Forest transitions, trade, and the global displacement of land use

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Reducing tropical deforestation is an international priority, given its impacts on carbon emissions and biodiversity. We examined whether recent forest transitions—a shift from net deforestation to net reforestation—involved a geographic displacement of forest clearing across countries through trade in agricultural and forest products. In most of the seven developing countries that recently experienced a forest transition, displacement of land use abroad accompanied local reforestation. Additional global land-use change embodied in their net wood trade offset 74% of their total reforested area. Because the reforesting countries continued to export more agricultural goods than they imported, this net displacement offset 22% of their total reforested area when both agriculture and forestry sectors are included. However, this net displacement increased to 52% during the last 5 y. These countries thus have contributed to a net global reforestation and/or decrease in the pressure on forests, but this global environmental benefit has been shrinking during recent years. The net decrease in the pressure on forests does not account for differences in their ecological quality. Assessments of the impacts of international policies aimed at reducing global deforestation should integrate international trade in agricultural and forest commodities.

reforestation | deforestation | leakage | Reducing Emissions from Deforestation and Forest Degradation | embodied land

People continue to convert tropical forests into fields and pastures with deleterious ecological and climatic impacts even as some countries have experienced forest transitions, shifts from net deforestation to net reforestation (1–5). (In contrast with the definition of "reforestation" in forest science (1), we use the term "reforestation" to refer to any increase in forest cover, whether natural or plantation, over an area that previously was not covered by forest.) A better understanding of the economic, political, and biophysical conditions associated with these reversals in forest-cover trends should provide insights regarding policies for countries intending to reduce their rates of deforestation [e.g., to comply with Reducing Emissions from Deforestation and Forest Degradation (REDD)+ agreements under the United Nations Framework Convention on Climate Change (UNFCCC)] (6).

One theory argues that forest transitions occur because, over time, farmers discover their most productive lands, concentrate production on them, and abandon their least productive lands which then revert to forest (2). The local losses in agricultural production lead to the displacement of agricultural demand to heretofore uncultivated and more productive lands outside the country, which are less extensive than the abandoned lands in the countries experiencing forest transition ("FT countries"). If, over time and across nations, this pattern generates net reforestation, we could argue that we are in the midst of a global forest transition.

An alternative understanding of this dynamic involves "leakage," i.e., a displacement of deforestation to neighboring locations through migration of agents of deforestation or through trade in timber or agricultural products. Leakage decreases the regional and global environmental benefits of policies aimed at conserving natural ecosystems. For example, the rapid net gain in forest area in Vietnam since the early 1990s has been accompanied by an increase in timber imports from neighboring countries, a significant fraction of these imports being illegal (7). Strengthened forest-conservation policies and economic expansion in Vietnam led to the displaced demand. The associated increases in deforestation in the neighboring countries stemmed from demands originating outside their borders, an increasingly common circumstance in a globalizing agricultural economy (8, 9). Past forest transitions in Europe and New England in the 19th and early 20th centuries were facilitated by imports of timber from other regions (10, 11). Importing wood is the economic equivalent of exporting ecological impacts (12, 13). The international timber trade thus creates illusory images of conservation by preserving forests in accessible, affluent political jurisdictions while extracting natural resources from remote places with permissive or poorly enforced environmental policies (14). If local forest protection merely shifts forest-conversion pressure to natural forests elsewhere in the world, these policies will not achieve a net gain for nature at a global scale (12). This circumstance is particularly likely if pressures for conversion shift from degraded forests in long-settled, urbanized countries to biodiverse and carbon-rich primary forests in countries with short histories of forest exploitation and agricultural expansion.

To investigate these possibilities, we express the quantity of traded forest and agricultural products in terms of the land area necessary to produce them. Trade data allow computation of the balance of virtual or embodied land use being imported or exported at a national scale (15, 16). Gross displacement of land use generated by a country refers to the land use embodied in its imports of land-demanding products. Because most countries export as well as import such products (7), and higher agricultural exports often are associated with higher deforestation rates (9), a calculus of a country's net impact on global forest cover also must include the impacts of its exports. The land use embodied in exports is called "gross absorption" (of demand from elsewhere). Net displacement of land-use demands via international trade occurs when the land area required to produce the goods being imported exceeds the land area required to produce the goods that are exported. The opposite situation, i.e., when net displacement is negative, is called "net absorption." Both displacement and absorption occur when there is a "temporal, spatial, sectoral or social separation between consumption and production of a material good" (7).

This study tests whether there is an association over time between a reversal in national deforestation trends and an increase in net imports of wood or agricultural products. We are interested mostly in countries that recently have controlled deforestation and increased their forest cover. The hypothesis being tested was that, at a national scale, a slowing of deforestation and/or net reforestation is associated with an increase in net displacement or a reduction in net absorption of land uses via international trade. We analyzed the historical association of

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changes in nations' forest and agricultural land uses with changes in their net displacement/absorption of land embodied in trade of commodities whose production has a significant land-use impact. In particular, we asked to what extent an increase in forest area in FT countries is offset by the net land use displaced abroad to produce the imported agricultural and forestry products, net of exports. Did recent forest transitions result in a net saving of land area, or did they just redistribute the pressures on forests geo-

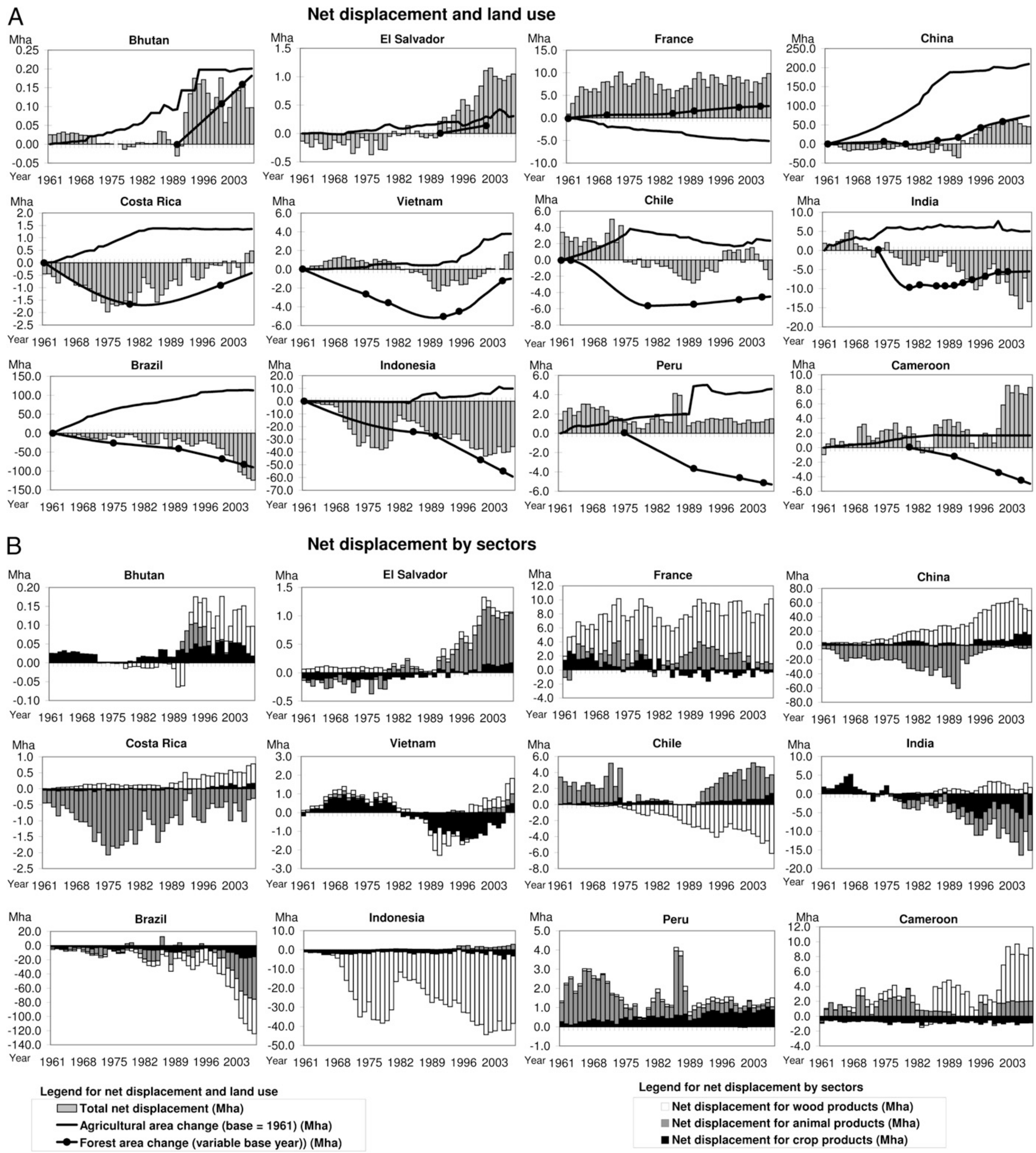

Fig. 1. Historical change in forest and agricultural area and in net displacement of land-use demand for the 12 countries studied. (*A*) Total net displacement/absorption across the three sectors, compared with forest cover and agricultural area. For visual representation, these two areas are represented as change in hectares compared with a base year that depends on the country. Data sources for forest and agricultural area are given in *SI Materials and Methods*. The dots in the forest-cover trends indicate actual data points, which were joined by spline interpolation. (*B*) Net displacement/absorption for the three sectors: crop, animal, and wood products.

graphically? Results could provide insights regarding the possibility of a global-scale forest transition.

We selected 12 countries representing a diversity of forest-cover trends and trade patterns. They include eight FT countries: the seven developing countries that recently experienced an forest transition (Costa Rica, Chile, El Salvador, Bhutan, China, India, and Vietnam) and one developed country that experienced a forest transition during the 19th century (France). For comparison, we selected four tropical countries that have not experienced forest transitions ("non-FT countries"): Brazil and Indonesia, which together represent 36% of the forest area and 61% of the gross deforestation in the humid tropics between 2000 and 2005 (17); Cameroon, an African country with high deforestation rates for the region (18); and Peru, a second neotropical country with low deforestation rates.

Quantities of traded goods in the agricultural, livestock, and forestry sectors were converted into the areas needed to produce those commodities based on yields and other characteristics of production systems in the producing country. We first calculated gross and net displacement for each of these three sectors. As a coarse measure of the effects of a country's trade on forests abroad, we then calculated the sum of the three sectoral net displacements. Net displacement has positive values, and net absorption has negative values. The Food and Agricultural Organization of the United Nations (FAO) and country-specific sources provided the data on forest cover trends (Fig. 1 and *SI Materials and Methods*). Linear bivariate regressions of net displacement/absorption on forest cover were performed on panel data of the different groups of countries and individually for each country to test the association between the two variables, correcting for temporal autocorrelation. We also controlled for economic growth, adding gross domestic product (GDP) or GDP/capita or their logs in the panel regressions. To assess the balance between net displacement/absorption and reforestation for the FT countries since the turning point of the forest transition, accumulated reforestation was calculated as the product of the area reforested multiplied by the number of years in which each new hectare has been under forest cover. Net accumulated land sparing was calculated as the accumulated reforestation minus the net area of land-use demand displaced abroad multiplied by the number of years for which each unit of area was displaced. A negative number indicates that, on net, a nation's population creates more land clearing through its consumption of agricultural and forest products than it releases by reforesting lands within its borders.

Results

For most FT countries, there was a statistically significant and positive association between trends in forest cover and net displacement ($P < 0.0001$; Fig. 1 and Table 1; also see regression plots in Figs. S1 and S2). When forest cover increases, net displacement increases or net absorption is reduced, or the country shifts from the latter to the former. When GDP (or GDP/capita) was added to the panel regressions, it did not affect that relationship and was not statistically significant. However, the dynamic between forest cover and land-use displacement does vary across countries. Among the FT countries, Costa Rica and Vietnam show a marked U-shape trend in forest cover; Chile and India show a hockey-stick curve with less-marked reforestation; Bhutan, El Salvador, and France show sustained reforestation over the period for which data are available; and China shows stable forest cover until the 1980s followed by recent reforestation. The other countries show a deforestation trend.

Displacement differs historically among the FT countries, with three (Bhutan, El Salvador, and France) being characterized mostly by a net displacement throughout the period, three (Chile, China, and Vietnam) oscillating between net displacement and net absorption, and two (Costa Rica and India) showing mainly net absorption. The non-FT countries with high deforestation rates (Brazil and Indonesia) are characterized by a net absorption throughout the period, whereas countries with lower deforestation rates (Cameroon and Peru) show net displacement overall. The area of agricultural land decreased in France over the study period and in Chile after 1976. In several FT countries (Bhutan, China, Costa Rica, India, and Peru), the area of agricultural land remained stable after the forest transition but did not decrease. In the other cases, the agricultural area increased.

Table 1. Linear regression of net displacement on forest cover

Panel regressions	Estimate
Countries with a forest transition	0.556***
Countries without forest transition	0.332
Regressions by country	
FT countries	
France	0.464†
Bhutan	0.313
China	0.928***
India	−0.0961
Vietnam	0.668*
Costa Rica	0.564†
El Salvador	0.624**
Chile	0.713***
Non-FT countries	
Cameroon	−0.835**
Indonesia	0.781***
Brazil	0.841***
Peru	−0.0607

***$P < 0.0001$; **$P < 0.001$; *$P < 0.01$; †$P < 0.05$.

Increasing forest cover is not associated with a growing displacement of agriculture abroad in all agricultural economies. Neither India nor Bhutan exhibits the expected relationship. In France, the relationship is present but is weaker than in countries with more recent forest transitions ($P < 0.05$). For non-FT countries, the positive association between trends in forest cover and displacement holds only for the two high-deforestation countries (Brazil and Indonesia, both $P < 0.0001$). Deforestation is significantly associated with an increase in net displacement in Cameroon ($P < 0.001$) but not in Peru.

A comparison of the accumulated values of reforestation and net displacement for FT countries after the onset of the transition shows contrasting situations (Table 2 and Table S1). When only the forestry sector is considered, the pressure on global forests created by the seven recent FT countries through their imports of forest products represents around 120% of their accumulated reforestation (Table S1). When their growing exports of forest products are taken into account, the net displacement is reduced to 74% of their accumulated reforestation. When all sectors are considered, the countries' net displacement represents around 22% of their total accumulated reforestation (or 39% if India is excluded because of its particular pattern). Overall, these FT countries compensate for the land use displaced through their imports of wood products with the land use absorbed through their exports of agricultural products. Thus, it is important to include not only imports but also exports and the associated absorption in calculating the net land-use effects of forest transitions (Figs. S3–S5). During the last 5 y, net displacement by all sectors increased to around 52% of the accumulated reforestation (69% without India). The net gains through land sparing decreased over time. Four countries—Chile, Costa Rica, India, and Vietnam—were net absorbers during their reforestation periods: Because of their exports of forest and agricultural products, their net land sparing increased when this absorption is taken into account. Net absorption represents between 36% (for Vietnam) and 266% (for India) of the accumulated reforestation in these countries (Table S1). Costa Rica and Vietnam have shifted from net absorbers to net displacers during the last 5 y. For China, the displacement is smaller than its accumulated reforestation and offsets 45% of its reforestation in total (and 74% during the last 5 y). For Bhutan, El

Table 2. Typology of patterns of displacement and forest-cover change for the seven recent FT countries

Country	Net displacement*	Net accumulated land sparing*	Association between net displacement and forest cover* (see Table 1)	Description
Bhutan	>0	<0	+	Increasing net displacement, with negative net land sparing
El Salvador	>0	<0	+	
China	>0	>0	+	Increasing net displacement, with positive net land sparing
Chile	<0	>0	+	Decreasing net absorption, with positive net land sparing
Costa Rica	<0	>0	+	
Vietnam	<0	>0	+	
India	<0	>0	–	Increasing net absorption, with positive net land sparing

*See Table S1 for quantitative data on net displacement, accumulated reforestation, and net accumulated land sparing.

Salvador, and France, net land sparing is negative when net displacement is subtracted from their reforestation. These countries have used more land abroad than they have reforested within their boundaries.

Discussion

Forest-Cover Change, Trade, and Displacement. Economic theory predicts that interactions between trade and land use in countries are founded on the comparative advantages of different types of production, depending on the relative costs of production factors (19). As an illustration, during the past 2 decades, Chile has expanded its forest plantations (Fig. 1), so it now absorbs demands for wood products from other countries at the same time that it displaces abroad its own demands for crops and livestock. However, this case is the exception rather than the rule. The more prevalent pattern features forest recovery at home and land-use demand displaced abroad. Countries that increased forest cover, such as China, France, and El Salvador, displaced some of the demand for crops, livestock, and wood generated by their people to other countries (Fig. 1, Table 1, and Table S1). Agricultural expansion and forest exploitation elsewhere in the world facilitate forest regrowth in places undergoing forest transition (11).

This pattern, although readily visible, obscures important dynamics. It assumes that forests and fields constitute the universe of land uses, so an increase in forest cover implies a decline in fields under cultivation. This categorization of land uses neglects fallow and underutilized, degraded lands that are covered by scrub growth, including invasive species. These lands may become the sites for tree plantations, allowing, as in Chile, forest plantations to expand without a commensurate decline in agricultural land area or, as in China and Vietnam, forest and agricultural areas to increase simultaneously.

In addition to Chile, three nations depart from the forest growth–land-use displacement model. Cameroon and Peru exhibit continued losses of tropical forests coupled with displacement. This pattern is explained by a form of economic dualism involving two disconnected sectors. In one sector smallholders, engaged in shifting cultivation, continue to clear land to grow a mix of subsistence and marketed crops; in the other sector rapidly growing urban populations with nonfarm income sources become increasingly dependent on foreign foodstuffs. This pattern is most prevalent in Africa (20), but it also characterizes states such as Peru that earn substantial revenues from oil and spend most of it in urban areas (21).

Other forces shape the land-use–trade dynamic in important but often idiosyncratic ways. In India, increases in population, consumption standards, and forest cover occurred simultaneously. Rather than displacing demands for foodstuffs to other, more land-abundant nations, India began to absorb demands from other countries. First, India adopted new green-revolution seeds for cereals in the 1960s and 1970s, becoming self-sufficient in cereal production in the 1970s and beginning to export small quantities of cereals in the 1980s. After 1990, a growing proportion of the absorption of foreign demand occurred in animal (particularly dairy) products. The Hindu taboo on beef consumption and the ban on slaughtering cattle in most Indian states have led to very large numbers of cattle and high volumes of dairy production. In 2000, India had about 27% of Asia's population and more than 50% of Asia's dairy production. With the expansion in markets, cooperatives, and the spread of refrigeration technologies after 1990, Indian entrepreneurs began to market more of the country's dairy production abroad. With this shift from a subsistence to a market economy, the increase in exports did not induce a large-scale creation of pastures in India. Forests have increased largely through plantations on degraded lands (22), so India has been able simultaneously to increase tree cover and to absorb the increased demand for dairy products from other Asian populations.

In most cases, the displacement in land use stems from a growth in demand that cannot be met through national production. A decrease in absorption can correspond to agricultural production that is still growing but at slower rates than demand (e.g., meat production in China and agricultural products in Vietnam). An increase in displacement can correspond to a stagnation of production (e.g., for wood sector in India, China, Costa Rica, and Vietnam). In France, cropland area decreased, but agricultural production did not. In all these cases, reduction of domestic production was the result of conservationist policies reducing the extraction of round-wood or setting aside agricultural land.

An examination of the deviant cases suggests both the potential and the limits of interpreting forest transitions in terms of their effects on export agriculture. This approach illuminates forest-cover trends both in a set of countries experiencing forest transition and displacing their agricultural demands elsewhere (e.g., France, China, and El Salvador) and in countries absorbing these demands, undergoing large-scale agricultural expansion, and losing forest cover (e.g., Brazil and Indonesia). This approach is less illuminating when applied to societies such as India, Cameroon, and Peru, in which many cultivators practice peasant agriculture, producing for themselves and for local markets. In Peru, agricultural expansion does not lessen urban consumers' reliance on foreign sources of food. Similarly, as in India, the conversion of a largely subsistence and locally marketed sector such as dairy into an export sector produces anomalous results: the simultaneous absorption of demands for dairy from abroad and an increase in tree cover. To capture these complexities, the global approach used here needs to be complemented by an analysis of local dynamics of intensification, production, and consumption in FT countries.

Net Consequences of Change. With the increasing globalization of trade, more countries displace their demands for agricultural lands abroad (i.e., 6 of our 12 countries in 1961 versus 8 in 2006). The more striking change involves the concentration over time of agricultural expansion to absorb demand from abroad (23). Compared with patterns in the 1960s, a much larger proportion of the postmillennium displaced demand is being absorbed by a few countries (Brazil, Indonesia, and Chile for timber and India for dairy products). Consistent with this pattern, Brazil and Indonesia accounted for 64% of the global loss of old-growth tropical forests between 2000 and 2005 (9). The geographical concentration of agricultural expansion most likely reflects efforts to realize economies of scale by concentrating the planting of cultivars such as soybeans (24). It also reflects the exploitation and exhaustion of smaller and more accessible rain forests in smaller countries, a process that, in turn, drives timber and agricultural enterprises to focus their land-clearing efforts on the few countries with large blocks of still unexploited forests.

Beyond this global pattern, the FT countries exhibit considerable variability in their trade flows and landscape changes. Three of the four patterns present in the data (Table 2) provide empirical support for the forest-cover gain–agricultural displacement hypothesis. However, there is a major difference between decreasing net absorption, as in Costa Rica, where efforts to promote environmental sustainability took place at the cost of reducing beef exports, and increasing net displacement, as in China, where economic growth relies increasingly on external natural resources (Figs. S3–S5). Five of the seven countries in Table 2 exhibit net land-sparing gains, suggesting some empirical support for the possibility of a global forest transition, even as forest regrowth in one country displaces overseas some of the demand for forest and agricultural products. However, the net balance of land spared for nature globally is decreasing over time, as in China where most of the recent reforestation was offset by displacement. The Chinese example suggests that a rise in standards of personal consumption may be driving the decline in net environmental benefits from forest transitions. Indeed, in France, net displacement was much larger than the small reforestation gains during the last 45 y (Fig. 1).

Further work with net reforestation measures must engage with four measurement problems. First, net absorption of land-use demand in a country like Brazil indicates land spared abroad rather than verifiable reforestation. Idle farmland or degraded wastelands may increase in the countries that displace their land demand abroad. Likewise, displacement may not result in deforestation if the imports are produced on nonforested land. In the last decade, however, global agricultural land expanded mostly through the conversion of tropical forests (25). Second, land demand for wood products can have variable effects on forest cover, depending on logging practices (clear-cutting versus selective logging), on the origin of timber (from plantations, primary, or secondary forests), and on the likelihood that logged land will be converted into agricultural land. Adequate forestry management could allow simultaneous increases in harvests and forest biomass (26), but these management strategies are uncommon in the tropical regions that are the most likely to absorb the bulk of future displacement of land use for agricultural and forestry products. Overall, displacement of land use for both agricultural and forestry products from one country is likely to affect natural forests elsewhere, mainly in the tropics. For our sample of countries, the combination of uncertainties shows no evidence of systematic bias in the estimation of displacement (*SI Materials and Methods*). Third, illegal trade of wood products is not recorded in the trade databases used. Net displacement thus is underestimated for countries that import timber illegally, as shown for Vietnam (7), and is overestimated for countries sourcing illegally traded wood.

Finally, an accounting of land-use changes in terms of area does not measure large differences between forests in terms of carbon stocks, biodiversity, ecosystem services, and contribution to livelihoods. For example, when reliable data on plantations versus natural forest regrowth are lacking, an increase in total forest cover can hide a decline in natural forest area (22). A more thorough assessment of the net consequences of land-use displacement must include these factors as well as the environmental effects of transporting goods and of inputs and effluents associated with different modes of production.

Costa Rica and China illustrate both the potential and the difficulties of such an assessment. Costa Rica has a simple trade structure, with most of the exchanges taking place with the United States. The main exports are beef, coffee, and bananas (the last two also being exported to Europe); the main imports are wheat, soybeans, maize, paper, and paperboard. Costa Rica is a biodiversity-rich, humid tropical forest country. Its imports of wood products originate from North American temperate ecosystems. Saving forests in Costa Rica at the expense of forests in the United States leads to a more positive balance in terms of carbon sequestration and biodiversity conservation than suggested by calculations of land-use areas. The trade structure of China is more complex. Large amounts of products transit via Hong Kong and Macao; destinations are not always recorded, trading partners are numerous, and trade is diversified. The main imported crops are soybeans (from Brazil, Argentina, and the United States), wheat (from North America and Australia), and maize (from the United States in the 1960s through the 1980s and from Southeast Asia and Australia later). Beans, maize, rice, and tea are exported mainly to Asia and Africa. Land-use demand for animal products shows a declining net absorption. Animal products come mainly from North America and Australia and are exported mainly to neighboring countries. Wood production is increasingly displaced to Southeast and East Asia, Russia, North America, and African countries, and wood products are exported globally. Thus, goods are traded with countries from different biomes (temperate, boreal, tropical, and subtropical) and with developing and developed countries. China often imports raw products (e.g., round-wood, soybeans, maize) and exports processed goods (e.g., wood furniture, paperboard containers, meat). Given these complexities, tracing the true ecological impacts of the land use embodied in China's trade is challenging.

Conclusion: Policies, Trade, and Pathways to Forest Transitions

In most countries that have experienced forest transitions, displacement of land-use demand abroad accompanies forest recovery. This increase in displacement appears to be associated with reforestation rather than an independent, direct effect of economic growth in these countries. In the countries we studied, additional global changes in land-use embodied in their net wood trade offset 74% of their total reforestation. Because of their exports of agricultural products, this net displacement represented 22% of their total reforestation when all sectors are included but increased to 52% during the last 5 y. So far, these countries have contributed to net global reforestation and have decreased pressure on forests, but this global environmental benefit has diminished in recent years. This accounting, although useful, does not measure the full ecological and social consequences of reforestation in one place and displacement of land uses elsewhere, because it does not consider the large differences among forest types in carbon stocks, biodiversity, ecosystem services, and cultural value.

For some countries, economic globalization facilitates a national-scale forest transition through the displacement of agricultural demands overseas. Other countries absorb these demands, undergo large-scale agricultural expansion, and lose forest cover. Some countries deviate from this pattern: In India, in particular, reforestation has been associated with an increased absorption of land-use demand from abroad. The observed association between changes in forest cover and trade in agricultural and wood products does not imply that global trade alone is sufficient to induce major land-use transitions and spare land for nature. Policies targeting forest conservation, reforestation, agricultural intensification, and land-use planning also contribute to forest transitions and may be critical to obtain net land sparing (27, 6, 5). Leakage, although present, does not entirely offset the ecological benefits from these policies. Even with such policies, displacement also can occur as a result of economic specialization in a particular sector, as in Costa Rica and Cameroon, or economic growth that increases national demand for some commodities, as in Vietnam (7) and China.

Given the geographic heterogeneity of the world's forests in their ability to provide ecosystem services of global value, adjustments of spatial patterns of land use on a global scale can contribute to land sparing and can enhance ecosystem services. Absent any global governance regime for forests, land-use transitions are shaped by national land-use policies, the free-trade regime, and decisions by traders. Local-level policies to control deforestation, although necessary, will not be sufficient to slow the destruction of forests on a global scale. There are policy options to increase forest cover in a country without exporting deforestation elsewhere. International policies, such as those under the UNFCCC's Kyoto Protocol or REDD+, aimed at rewarding countries that engage in reforestation/afforestation and reduce deforestation, could monitor the displacement of land use via international trade. Approaches relying on incentives and certifications, such as the Roundtable on Sustainable Palm Oil (28), forestry certification schemes (29) and the European Union plan for Forest Law Enforcement, Governance and Trade (FLEGT) (30) can reduce deforestation provided that (*i*) the encompassed production accounts for a significant share of the global supply and area suitable for production, (*ii*) indirect effects of land-use displacement are taken into account, and (*iii*) the policy mandates not only the sustainability of the traded production but also an overall change in the sustainability of the production systems in the country, such as in the Voluntary Partnership Agreements of the FLEGT scheme (30). Otherwise, forest encroachment still might occur, with net costs to the global environment. This discussion also applies to policies supporting biofuels (31). By extension, if REDD+ policies are to be effective, they must be accompanied by trade regulation and efforts at global land-use management beyond the borders of individual countries.

Materials and Methods

Calculation of Displacement and Absorption. All calculations of displacement/absorption were based on data from the country or region actually producing the traded goods. Net displacement thus measures the area that actually has been used in other countries to produce all crops and livestock products consumed in the country for which displacement was calculated. For each country, all imports of crop products, meat and dairy products, and wood products for 1961–2007 were compiled from the FAOSTAT (http://faostat.fao.org/) and United Nations COMTRADE (http://comtrade.un.org/db/) databases. For crop and wood products, a subset of goods was selected, defined to represent at least 80% (usually >90%) of the total quantity of imports of each year. For each sector and selected products, the proportions of imports coming from the main source countries in 1970, 1980, 1995, 2000, and 2005 were identified in the COMTRADE database and were linearly interpolated for the other years. The characteristics of the production systems of each source country were derived from FAOSTAT for crop production, from FAOSTAT and refs. 32, 33, 34 and http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html for animal production systems by world regions, and from refs. 35 and 36 for of wood production systems globally and by country (*SI Materials and Methods*). Yields varied over time for agricultural products but were constant for forestry products. Based on these characteristics, the annual area needed for the main products imported was calculated and was extrapolated to the annual area required for the total quantity of imported products based on the proportion of imports included in the main products. This value represented the gross displacement for each sector. The same method was used to calculate the annual area required for the total quantity of exported products (i.e., the gross absorption) by sector.

Association of Displacement, Land Use, and Forest-Cover Change. Bivariate regressions were used to test the association between net displacement/absorption and forest-cover change instead of correlations because of the panel structure of the data and the presence of serial correlation. We used linear panel regressions for the two groups of countries and ordinary least squares linear regressions for each country (*SI Materials and Methods*).

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