the example of Malagasy smallholders growing rice at the forest margin, considers a case in which there is a market imperfection in land (farmers can't rent more, only clear it) and policies may change the mean and variance of the staple food price of rice (for example, trade liberalization combined with market deregulation may increase both the mean and the variance). In this case, differences in the initial land endowment feed back into production decisions, so that land-poor households which are net buyers of rice unambiguously respond to increases in the mean and variance of the staple price with more deforestation. For relatively land-affluent households who are net sellers of rice, increases in the mean or variance of the price of rice have an ambiguous effect on incentives to deforest. In general, most relaxations of the simple micro assumptions lead to violation of separability (Singh, Squire and Strauss (1986), pp. 48-58), so that in reality, all traded-goods prices impinging on the agricultural household may affect incentives to deforestation whether the households are using fuelwood exclusively, "modern" fuels (fossil fuels and electricity) exclusively, or a mix of the two.

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[7]Singh, Squire and Strauss (1986), p. 20.

[8]See Elnagheeb and Bromley (1994) for an application to the Sudan.

II. Some Pre-Modeling Issues

Definitions and data quality

At the outset, it should be recognized that "deforestation" is a term with multiple meanings. In their review of deforestation models, Kaimowitz and Angelsen (1998, p. 3) define deforestation as "situations of complete long-term removal of tree cover," while recognizing that other phenomena such as biomass loss, shortened fallow length in shifting cultivation and other types of forestry degradation may be of interest to policymakers. The FAO [9] defines net deforestation as clearing of forest lands for all forms of agricultural uses, as well as for other land uses such as settlements, infrastructure and mining. A "forest" in a developed country is considered to have at least 20 percent tree crown cover on maturity, which can include less forested young stands and temporarily cleared areas, while in a developing country a "forest" can have as little as 10 percent permanent long-term tree crown cover, and can include mixed forest/grasslands with a continuous grass cover on the forest floor. Phenomena such as forest fires and selective logging are not scored as deforestation (since the trees can grown back), but rather as "degradation." Furthermore, developing country forests can be broken down into natural forests and plantations (afforested and reforested areas for human usage). Natural forests in turn can be "closed forests" (it's dark during the day, and there's no grass on the floor) or "open forests" (mixed forest/grassland with grass on the floor). The FAO considers that in developed countries, it's hopelessly impossible to tell the difference between a natural forest and a plantation, so they don't try.

The FAO publishes two sources of cross-country data on forest cover, the Forest Resources Assessment, which covers only tropical, closed, broad-leaved forests, and the Production Yearbook, which divides land into forest & woodland, cropland, permanent pasture, and other land. In the 1990 Forest Resources Assessment (FAO 1993), only 21 of the deforestation estimates for the 90 countries were based

[9] This description of the FAO definitions relies on World Resources Institute (1998), pp. 300-302.

on two or more national forest inventories. For the other 69 countries, deforestation over 1980-90 was extrapolated from a single forest assessment (sometimes as old as 1965) using a regression model with population density and ecological variables as the only explanatory variables. The Forest Resources Assessment data, among the most widely cited, thus reflect primarily population growth rather than data obtained from aerial photography or satellite imagery. Plantation area is sometimes figured as "approximately" the residual between total and natural forest, and even less reliable. The FAO Production Yearbook data arise from national government responses to questionnaires and are of lower quality. It is in general of worse quality than the Resources Assessment, as well as differing greatly from it. Neither source corresponds well with the limited number of national assessments based on aerial photography or satellite imagery.

Deficiencies in the cross-country data hopelessly contaminate attempts to estimate an "environmental Kuznets curve" for deforestation.[10] There have been a number of such attempts (cites): were any based on strong data it might be possible to formulate arguments along the lines "Trade liberalization leads to per capita income, and this leads to (acceleration/deceleration/reversal) of the rate of deforestation (depending on the stage of development). At present, though it appears likely that the managed forests in more affluent countries are stable or net-reforesting, the evidence for increased income growth influencing deforestation one way or another in developing countries appears tenuous.

Econometric studies based on household survey data[11] are probably a preferable source for calibrating price and/or income parameters which could link prices in traded goods to changes in land use. Such surveys, usually conducted by the same authors who publish the empirical work, may take as much as several

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[10]An "environmental Kuznets curve" is a cross-country statistical relationship between a measure of environmental quality and per capita income (cites). For many (but not all) measures of environmental quality, the environmental Kuznets curve takes on an "inverted-U" shape: environmental conditions deteriorate with income increases up through a certain level, but then improve at higher levels of income. The name comes by analogy with the inverted-U relationship between per capita income and income inequality estimated by Kuznets (1955).

[11]Kaimowitz and Angelsen (1998), pp. 28-35.

years to conduct. The sample sizes in these models range from a few dozen to as many as 5,000 households, with several hundred being typical. The households are usually observed for a single period, though there are two examples of panel surveys taken ten years apart (Foster et al. (1997), Ozório de Almeda and Campari (1995)). The data may be analyzed using regression, linear or quadratic programming, or simulation techniques. One limitation of this data is that household surveys exist for only a limited number of countries in the tropical zone,[12] because of the expense of conducting them. A second limitation is that the number and type of price variables analyzed varies from survey to survey. Reasonable calibration of price elasticities affecting household land clearing behavior is essential to building useful links between existing simulation models of trade liberalization and projections of land use effects of such liberalization.

Joint production of environmental services from forested land

Discussions of land use often implicitly suggest that the objective functions of policymakers consist simply of minimizing the rate of deforestation, in terms of number of hectares of land converted to alternate uses. Such a simplistic view overlooks two key points. The first is that the economic well-being of the rural poor in developing countries is also of concern, and a certain amount of land conversion may thus be socially desirable. The second is that forests provide multiple ecological services. On the local level, forest cover is useful both for erosion control, soil nutrient retention, and water cycle regulation, while removal of forest cover can induce local climate change (for example, by altering albedo and the surface energy budget) and increase sedimentation in rivers.[13] Forests also provide a global externality in the form of carbon sequestration, which is an important variable affecting the potential future course of climate change. Tropical forests in particular represent important habitats supporting biodiversity, which generates both global externalities (economic and aesthetic) and local benefits in the form of increased ecosystem resilience.

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[12]See Kaimowitz and Angelsen (1998, pp. 26-27), who cite analyses of household deforestation surveys for Bolivia, Brazil, Costa Rica, Ecuador, India, Indonesia, Mexico, Nepal, Tanzania, and Zambia.

[13]Lambin (1994), p. 7.

Different forest types vary in their attributes with respect to each of these environmental benefits. For example, natural old-growth forest may offer superior benefits in terms of biodiversity, while other types of forest cover such as shade coffee plantations may be useful in local biodiversity conservation strategies (*Science News* (1996)). Young trees in commercially reforested plantations may offer greater rates of carbon uptake than old-growth forest. The unique ecology of mangrove forests, which regulate salt marshes and support economic activities such as prawn fishing, is important for many countries and has spawned (no pun intended) a plethora of research.[14] Differences in the ecological services provided by different forest types are important for policy, are affected by differences in local processes of land use by humans, and can easily be obscured in a "one-size-fits-all" global approach to modeling.

Non-trade-related causes of deforestation

One of the most important questions to be addressed is the question of whether trade policy is in fact an important instrument influencing land use, or whether it is dominated by other policies and forces. The effects of trade policy may be large or small relative to other effects on land use. For example, there is an increasing consensus that road-building is an important driver of deforestation, by making remoter forests more accessible. It is not obvious that road-building is significantly influenced by trade policy, at least in terms of first-order effects. It may thus appropriate for analysts to treat road-building as exogenous, but this is unclear. Road-building in tropical forests might be driven largely by government budgeting decisions. Alternately, road building may be driven by private logging companies seeking access, which may in turn be influenced by tradable prices of timber or heavy equipment. While we know that road building causes deforestation, it is important to gain a better understanding of the economic determinants of road building in tropical forests, or the manner in which it is regulated.

[14]Including, since 1996, a new scientific journal, *Mangroves and Salt Marshes*, published by Kluwer Scientific Publishers.

Property rights in land, and land tenure regimes play a large role in discussions of forest conversion, and seem more obviously to be exogenous to trade policy. While security of land tenure is obviously important for land use decisions, there is substantial controversy over the sign of the effect, e.g. is deforestation greater under weak property rights in land (which causes neighbors to treat the forest like an open-access common resource and overharvest it) or strengthened property rights (which may induce settlers and squatters to clear land in order to obtain title)? Similar controversies surround the effects of differences in the efficiency of local land markets.

III. What Do We Need to Know About Agriculture at the Extensive Forest Margin?

The foregoing discussion helps provide a focus on the nexus of causality which will be most important to understand and model when analyzing the effects of trade liberalization on land use. This chain of causality runs as follows:

1. Trade liberalization changes prices of traded goods relative to each other. It also changes the price of factors of production through Stolper-Samuelson effects, and, secondarily, the relative prices of non-traded goods by changing prices of intermediate inputs. Liberalization changes also change real incomes both through increased opportunities for export earnings and reductions in consumer prices.
2. Price changes in turn influence the production, consumption, and investment[15] decisions of agricultural households. One of these decisions is the decision on how much land to clear. The land clearing decision is more or less intertwined with the household's other decisions, depending on the degree of separability in the actual decision problems the household faces. Price and income changes may affect the behavior of commercial logging operations, which in most countries are secondary but still non-trivial agents of land clearing

This suggests the following modeling strategy: Identify the set of prices which most strongly influences the land clearing decisions, as well as the income effects; estimate the price and income effects of trade liberalization; and feed these estimates into a reasonable model of the household land clearing

[15]Investment should be understood broadly to include investment in human capital through education, in equipment, in children, as well as in such agricultural activities as land clearing and the building and repair of irrigation systems, terraces, and erosion breaks.

problem, to obtain estimates of land clearing changes induced by trade liberalization.

Kaimowitz and Angelsen (1998) identify 39 papers which provide regression-based estimates of the effects of various variables on land-clearing decisions, exploiting variation between either micro-agents (households and firms) or regions, and another 12 papers which employ programming or other simulation techniques at the micro or regional level of aggregation. They provide an overview of the structure and results of these papers. I was able to examine eight papers in this category, one of which was too recent to include in the Kaimowitz/Angelsen database.[16]

Another potential source of price and income elasticity estimates bearing on land use is the vast quantity of traditional agro-econometric work which estimates supply and demand elasticities for production and trade of one or more agricultural commodities or for timber. All of this literature potentially bears on deforestation, depending on the assumptions one is willing to make. If increased agricultural or timber production of necessity requires increased acreage, then price changes leading to increased production also lead to increased deforestation. This result becomes more pointed if an acreage-response model is estimated, rather than simply using production as the dependent variable. A subset of econometric studies of agricultural production or acreage explicitly note the linkage between production and deforestation.[17] The traditional agro-econometric work potentially provides a rich source of parameter estimates for the analysis at hand, as long as one is willing to buy into the assumption that acreage increases for agriculture or forestry represent forest cover changes with the reversed sign. This is not necessarily true for a variety of reasons.[18]

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[16]These include Holden (1993), a programming model calibrated to household data from Zambia, and seven regression analyses, with the sample characteristics indicated after each citation; Krutilla, Hyde and Barnes (1995), developing-country cities and their periurban areas; Godoy et al. (1996), Amerindian households in Bolivia; Godoy et al. (1997), Amendian households in Honduras; Andersen (1997); municipalities in the Brazilian Amazon; Pichón (1997), households on the Ecuadorian Amazon frontier; and Amacher, Hyde and Kanel (1999), Nepali households, focusing on fuelwood production and consumption.

[17]E.g. Elnagheeb and Bromley (1994) for Sudanese agriculture, and Barbier et al. (1995) for Indonesian wood production.

[18]"Timber production or cropped areas ... may often not be good proxies for deforestation for several reasons. Forest can be cleared for different reasons. Logging frequently does not lead to complete removal of tree cover. Agriculture can expand either at the expense of forest or of fallow and other land uses." (Kaimowitz and Angelsen (1998), pp. 71,72).

Some of the strongest empirical results from these studies come from locational variables which are exogenous to trade; for example, deforestation is greater in areas where there are more roads, as well as areas closer to urban centers, nearer to the forest edge, with higher-quality soils, and with fragmented rather than large, compact forest cover.

Estimates of price and income effects

Both crop output and cropped area respond positively to increases in agricultural prices, both on a cross-country basis (Binswanger et al. (1987)) and in regional time-series studies (e.g. Elnagheeb and Bromley (1994)). This presumably implies that higher agricultural prices lead to increased deforestation. This effect is generally not tested in regressions on household data, presumably because of the absence of meaningful price variation among households within the same local survey. Programming studies of households do sometimes model the price effect, but their results arise directly from their assumptions (Angelsen (1999)). If households conform to the assumptions of the standard agricultural household model (i.e. they can buy and sell labor, and their farm activities are run as profit-maximizing enterprises), then higher agricultural output prices lead to higher demand for agricultural land, and thus more deforestation. If farms are isolated from labor markets, and if peasant preferences place a high weight on leisure (as they may in near-subsistence conditions), then higher output prices could theoretically lead to lower land clearing. Intermediate between the market model and the subsistence model are the class of farm models inspired by Chayanovian concepts of peasant behavior (Chayanov (1966); e.g. Holden (1993)), under which there is an income-leisure tradeoff above the subsistence level and off-farm labor opportunities are limited. In this model, poor peasants deforest when crop prices are low (since they'd starve otherwise), and rich peasants deforest when crop prices are high (since they can make money at it). The available empirical evidence at the cross-country and regional levels suggests that the market model is more generally applicable than the subsistence or Chayanovian models, and that higher agricultural prices induce deforestation.

The evidence on the prices of agricultural inputs is mixed. Certain inputs, such as fertilizers, seeds, pesticides, and hand tools, are complementary with land, and falling prices of these inputs create incentives for more intensive cultivation, which would reduce deforestation. On the other hand, falling input prices can make agriculture in general more profitable (as compared to urban activities), which can increase cropped land and reduce forest cover.[19] The available evidence on fertilizer prices is ambiguous, with both intensification effects and agricultural-profitability effects appearing in different studies of different regions. For non-fertilizer inputs, the available empirical evidence suggests that agricultural-profitability effects dominate, with deforestation associated with low prices. The effect of the prices of land clearing inputs is unambiguous, however. Ownership of chainsaws was found to induce forest clearing by both Pichón (1997) in Brazil and by Godoy et al. (1996) in Bolivia, who also found that the local presence of stores, which sell axes, cutlasses, etc., was associated with increased land clearing.

Increases in the off-farm wage and increased off-farm employment opportunities are unambiguously associated with reduced pressure on forest cover from the standpoint of microeconomic theory, since higher off-farm wages draw people out of agriculture. (Holden (1993), Godoy et al. (1996, 1997), Pichón (1997)). There is little empirical evidence of this at the household level, however, because of limited data on wages and off-farm labor (Angelsen and Kaimowitz (1999, p. 84)). Since off-farm wages and employment opportunities can be affected by changes in relative prices, they provide a potentially strong link between trade liberalization and land use.

The effect of incomes on land clearing is theoretically ambiguous, since higher incomes are associated both with increased demand for farm and forest products and with higher off-farm employment. Godoy et al. (1996) in Bolivia and Godoy et al. (1997) for Honduras, both using household rather than

[19]For products such as tractors, harvesters, and other inputs which are more useful under extensive cultivation schemes, price increases (decreases) should be unambiguously associated with less (more) deforestation, since the intensification effect and the agricultural-profitability effect operate in the same direction. This proposition seems to be relatively untested empirically. Technological changes, such as irrigation, that increase the profitability of already-existing farms are likely to reduce pressures on forests.

cross-country data, find an inverted-U relationship between rural incomes and deforestation; in Bolivia this relationship peaks at about 2-3 times the typical level of family income. One hypothesis which could explain this result is that higher-income households have better access to schooling, which is in turn associated with better information both about off-farm employment opportunities and improved agricultural practices. However, Krutilla et al. (1995) find that periurban deforestation is higher around tropical cities with higher incomes.

As stated earlier in the paper, increased timber prices appear to have a positive effect on land clearing, though the evidence is not uniformly strong. Increased prices for fuelwood are associated with increased land clearing (Amacher et al. (1999) for Nepal), and increased charcoal prices are associated with increased land cropped (Elnagheeb and Bromley (1994) for Sudan). This in turn implies that prices of traded goods which are substitutes or complements for fuelwood or charcoal (e.g. oil, kerosene, stoves of different designs) may likely have significant effects on forest cover through the fuelwood channel.

IV. What Can Be Done With Existing Modeling Frameworks?

Alternatives to CGE Modeling

A wide variety of modeling approaches have been deployed to understand the causes of deforestation. These include analytical models, econometric models, and simulation models of a variety of types. Of these approaches, most are not suitable for the analysis of trade liberalization effects on land use. Most do not include the instruments of trade policy, such as tariffs and quantitative restrictions. Models of land use which contain relative prices and incomes as exogenous variables at least represent channels by which trade policy might affect land use, but they do not tell us how trade policy affects relative prices and incomes.

There is a substantial body of research which models land use with methods having little or no underpinning in economic behavior whatsoever. Lambin (1994) reviews models of deforestation processes under the framework of the TREES (Tropical Ecosystem Environment Observation by Satellites) program of the European Commission and European Space Agency. These models are broadly classed as follows:

- Markov chains, which are random (stochastic) processes that calculate the probability that land changes uses based on its immediately preceding use)
- Logistic models, which exploit the fact that the rate of deforestation must slow down in a nearly deforested area to generate the flat "S" shape of the logistic function,
- spatial regression models, which use satellite data from geographic information systems (GIS) to statistically estimate limited-dependent variable equations (e.g. 1 = forest, 0 = no forest), with the characteristics of land depending on that of nearby parcels (spatial autoregression),
- von Thünen's model of periurban land use change, which analyzed economic rent and agricultural decisions as a function of distance to market,
- ecosystem simulation models, which use systems of differential equations and can sometimes be subject to unstable behavior of the "Limits to Growth" type,
- Dynamic spatial simulation models, which work something like the old computer game of "Life," with cells changing based on the content of neighboring cells, and
- economic models.

While economic considerations can be introduced into some of the "non-economic" frameworks for modeling land use, most of the above methods are several steps removed from anything that would be applicable to the analysis of trade liberalization.

Kaimowitz and Angelsen (1998), focusing only on economic modeling frameworks, produce the following typology:

- Household and firm-level models
    - Analytical open-economy models
    - Analytical subsistence and Chayanovian models
    - Empirical and simulation models
- Regional-level models
    - Spatial simulation models
    - Spatial regression models
    - Non-spatial regional regression models
- National and macro-level models
    - Analytical models

- Computable general equilibrium (CGE) models
- Trade and commodity models
- Multi-country regression models

The contents of these models, differentiated by their level of aggregation and the technique used (analytical, empirical/regression, simulation/CGE), are mostly self-explanatory. "Trade and commodity models" refers to estimation of standard supply and demand functions with crop output, crop land area and /or forest area as dependent variables.

Of these models, the analytical models cannot be used directly to estimate the results of anything, because they contain no numbers, only algebraic relationships. The econometric models, including the "trade and commodity" models, can be used to estimate the effect of price and income changes on land use, but are silent on the question of what price and income changes to be expected from trade liberalization, often do not contain the full set of relative prices which may be empirically important for the analysis. The results of empirical household models, in particular, may not generalize well beyond the regions and products covered in the survey sample.

This leaves simulation methods, including (but not limited to) CGE models. CGE models are capable of representing complex global trade liberalizations (such as a WTO round, or a regional trade agreement) and estimating the price and income effects of these for many commodities and regions in a way which takes full account of international and inter-industry relationships of demand and supply. The drawback of standard CGE methods is that they contain relatively naive representations of land use and forests, or no representations whatsoever. Thus, standard CGE frameworks must be supplemented with additional processes or information if they are to yield useful information on land use or deforestation.

Adaptations of CGE Modeling to Land Use Issues

Many applications of CGE analysis to trade liberalization rely on the GTAP database, either using the GTAP model (Hertel (1997)) or general-equilibrium equation frameworks supplied by the modeler. In this model, the total amount of agricultural land in each region is fixed; none can be created or destroyed, though land might move between agricultural sectors. Thus, the unmodified GTAP framework does not yield immediate information on land use. Some modest indirect inferences can be drawn by looking at changes in land rents; in regions where land rents go up, if the quantity constraint on land were lifted, and some process of land conversion were introduced, one would expect that some forest land would be converted to agricultural uses; similarly, afforestation would take place in regions where land rents declined (Ferrantino (1997)).[20]

At the other extreme, models of land use can sometimes incorporate quite sophisticated representations of the agro-forestry system. Alig, Adams and McCarl (1998) examine the impacts of various agricultural polices on land shifts between forests and agriculture in the United States, using a dynamic, non-linear programming model of the U.S. forestry and agriculture sectors, called FASOM (Forest and Agricultural Sector Optimization Model). In their model, forested land is differentiated by region, ownership class (timber industry/other private), age cohort of trees, forest cover type, site productivity class, timber management regime, and suitability of forested land for agricultural use. Forest harvest ages are an endogenous variable in a multiple-decade forest production process; there are six separate demand functions for sawlogs, pulpwood and fuelwood (each in hardwood and softwood), and naturally regenerated forest is distinguished from new planting of forest stands.

Alig et al. use FASOM to analyze four policy proposals, including restoration of agricultural supports eliminated in the 1995 Farm Bill, maintaining a permanent Conservation Reserve Program, large-scale afforestation for carbon sequestration, and elimination of timber harvests on National Forest

[20]Andersen (1997) though, gives microeconometric evidence for Brazil which associates increased land clearing with declining, rather than increasing land prices. (The land price presumably capitalizes the value of future rents). He attributes this result to land clearing primarily taking place at the extensive margin where land prices are low, and to the association of higher land prices with increased profitability of sedentary agriculture relative to slash-and-burn methods.

timberlands. They do not analyze any trade policies, and there is little or no linkage between the agriculture and forestry sectors and the rest of the economy, through which trade policies for manufactures could be transmitted to these sectors. Clearly, FASOM sacrifices much detail of interest to trade policymakers in order to focus on details of interest to land use policymakers. Also, the empirical calibration of many of the relationships in FASOM rely on an extensive program of ongoing research in the U.S. Department of Agriculture which is unlikely to be duplicated in many of the countries with tropical forest cover.

The following examples give a broad overview of existing applications of CGE models to land use policy questions, and are not meant to be an exhaustive list. While not all the models described below explicitly incorporate trade policy[21], or permit changes in the overall endowment of land in economic use, they are illustrative of the types of techniques which have been employed.

Cruz and Repetto (1992) use a conventional Shoven-Whalley type CGE model to analyze the environmental impact of structural adjustment policies in the Philippines during the early 1980s, including a 20 percent devaluation, a trade liberalization, and both together. The model contains fourteen production sectors, including forestry, forest products, and six land-using agricultural sectors. Land use in the agricultural and forestry sectors is accommodated by nesting a CES production function of land and capital within a higher-level CES function of labor and land/capital.[22] The quantitative results are reported in the form of output changes in sectors believed to be environmentally sensitive. There are no direct results on land conversion from natural to economic uses.

Coxhead and Jayasuriya (1994) conduct experiments using a CGE model with parameters which are "entirely hypothetical ... (but) broadly representative of Asian developing economies (p. 31)". The policy

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[21]Additional CGE models reported containing trade liberalization experiments pertinent to deforestation, but which were not available to be examined for this review, include Barbier and Burgess (1996) for Mexico, López (1993) for Ghana, and Thiele and Wiebelt (1994) for Cameroon, and van Soest (1996). Other models include results for devaluations, or agricultural export taxes.

[22]In 1992, the authors were able to write that "(f)ew other neoclassical CGE models include a land input." (Cruz and Repetto (1992), p. 58).

goal of the model is to understand changes in erosion-prone upland land use. The model contains four sectors (upland food, upland tree crops, lowland food and manufacturing). As in the Cruz/Repetto model, an initial land endowment moves from sector to sector (but not between the upland/lowland regions) and is neither created nor destroyed. The model is used to analyze technical improvements in each of the three land-using sectors and increases in manufacturing-specific capital. Environmental effects are reported in the form of output changes and land use changes.

Thiele (1995) analyzes policy changes affecting tropical deforestation in Indonesia using a trade-oriented CGE model with a submodel for the forestry sector along the lines of Dee (1991). In the forestry submodel, land is combined in Leontief fashion with a nested subaggregate of labor, capital and intermediate inputs, within which substitution is permitted. The forestry model includes an endogenously determined rotation period[23] constrained by a minimum harvest age manipulated by policymakers. The growth of trees takes place according to a logistic function. The supplies of land and other factors are exogenously fixed; land can shift among three crop categories and forestry, but not between two Indonesian regions (the Inner and Outer Islands). Three non-land-using sectors (fertilizer/pesticides, wood processing, consumer goods) contain strong linkages to agriculture and forestry, and six other sectors close the economy. Policies modeled include an increase in the minimum harvest age, land conversion to national parks, a factor tax on forest land income, and a reduction of the discount rate in forestry[24] (which is meant to represent an improvement in land tenure rights for timber concessionaires). Environmental results reported are in the form of sectoral production, land use changes in the Outer Islands, and changes in both the forest rotation period and the harvest volume per rotation.

Wiebelt (1995) uses a CGE model to analyze deforestation in the Brazilian Amazon. His model divides Brazil into two regions and contains eleven sectors, of which six use land (food crops, cash crops,

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[23]The length of time between two harvests in a specific area.

[24]The main CGE model appears to be a single-period model. The discount rate enters in through the forest submodel and is used to determine the rotation period and harvest per rotation.

other agricultural products, timber, livestock, and mining). Wiebelt models the open-access nature of land rights by assuming land to be in abundant supply at fixed rental rates, with each region having its own rental rate for land. The environmental results reported are thus in terms of increased land use. The model is used to analyze the effects of a devaluation, a tax reform that equalizes value-added subsidy rates across sectors, and a tax on non-forestry land in the Amazon.

Persson and Munasinghe (1995) use a CGE model to analyze the effects of government policies on Costa Rican forests in the presence of incomplete markets. Unlike the previous models, the Persson/Munasinghe model includes an explicit deforestation activity, in which forested land can be converted to cleared land. Loggers and agricultural squatters engage in separate deforestation activities. While the returns to these activities are independent, the return to logging declines with increased deforestation by squatters, and the return to squatting declines with increased deforestation by squatters. Squatters use some cleared land for subsistence agriculture and sell the rest to the agricultural sector. Squatters do not sell timber or use firewood.

Property rights to land can be "turned on and off" in the model. When property rights are undefined, loggers and squatters take only the private costs of deforestation into account; when they are well defined, logger and squatter costs include the opportunity cost of reduced future forest production, and there is an incentive to conserve forest.[25] By construction of the model, stronger property rights lead to less deforestation. Besides direct experiments with the property rights regime, the authors conduct comparative statics with respect to the discount rate and with a variety of taxes and subsidies. Though the model has a trade link with the rest of the world, no trade policy experiments are undertaken. Environmental results report the outcome of the deforestation activity, production in various sectors, and a measure of "green GDP."

[25]Like the Thiele model, the Persson/Munasinghe model is a static model with implied dynamic features, such as discount rates, playing a role in the forest-related processes.

Unemo (1995) examines changes in land use in Botswana, focusing on overgrazing in the livestock sector. Land use enters into the livestock and agriculture sectors, and is assumed to be suboptimally excessive because landowners do not take into account the effects of overgrazing on productivity. Specifically, individual herdsmen's output is increasing in their own number of cattle but decreasing in the total number of cattle. Land is assumed not to move between livestock and agriculture, as it is allocated by District Land Boards under the Tribal Land Act of 1968. Four additional sectors include a meat processing sector. A variable called the "stocking rate," calculated as the ratio of grazing land to the number of cattle, represents land pressure, and is the primary value of economic interest. Since grazing land is exogenous, an environmental improvement is defined as a decrease in the aggregate cattle stock. Experiments analyzed include removing the import tariff on crops, a fall in diamond prices, a fall in the terms of trade (simultaneous drops in the prices of diamonds and processed meat), capital inflows, and decreases in the supply of unskilled labor (due to increased migration to South Africa).

V. Conclusions and Directions for Further Research

At the present time, CGE models with forest submodels appear to be the most promising class of models for the analysis of trade liberalization effects on land use. The forest submodel may contain processes which are exogenous to the CGE model as a whole, or may (as in the Unemo "stocking rate") be entirely endogenously determined by other processes in the economy. The most useful features of such models include explicit land clearing processes, regional disaggregation, and representations of foresters' decision-making problem, as well as disaggregated representation of traded-goods sectors and trading regions suitable for modeling specific trade liberalizations. The currently feasible disaggregated represention of several dozen sectors and regions in trade-oriented CGE models, and their global coverage, contrast with the more aggregated and localized focus of most forest-oriented CGE models.

The insights from the household agricultural literature have not been fully incorporated into CGE models. Examples of this include the joint production of agricultural goods and fuelwood by the household, the wide variety of prices affected by trade liberalization which can impact land clearing, and the ambiguous effect of land tenure regimes on agents of land clearing. Incorporation of some of these features into the forest submodel, particularly joint production and richer price linkages, could significantly enhance the usefulness of available models.

An important challenge for modelers in this area involves the role of the off-farm wage. It is widely believed that an increase in off-farm wages could reduce deforestation significantly. There are two significant empirical problems with exploiting this insight at present. First, current CGE models either contain a single wage or perhaps several wages disaggregated by skill level or occupational category. It is not clear if any of these is a good proxy for the off-farm wage relevant to practitioners of shifting cultivation; also, modelers are not always careful about distinguishing the effects of liberalization on *real* wages (taking into account cheaper consumer prices) from the wage reported in terms of the model's numeraire. Second, as noted above, there is at present relatively little empirical work with which to benchmark the effect of off-farm wages on land clearing.

A possible creative modeling approach is to use existing results from household econometric models as forest submodels in conjunction with CGE modeling results on trade liberalization. The strategy would be to conduct the trade liberalization experiment in the normal way and feed price and income parameters into the econometric results obtained in a particular survey, thus giving estimates of the effects of (the Uruguay Round/the Millennium Round/ a regional liberalization) on land clearing in (the Ecuadorian Amazon/the Nepali highlands/whatever). A speculative, but potentially interesting, elaboration on this strategy would involve enhancing the set of price variables used in a particular household econometric model with relationships for additional relevant prices derived from similar models estimated from other regions, or from the modeler's judgment.

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