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Agricultural Technology and Forests: a Recapitulation

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1. Viewing the Link in the Larger Context

The opportunity for farmers or companies to capture a forest rent by converting forest to pasture or cropland largely drives deforestation. A number of factors help create such opportunities beside agricultural technologies. These include high output prices, road construction and maintenance in forested areas and cheap and abundant labour and capital, among others.

To understand the link between agricultural technology and tropical deforestation, one must view it within this larger context. The contributors to this book have sought to keep a clear focus on the link between technology and deforestation, without losing sight of the context in which that link occurs. This chapter summarizes their main findings and draws general lessons.

Section 1 presents six representative situations with regard to the technology–deforestation link in different agricultural systems or contexts and recapitulates the key points from each chapter. Section 2 looks at the main conditioning factors that determine how technological change affects forests at a more general level.

2. Six Typical Technology–Deforestation Stories

We divided the cases presented in this book into six categories: developed countries, commodity booms, shifting cultivation, permanent upland (rain-fed) agriculture, irrigated (lowland) agriculture and cattle production. Several of the book's chapters deal with more than one category (Table 21.1).

Table 21.1. The six typical technology–deforestation stories discussed in the book.

Context	Chapters	Key lessons
1. Developed-country history	Mather (3) Rudel (4)	Reforestation and agricultural yield increase can be part of a development that also includes technologies less suited for marginal land, new off-farm jobs and forest regulations
2. Commodity booms	Kaimowitz and Smith (11) Ruf (16) Wunder (10)	When the right (wrong?) conditions exist (technology, export market, cheap labour and capital, abundant forest, favourable policies), large-scale deforestation difficult to stop by economic incentives. Direct regulations (e.g. protected areas) needed
3. Shifting-cultivation systems	Holden (14) de Jong (20) Ruf (16) Yanggen and Reardon (12)	New technologies can, in principle, reduce the need for land, but farmers often choose to expand land area. If migration is also attractive, the innovations easily become deforestation agents
4. Permanent upland cultivation	Cattaneo (5) Coxhead *et al*. (19) Holden (14) Jayasuriya (17) Pichon *et al*. (9) Reardon and Barrett (13) Reid *et al*. (15) (Roebeling and Ruben (8))	Outcome depends on factor intensities and market conditions. A potential for 'win–win' if new technologies can shift resources from more extensive systems. But long-term effects on migration can increase pressure on forests, and higher farm surplus can be invested in forest clearing
5. Irrigated, intensive agriculture	Jayasuriya (17) Ruf (16) Shively and Martinez (18) (Rudel (4))	Probably good due to supply effects and possibly also labour-market effects, but several caveats: might be labour-saving, relax capital constraints and increase demand for upland crops, all of which stimulate deforestation
6. Cattle in Latin America	Cattaneo (5) Roebeling and Ruben (8) Vosti *et al*. (7) White *et al*. (6) (Pichon *et al*. (9))	Improved pasture technologies, if adopted, tend to increase farm income and deforestation, presenting a win–lose situation. Policy packages have the potential for 'win–win'

2.1. Developed countries

The concept of a forest transition plays a central role in the historical reviews by Rudel and Mather. This implies that forest cover declines before it levels out and slowly increases again. Since the first half of the 19th century, forest cover has risen in several European countries, including the three studied by Mather: Denmark, France and Switzerland. At the same time, agricultural yields have steadily increased. This might suggest that growth in yields helped reverse the decline in forest cover. But, as both authors note, these processes occurred in the context of radical social changes, which undoubtedly had their own large impact on forest cover, which makes it difficult to assess the marginal effect of technology on forest cover.

What were these other changes? In both Europe and the USA, better transport networks made agriculture more commercially orientated, weakened the connection between local population growth and agricultural expansion and allowed for more specialized production based on local conditions. These factors, combined with new agricultural methods that tended to be more suited to fertile lands, helped shift agricultural production from marginal to fertile regions. Some abandoned marginal agricultural lands reverted to forest, either through natural regrowth or through tree planting. Deforestation continued in some more favourable agricultural areas, but reforestation of marginal lands more than offset it.

The rural exodus, largely driven by new industrial jobs in the cities, reduced the labour available for agriculture, grazing and fuel-wood collection, thus raising its cost. Even though the mechanization of the American South allowed farmers to cultivate the same area with less labour, a steadily expanding urban labour demand absorbed the labour that mechanization expelled, so deforestation did not rise as a result. In many European countries, migration to 'the New World' relieved the pressure from otherwise growing rural populations. Shifts in energy supply from wood to coal and later other fossil fuels reduced demand for fuel wood. This also contributed significantly to the forest transition.

Political and cultural changes played a central role as well. The state emerged during the 19th century as a legislative and technical agent of environmental management. The enclosure movement and special laws separated woodland from farmland in Europe. As Mather notes, society began to view forests differently; in particular, forests became 'more than timber'.

The history of the present high-income countries offers several relevant lessons for today's low-income countries. The European and North American experiences demonstrate that new agricultural technologies and yield improvements can go together with increasing forest cover. But other elements of development, such as the growth in urban employment, policies that clearly separated forest from agricultural land and an active state, willing and able to enforce environmental regulations, were at least as important as agricultural technologies.

While the history of the developed world and present-day developing countries have certain similarities, one must take care not to go too far in drawing the parallels. The world economy has changed over the years. Developing countries are increasingly integrated into a global economy, which is very different from the one that existed 100 years ago. The policy environment also differs. Rudel notes that 'The American state launched more programmes that affected forests than the contemporary neoliberal states of the developing world will ever do.'

2.2. Commodity booms

Commodity booms offer the most sensational stories of how new technologies – combined with other factors – can convert millions of hectares of forest to cropland in short periods of time. Wunder's chapter on bananas in Ecuador, Ruf's work on cocoa in Côte d'Ivoire and Sulawesi (Indonesia) and the piece by Kaimowitz and Smith on soybean in Brazil and Bolivia provide examples of such booms. Note, however, that the factor intensities of the new technologies differed sharply in the three cases. Soybean is highly capital-intensive, while cocoa is labour-intensive. During the early stages, banana production was labour-intensive but it became increasingly capital-intensive.

Commodity booms and deforestation generally occur when five conditions coincide:

1. International markets can absorb the additional supply without significantly depressing the price.
2. Policies stimulate forest conversion to the new crop.
3. Production can expand into abundant forest areas.
4. Cheap labour is available to plant the new crop.
5. Someone provides the capital to finance the expansion.

The history of cocoa over the last four centuries resembles a cyclone that moves from country to country, wreaking destruction on large tracts of tropical forest. The key to understanding this process is the concept of forest rent, defined as the extra surplus (reduced costs) farmers get by producing a crop on recently cleared forest, rather than in an area that has had crops for some time. Pests, diseases and weeds make it much more expensive to produce cocoa in old cocoa plantations. In addition, the rural labour pool ages and becomes less productive after the first few decades of agricultural colonization. To a lesser extent, this applies to other crops as well. Thus, once farmers have exhausted the forest frontier in a given region or country, some other region with large forest areas will attain a cost advantage and take over. It is Adam Smith at work. The invisible hand guides production to regions with the lowest production costs, sometimes assisted by both visible and invisible political lobbying aimed at facilitating the move.

Commodity booms are linked to labour migration or large pools of underemployed labour, at least when they involve labour-intensive production systems. Again, migration often responds not only to market signals pointing to new economic opportunities, but also to policies that encourage people to move. The first president of Côte d'Ivoire actively promoted migration to the forest frontier, with the slogan 'the land belongs to those that develop it'. Similarly, Indonesia's transmigration programme moved several million people from Java and Bali to the outer islands, including Sulawesi. In both cases, not only did the new migrants provide the necessary labour for the cocoa booms, but immigration also stimulated local inhabitants to 'race for land' with the new migrants by planting cocoa.

As has occurred with agriculture in general, production in the three cases has become more input-intensive over time. In the banana case, the new 'Cavendish' variety required more infrastructure and inputs than the old 'Gros Michel' variety, besides being more perishable. This made production less mobile, which benefited the forest, but excluded smallholders, who lacked sufficient capital to grow the new variety. Similarly, Ruf provides examples where farmers have begun to apply herbicides in their cocoa plantations and notes that this could help prevent the weed problem associated with replanting old plantations.

In both the banana and cocoa cases, greater use of capital inputs had the potential to reduce pressure on forests, but farmers expressed little interest in this type of technology until they ran out of forest where they could expand their operations. In Ecuador, farmers adopted the 'Cavendish' variety after extensive expansion had reached its limit. Ruf also notes that forest scarcity was a major force driving herbicide adoption. Moreover, even in cases when farmers adopted herbicides while a forest frontier still existed, herbicides apparently did not reduce cocoa expansion into forest. As a village leader in Sulawesi noted, 'the fish in the river always look thirsty'.

The dynamic investment effect Wunder and Ruf observe partly explains why technological change did not reduce deforestation in these cases. Ruf describes how the Sulawesi cocoa farmers invest their surplus in expanding their cocoa farms. Wunder points to macro-level investment effects. The banana boom generated additional income for the government, which the latter used in part to invest in infrastructure and credit for further agricultural expansion.

The soybean story differs significantly from cocoa and, to a lesser extent, bananas. It involved heavy capital costs for transportation, storage, processing and marketing. This permitted the industry to achieve regional economies of scale. Once technology and favourable policies helped production reach a critical level, economies of scale and cheap land on the frontier combined to greatly stimulate forest conversion. High capital requirements could have constrained soybean expansion, but they did not. Subsidized credit was plentiful in Brazil until the 1990s and Bolivian farmers had access to private credit.

Not all the soybean expansion took place at the expense of natural forest. Some of it replaced other types of natural vegetation or other crops. But, even where soybean replaced other crops, as in southern Brazil, it had wide-ranging effects on forests. Soybean cultivation there displaced labour and many small farmers could not afford the machinery and chemicals that growing soybean requires. Many sold their land and moved to the Amazon frontier, where they cleared forest for crops and pasture. Cattaneo's simulation model of Brazil backs up this story. He found that capital-intensive innovations outside the Amazon that were labour-saving led to substantial increases in deforestation within the Amazon.

2.3. Shifting cultivation

Some 200–300 million farmers in the tropics practise shifting cultivation. After one or a few years of crops, they leave their land fallow for some longer period to allow the soil to recuperate. For a long time, Boserup (1965) and others have argued that this system is a rational response on the part of farmers to situations of land abundance. Boserup further argued that, as long as land remains abundant, expanding the area cultivated will generally provide higher returns per day of labour than cultivating existing agricultural land more intensively. As a result, farmers tend to exploit the extensive margin before they exploit the intensive one. This is bad news for those interested in forest conservation, since it implies that farmers will not intensify until the forest has already disappeared. Mounting evidence supports Boserup's main claim, pointing to a key dilemma.

Still, in some instances, farmers intensify even when forest is still available. This volume discusses three important forms of intensification of shifting-cultivation systems. Holden examines the introduction of a new principal crop – cassava – in the *chitemene* shifting-cultivation system in Zambia. De Jong and Ruf look at the introduction of commercial tree crops (rubber and cocoa, respectively) following annual crops. This can be seen as enriching the fallows, but often the new cash crop becomes the dominant reason for expansion. Yanggen and Reardon explore the impact of kudzu fallows in Peru, which farmers use to help fallow soil to recuperate more rapidly, enabling shorter rotations.

Intensification of shifting-cultivation systems can increase the output of total agricultural land (cropping and fallow) several-fold. The adoption of cassava in northern Zambia multiplied the carrying capacity of the shifting-cultivation system two to six times. It also allowed farmers to convert to a short-rotation fallow system with a carrying capacity about ten times higher. It was labour-saving and coincided with a major out-migration of males, who went to work in the copper industry. Thanks to the exodus of workers, the new technology did not result in freeing additional labour to clear more land. Thus, in the short term, the replacement of finger millet by cassava reduced deforestation. However, Holden argues that, in the long run, the introduction of cassava will probably induce more deforestation and soil degradation, since higher agricultural productivity has paved the way for higher population densities and allowed families to settle in new marginal areas.

In the past, many analysts have blamed the introduction of rubber into shifting-cultivation systems in South-East Asia for provoking large-scale forest conversion. De Jong critically examines this claim. In the areas of West Kalimantan (Indonesia) and Sarawak (Malaysia) that he studied, rubber contributed little to encroachment into primary forest. On the contrary, it favoured the incorporation of additional tree cover in lands previously used for agriculture, and rubber gardens (or rubber-enriched fallows) produce various economic and ecological benefits. This result contrasts with both Ruf's description of the cocoa story in this volume and the experience with rubber elsewhere in Indonesia, where tree crops have promoted deforestation.

What makes de Jong's cases different? First, farmers had a reserve of already cleared land where they could plant rubber. Secondly, many of these areas were quite isolated and had low in-migration. Thirdly, government enforcement of forest regulations constrained forest encroachment. In the case of cocoa in the neighbouring island of Sulawesi and of rubber in other regions, these conditions did not hold. In these cases, a large labour reserve, reasonable accessibility and new economic opportunities induced migration, while government forest regulation provided few checks. In fact, the state apparatus actively encouraged forest conversion. Under these circumstances, tree crops can rapidly reduce the primary forest cover.

Improved fallows provide a third way to intensify shifting-cultivation systems. Kudzu is a leguminous vine that fixes nitrogen and makes more nutrients available to the soil, which speeds up soil recuperation. It also suppresses weeds, reducing the demand for labour for clearing and weeding. Kudzu therefore permits shorter fallow periods. This should reduce the stock of fallow land, allowing for a larger forest area. It is a low-cost, labour-saving technology that increases yields (of total agricultural land, including fallow) and could potentially save forests. What more could you wish for? But, as Yanggen and Reardon point out, no one can guarantee the forest-saving part. Indeed, higher productivity and labour saving pull in the opposite direction. The two authors' econometric analysis shows that kudzu reduces primary-forest clearing, but boosts secondary-forest clearing, with the net effect being a modest rise in total forest clearing.

In all cases examined, intensification greatly increased yields at a low cost. Under such circumstances, farmers will be prone to intensify their shifting-cultivation systems, even where forest remains abundant. However, it does not necessarily follow that intensification will reduce deforestation. One may well get intensification *and* expansion.

Finally, shifting-cultivation systems beg us to clarify what we mean by 'forest'. Does it include secondary forest and fallow and tree crops, such as rubber? We return to this issue later, in the next and final chapter.

2.4. Permanent upland (rain-fed) cultivation

Permanent upland cultivation (PUC) is common throughout the developing world, although many farmers combine it with shifting cultivation, irrigated cultivation, tree crops or cattle.[1] To understand the overall pattern of land use, we need to consider the demands each of these activities makes on the farmers' labour and capital constraints.

This volume discusses different types of technological change in PUC. These include adoption of high-yielding varieties, introduction of new crops, increased fertilizer application and pest control. Holden analyses the impact of a high-yielding maize variety, introduced in Zambia in the 1970s, accompanied by greater fertilizer use. This capital-intensive technological package discouraged extensive shifting cultivation, but depended on public support. Once the government reduced fertilizer subsidies and removed pan-territorial pricing as part of its structural adjustment policies, the process went into reverse. This provides an argument for renewed targeted support for intensive farming, although earlier policies put a heavy burden on government budgets.

Reardon and Barrett base their defence of 'sustainable agricultural intensification' (SAI) on roughly the same argument. They argue that, to produce more food without degrading the environment, farmers must use more capital, which they broadly define to include inorganic fertilizers, organic matter and land improvements. Reduced government support for farming, higher input prices and declining infrastructure investments encouraged farmers to follow an unsustainable path of intensification or to expand their activities further into the forest or other types of natural vegetation. Although they acknowledge that intensification *per se* will not necessarily reduce expansion, they argue that failure to move towards an SAI path will inevitably lead farmers to expand into the fragile margins. They also note that many quasi-fixed capital investments increase the productivity of the existing cultivated areas more than newly incorporated lands, which favours intensification over land expansion.

African agriculture takes place in a high-risk environment, related in part to widespread pests. Tsetse-flies transmit trypanosomosis in over 10 million km^2, causing morbidity and mortality in livestock and, to a much lesser extent, humans. Tsetse control makes animal traction possible, or at least more productive, and saves large amounts of human labour. While it obviously benefits farmers and animals, Reid *et al.* focus on the impact on forests, including woodlands. Trypanosomosis control encouraged agricultural expansion in their study area in Ethiopia, in part because households with fewer disease problems were able to plough more land.

Coxhead *et al.* also discuss the problems of pests and risk. Using household data from northern Mindanao, the Philippines, they explore how technological changes in vegetable production may affect farmers' demand for maize and vegetable land. Since vegetable production is more labour- and capital-intensive, one might expect a labour- and capital-constrained household that switches over to vegetables to occupy less land. However, Coxhead *et al.* find that technological changes that reduce yield variability and increase yields without affecting factor intensities will have small effects on farm area.

According to Pichon *et al.*, risk-minimizing strategies play a critical role in the land-use decisions of settlers in the north-eastern Ecuadorean Amazon. They conclude that two major reasons why these labour-constrained farmers grow coffee, despite the fact that it is a labour-intensive crop, are that it provides long-term income security and has a readily available market. This is another case where farmers proved willing to intensify even though they operate in a forest-abundant context. In this case, intensification seems to have reduced forest clearing. Those farmers whose production systems focus on coffee tend to maintain more than 50% of their plot in primary forest, even after several decades of working on their farm.

An important lesson emerges from these chapters. To predict the effect of technological change on total demand of farmland, one needs to adopt a whole-farm approach and take into account the interaction between different production systems within the farm. Each system fulfils household objectives, such as income generation, food security and risk prevention, to various degrees and has its own labour and capital requirements. Technological change that both increases yields and requires more labour has the potential to reduce overall farm demand for land, particularly in the short run.

2.5. Irrigated, intensive (lowland) agriculture

The Borlaug hypothesis suggests that new green-revolution technologies in lowland agriculture will save the forest by lowering food prices and thus making expansion less attractive and by increasing agricultural wages and thus making migration to frontiers less attractive. The chapters by Jayasuriya, Ruf and Shively and Martinez examine this issue in the Asian context. Rudel discusses the historical experience of the American South.

Shively and Martinez's study of Palawan in the Philippines provides evidence supporting the labour-market part of the Borlaug hypothesis. A project for improved small-scale irrigation systems raised the average cropping intensity (crops per year) and therefore labour demand. This resulted in a boom in the local labour market and pushed up wages. The availability of more and better-paid jobs in lowland agriculture in turn made it less attractive for the nearby upland population to expand their own agricultural activities, and forest clearing declined by almost 50%.

Green-revolution technologies, including irrigation, normally have a double effect on labour demand. Higher cropping intensity implies higher demand, but labour input per cropping season might decline, due to mechanization or the use of herbicides. The first effect dominated in Palawan. But Ruf presents a case from Sulawesi, Indonesia, where green-revolution technologies have saved labour and released it for use on the cocoa frontier.

Independently of its effects on labour markets, technological progress in intensive agriculture has output-market effects. Analysts normally use economy-wide models, such as the ones presented by Jayasuriya and Cattaneo, to study such effects. Generally, the price-reducing effect of higher agricultural supply resulting from the introduction of green-revolution technologies should favour forest conservation, particularly since food demand is generally inelastic. Nevertheless, there are important caveats. To significantly affect upland deforestation, upland and lowland crops should compete in the same domestic market. If one of them is traded internationally or they are not close substitutes in the domestic market, the impact is likely to be negligible. In addition, any positive output-market effect must outweigh effects pulling in the opposite direction. For example, if lowland technologies displace labour and induce migration to forest frontiers, this effect could potentially override the output-market effect. Further, as in other types of agriculture, technological progress in intensive agriculture can help farmers overcome capital constraints to expanding their agricultural areas by providing funds for investment, as evidenced in the cocoa study.

In the past, researchers have tended to overlook a point made by Jayasuriya – that technological progress in intensive agriculture (and elsewhere in the economy) can raise the demand for upland crops and therefore stimulate forest conversion to expand the area of these crops. In situations where upland products are not traded in the international market and have a high income elasticity, technological progress in lowland agriculture might increase pressure on forests. This may apply, for example, to vegetable or beef production.

2.6. Cattle ranching in Latin America

As White and his colleagues note, to farmers in tropical Latin America cattle represent status and high and stable incomes. To environmentalists they are a chewing and belching nemesis that destroys forests. Both views are correct. Cattle are often farmers' most profitable option. But cattle (not crops) are the main agent of deforestation in Latin America.

Pastures in the Latin American tropics take up a lot of land and often rapidly degrade. Therefore, many have argued that pasture intensification will reduce the need to chop down trees to create additional pastures. Moreover, if one can make the pastures more sustainable, farmers will not have to abandon their existing pastures and create new ones. The arguments have a certain logical appeal, but do they pass empirical tests?

Technologies to improve pastures and beef and milk production are available. Thus, as Vosti *et al*. note, there are three possible scenarios:

1. In the lose–lose scenario, farmers do not adopt land-saving technologies. As a result, their traditional system deteriorates, their income declines and deforestation continues or even accelerates.

2. In the win–win scenario, farmers adopt the new technologies and both income and forest cover increase.
3. In the win–lose scenario, farmers adopt the technology and income increases, but the new technology makes it more profitable to establish new pastures and deforestation increases.

Four chapters in this volume provide tentative answers regarding which scenario seems more likely. Vosti and his colleagues use a linear-programming farm model to show that smallholders in the western Amazon of Brazil are likely to adopt more intensive pasture and cattle production systems. These provide much higher income than traditional technologies; however, they increase pressure on forests. The technologies' greater profitability provides farmers with higher incomes, which relax their capital and labour constraints and permit them to increase their herd size to the privately optimal level. This implies that the win–lose scenario will dominate.

Roebeling and Ruben use a similar methodology to examine the impact of technological change in the Atlantic zone in Costa Rica. Their model predicts that a 20% increase in pasture productivity will lead to an almost 10% increase in pasture area and an almost 28% decline in forest area on the agricultural frontier. The increased pressure comes from large haciendas (> 50 ha) rather than small and medium-sized farms, whose main land uses are cash crops and forest plantations.

While Vosti *et al.* and Roebeling and Ruben both use partial equilibrium models, Cattaneo analyses the general equilibrium effects of improved pasture technologies. He argues that those who claim that improved pasture technologies reduce deforestation have not sufficiently considered the long-term effects. In the short term, the presence of labour and capital constraints makes many improvements in pasture technologies reduce deforestation. However, in the long term, when resources are more mobile, any improvement in the livestock sector will substantially increase deforestation. None the less, technological progress in the livestock sector is much more beneficial to farmers than new annual crop and tree technologies, again confirming the win–lose scenario.

Deforestation is not just a function of technological change. As White *et al.* suggest, the causal relation can also be reversed. They hypothesize that forest scarcity resulting from past deforestation promotes pasture intensification. This brings us back to Boserup (1965). If possible, farmers will expand before they intensify. What White *et al.* add to Boserup is the mechanism that generates this sequence. Forest scarcity leads to higher land prices. This makes it more attractive to expand beef and milk production through pasture intensification, rather than by purchasing additional land. The authors draw on field research in three locations with varying degrees of forest scarcity in Peru, Colombia and Costa Rica. In the Peruvian site, Pucallpa, which still has abundant forest, ranchers' optimal private choice is extensive cattle production and continued deforestation. Thus, we have a case of lose–lose. The Costa Rican site in the Central Pacific region has little remaining forest and high land prices. Farmers intensify to avoid pasture degradation, but with limited impact on forest, since most of it is already gone. The Colombian site, which has an intermediate level of forest cover, provides some reason for optimism. There the short-term effect of new technologies on forest cover appears positive, although the authors argue that to control deforestation in the long term will require other types of policy measures.

The above chapters join an increasing literature that questions whether more intensive pasture technologies will help conserve forests. Does this imply that one must choose between poverty and deforestation? Not necessarily. The general trade-off identified provides a potential entry point for policy-makers. In principle, at least, as Vosti *et al.* point out, policy-makers may be able to offer ranchers improved technologies in return for accepting other policies that limit their ability to expand their pastures. Thus, while pasture technologies are no panacea and, if adopted independently of other policy measures, may increase deforestation, they may form part of the overall solution.

3. Factors that Condition the Technology–Deforestation Link (Fig. 21.1)

In the introductory chapter, we identified several conditioning factors that determine whether technological progress in agriculture leads to more or less deforestation. The case-studies have explored the role of these different factors. Looking back at the seven main variables listed in Chapter 1 (section 3.2), we

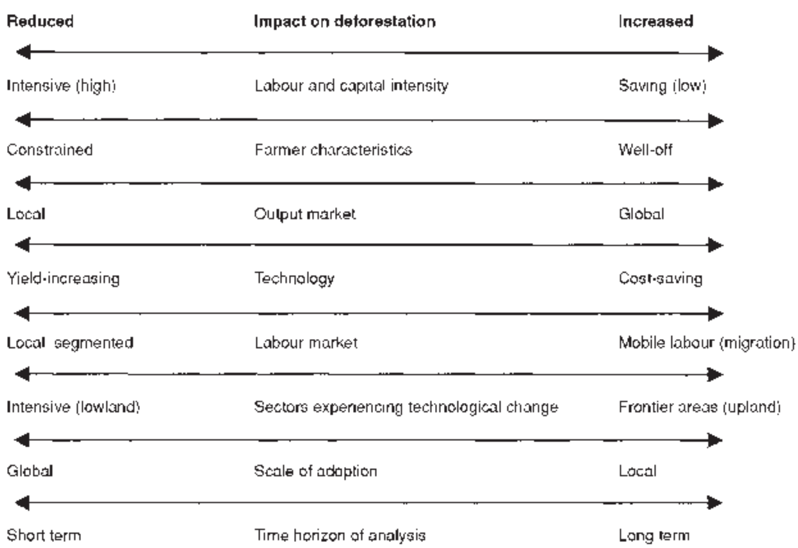

Fig. 21.1. Important dimensions in the technological change–deforestation link, with tentative impacts on deforestation.

have been able to amass a varying amount of empirical evidence on the role of the different factors. We have strong evidence to support the critical importance of the type of technology, the labour-market (migration) effects and the role of credit and higher income in relaxing capital constraints and stimulating farm investments. For all these variables, the empirical evidence corresponds well with the theory-based hypotheses of Chapter 2.

Many chapters have also discussed the role of farmer characteristics, output markets and agroecological conditions, but data appear less systematic and it is more difficult to draw general conclusions based on the evidence in the cases. Finally, the empirical evidence on the role of the institutional context, and the land-tenure regime in particular, is generally weak and calls for further comparative research.

3.1. The labour and capital intensity of the new technology

In Chapter 2, we classified technologies according to their factor intensities (labour per hectare, capital per hectare, etc.). Since most farmers are capital- and/or labour-constrained, how new technologies affect their total capital and labour requirements matters a great deal for how much land they can cultivate. This comes through clearly in the cases where the authors used linear-programming models (Holden, Roebeling and Ruben and Vosti *et al.*). In particular, when markets are imperfect, the households' endowments of labour and cash critically influence the outcome in regard to forest and it becomes much more likely that technological progress can promote forest conservation.

In situations where farmers are not capital- or labour-constrained, it is less important how labour- and capital-intensive new technologies are. Soybean is very capital-intensive, but subsidized credit and access to private credit removed a potential brake on expansion (Kaimowitz and Smith). Similarly, migration, both spontaneous and through government transmigration programmes, ensured a steady supply of labour to the cocoa frontier in Sulawesi (Ruf). How constrained farmers are does not only relate to the functioning of the labour and credit markets; the time horizon of the analysis also matters. In the long term, the technology's input intensities and farmers' constraints are less important (Cattaneo and Holden).

Farmers prefer to adopt technologies that enlarge their opportunities, rather than limiting them. Thus, for example, if farmers are labour- or capital-constrained, they put a high value on labour and are less likely to adopt labour- or capital-intensive technologies, respectively. Sometimes, however, they adopt these technologies anyway, provided they are very profitable or have other desirable characteristics, such as reducing risk or fitting in well with the farmers' seasonal labour requirements. Coffee adoption among smallholder settlers in Ecuador illustrates this point (Pichon *et al.*). The shifting-cultivation stories are mainly about farmers adopting labour-intensive technologies

(Holden, de Jong, and Yanggen and Reardon). But, again, intensification does not guarantee that deforestation stops or even slows down, particularly in the long term.

3.2. Farmer characteristics

Farmers range from poor, isolated and subsistence-orientated peasants to rich, commercially orientated landowners. Each type of farmer tends to specialize in different crops and production systems, making certain innovations relevant only for particular groups of farmers. The Roebeling and Ruben chapter on Costa Rica highlights this. In that case, the large haciendas only produce cattle, while small and medium farms are involved in a range of activities. Thus new pasture technologies mainly increase forest clearing from large farms, something which also has distributional implications.

Farmers respond differently to new technological innovations – in terms of both technology adoption and forest impact. Smallholders tend to be more cash-constrained. This might prevent them from using certain technological innovations, as illustrated by the soybean story from southern Brazil (Kaimowitz and Smith). In that case, only large commercial farmers adopted the technologies associated with large-scale deforestation. Capital-intensive technologies can therefore make poor farmers becoming losers in several ways: they cannot afford the new technologies, they might suffer from lower wages and output prices and deforestation reduces forest-based incomes and environmental services.

Not only are their constraints different, but smallholders tend to emphasize different objectives. For example, they generally emphasize food self-sufficiency and risk avoidance more than large farmers. Coxhead *et al.* find evidence that smallholders in their study area overuse natural resources as an insurance against yield (and price) risk. Thus, risk-reducing technologies could be appropriate for this group of farmers and might help conserve forests.

A low market value of their labour characterizes smallholders. Often they only participate in the low-paid, unskilled, rural labour market. If frontier land is open-access and allocated on a first-come, first-served basis, the low opportunity cost of smallholders' labour makes it attractive for them to migrate to the frontier. Once an active land market develops, poor smallholders may find it more difficult to purchase land, but large landowners may still take advantage of the low opportunity cost of their labour to hire them to engage in activities associated with forest clearing.

3.3. Output markets

The idea that technological progress increases supplies, which lowers output prices and sometimes even reduces farmer incomes, is often referred to as the ‘treadmill effect’. Because the demand for food is generally inelastic, small changes in supply can lead to significant price changes, benefiting net consumers but making net producers lose.

The empirical question is how big this price effect is. The magnitude is the product of two factors: overall market demand elasticity and the relative supply increase. If only a small fraction of producers adopt the new yield-increasing technologies, the price effect will be small. This might apply to export crops in cases where each country has a small share of the global market. As a result, commodity booms tend to involve export crops, since world markets can absorb large supply increases with less effect on price. Sometimes, however, commodity booms are so large that they significantly influence global supply and hence depress global prices. This was the case in most of the commodity booms examined in this volume. Nevertheless, in several cases, the negative effect of increased supply on world prices was partially mitigated by rapid growth in consumer demand (Kaimowitz and Smith, and Wunder).

While the overall food demand might not respond much to price changes, this does not necessarily hold for particular food crops, as consumers can switch. Further, many agricultural products that are not foodstuffs, such as rubber and cotton, have synthetic substitutes, making their demand more elastic.

Technologies that producers widely adopt, such as new rice varieties, will typically have a large impact on market prices and this should put a brake on land expansion. Cattaneo, for example, in his economy-wide simulation model, discusses technological progress in the production of food crops (rice, manioc and beans) sold in the domestic market. Land availability does not constrain production and expansion goes on until lower prices make it unattractive to continue.

The link may be more complex in situations where governments heavily influence food prices. Rudel observes that, in the case of the USA, the government did not allow the market to work. Higher yield did not depress market prices as much as one might expect, because price-support programmes maintained high prices. In that case, the government used other policy measures to balance food markets and to convert marginal agricultural land to forest.

Finally, many types of technological change do not increase yields. They only reduce costs. Thus, they do not directly affect supply and output prices, although they may affect supply indirectly by increasing the profitability of production. For example, mechanization typically reduces labour inputs, often without increasing yields. A chain-saw can allow a farmer to clear four to five times more land, but does not necessarily improve yields. Thus an important dimension of new technologies is to what extent they increase yields or just lower costs.

Most of the case-studies do not report on significant price reductions due to technological progress, although Cattaneo’s study of Brazil and Kaimowitz and Smith’s study of soybeans in Brazil and Bolivia clearly point to downward pressure on prices resulting from supply increases. The fact that the cases do not identify more situations where such effects occurred is partly due to the farm-household (partial equilibrium) approach of most studies. But it might also reflect that many of the relevant technology changes taking place in frontier agriculture are location-specific and only result in a small change in overall market supply. More generally, it underscores the need to distinguish in the debate between development of new technologies that are applicable to large areas of intensive agriculture (*à la* Green-Revolution technologies) and the adoption of well-known technologies in frontier areas, which contribute a relatively small share of total production.

3.4. Labour markets and migration

In isolated forest-rich economies, one can expect labour-intensive technological change to have a positive or minimal impact on forests. Labour shortages and/or higher wages quickly constrain any expansion. On the other hand, where the regional and/or national labour markets function reasonably well and there is high labour mobility (migration), labour shortages are less likely to limit expansion. Several chapters (see particularly Cattaneo and Jayasuriya) note that the extent of interregional flows of labour and capital plays a crucial role in determining how much the agricultural sector expands, particularly over the long term.

When labour-intensive technological change takes place outside the frontier areas, active labour markets can help to curb deforestation. Employment opportunities outside the frontier will attract labour away from forest-clearing activities in the uplands, as illustrated by the Philippines irrigation study (Shively and Martinez). But, again, labour-saving technologies will foster greater migration to the frontier, as illustrated by the green-revolution technologies in Sulawesi (Ruf) and soybeans in Brazil (Kaimowitz and Smith).

Technological changes in agriculture that improve yields allow local agricultural production to feed more people. Although a higher carrying capacity might benefit the forest in the short term, in the long term it has several indirect effects that are likely to reduce forest cover. Higher populations are often associated with more public services and infrastructure, which attract additional migrants. Three examples in this volume are potatoes in 19th-century Switzerland (Mather), maize in Zambia (Holden) and bananas in Ecuador (Wunder). In all three cases, new crops sharply raised the carrying capacity of the region or country involved, but higher population densities were associated with forest loss.

3.5. Credit markets, farmer income and investment effects

Most farmers cannot borrow money freely and their cash holdings are limited. This sometimes makes them reluctant to adopt capital-intensive technologies, although there are definitely exceptions, cattle being the most prominent. When capital-constrained farmers do adopt capital-intensive technologies, their limited capital resources should make it much harder for them to expand their activities.

But, as noted earlier, new technologies not only influence farmers' demand for capital, they also affect how much capital they have access to. Technological progress increases farms' surplus and hence their ability to purchase farm inputs and make new investments (e.g. Ruf and Vosti *et al.*). Higher yields might also improve access to informal credit (Roebeling and Ruben). These factors make farmers able to increase their investments and buy more inputs, but the effect on deforestation is not obvious.

Consider the typical situation of a Latin American farmer who produces cattle, crops and forest products. Cattle offer less income per hectare but the highest rate of return on capital and labour. Capital constraints generally limit farmers' ability to expand their cattle herds. If a new crop technology boosts overall farm income and livestock are still farmers' most profitable alternative, the farmers may use their higher incomes from crop production to buy more cattle. Thus pasture may expand, rather than the cropping system that experienced the technological progress.

In contrast, a typical African farmer may combine one relatively high-yield–high-input ('land-intensive') system with a low-yield–low-input ('land-extensive') system. The former offers the highest returns to labour, but the farmer does not have enough capital or access to credit to specialize exclusively in that system, so she or he also uses the extensive system. In this case, greater access to credit or higher incomes from any source would allow the farmer to switch to the intensive system and reduce overall demand for land and deforestation (see Holden, and Reardon and Barrett).

Both cases boil down to the question of which type of investment gives the highest return: the land-extensive system, the land-intensive system or possibly some off-farm activity. Higher income due to technological progress would, *ceteris paribus*, reduce the demand for land in the last two cases but not in the first.

The question just raised has a bearing on the impact of higher wages and off-farm income, which have a dual effect on land demand. Higher opportunity costs of labour should make farmers work less in agriculture, thus reducing the demand for land. But more off-farm income relaxes the capital constraint. Farmers can now buy more seeds, fertilizer, machinery, cattle, labour, etc. As just argued, this latter effect could increase or decrease the demand for land, depending on whether land intensification or land extensification is more attractive. In their study of cattle in the western Amazon, Vosti *et al.* found the investment effect to dominate, leading to more pastures and less forest on the farm.

Once most natural vegetation has disappeared in an area, rising incomes resulting from agricultural productivity improvements can generate new demands for timber, fuel wood, fruits, nuts and other non-timber forest products. Growing markets for these products in turn often stimulate periurban households to plant trees as a commercial activity. In such contexts, forests cease to function as a residual land use and take on economic and social characteristics similar to those of agricultural land uses.

The role of capital (credit) constraints in determining farmers' demand for land and of technological change (and other factors) in relaxing these constraints provides very significant lessons from the cases of this book. Together with the migration effects, this appears key in any long-term analysis of the impact of new technologies on forest cover. It also challenges the conventional wisdom that poverty causes deforestation. Indeed, many studies in this book suggest the opposite – that poverty constrains deforestation.

3.6. Scale

Depending on what scale one focuses on, technological change may be seen to have rather different effects on deforestation. The Borlaug hypothesis appears more relevant at the national or global scale. At this scale, increased output and employment opportunities are likely to push down prices and discourage further forest conversion, although, if the technology is labour-saving and no alternative employment opportunities emerge, the opposite may occur. The counter-argument – that technological progress makes expansion more attractive – tends to assume that prices remain constant. This is a more plausible assumption when one looks at the household or village scale. Thus, situations that are win–lose at the local level may be win–win at the global level. This becomes less probable, however, once one takes into account the large areas of degraded lands, fallow and other land uses that fall under neither 'agricultural' land nor forest.

3.7. Short- and long-term effects

Technological changes can affect forest clearing in distinct ways and even opposite directions over time. In the short term, farmers take prices, wages, interest rates, labour and capital resources, government policies, transport, marketing and processing infrastructure and their own incomes as fixed and make their decisions accordingly. Over time, technological change can modify all of these things and this can lead to rather different outcomes. Particularly the chapters by Holden and Cattaneo illustrate that many of technological change's short-term positive effects on forest conservation disappear with time, as labour and capital move and relax the labour and capital constraints that played key roles in the short-term analysis.

Any technological change large enough to significantly affect land use stands a good chance of altering general economic development patterns and political power relations. Standard economic models do not easily capture these aspects. High agricultural growth rates spur economic development, urbanization and the growth of the industrial and service sectors. This, in turn, may induce farmers to abandon land with poor soils and topography and allow them to revert to forest, as happened in Europe (Mather) and North America (Rudel).

Any decision about what time period to focus on must take into account the issue of irreversibility. For many years, conventional wisdom had it that forest clearing in the tropics led to irreversible damage to forest ecosystems. New evidence suggests that these ecosystems might be more resilient than previously believed. The social processes involved in widespread deforestation may prove more difficult to reverse than the biological ones, or at least take just as long. The transformations in land use, demographics, political clout, incomes and wealth and patterns of demand resulting from technological change often linger long after the technology itself has run its course. The families that migrated from Ecuadorean highlands in the 1950s and 1960s to work on the banana plantations on the coast remained there for generations, even though the jobs that brought them there eventually disappeared (Wunder). New soybean technologies in Brazil helped powerful agroindustrial lobbies to emerge in the south and they became a permanent interest group vying for agricultural subsidies (Kaimowitz and Smith).

3.8. The policy context

Policies influence several conditioning factors. Governments can restrict or stimulate migration. They can subsidize or – more commonly – tax agricultural products. They can ban or encourage trade in agricultural commodities. They can favour certain crops or production systems. They fund agricultural research and extension services, which make new technologies accessible to farmers. Therefore sectoral and general macroeconomic policies help determine both technology adoption and the impact technological change has on the environment.

Unfortunately, as noted by Coxhead *et al.* and Reardon and Barrett, policy-makers only give secondary attention to the long-term environmental consequences of their policies. The impact on forests often appears as the unintended or unplanned side-effects of policies intended to boost supply, improve trade balance, etc. Moreover, in many cases, governments are not just determining the general economic environment in which farmers operate, but are actively promoting deforestation.

As experiences in the USA and Europe show, if the more general policy and economic contexts support both economic development and conservation, ‘win–win’ situations are more likely to occur and their positive impacts will be stronger. Low agricultural prices and labour-intensive agricultural systems resulting from technological change will probably reduce agricultural land use in forest-margin areas much more where agricultural wage rates are high and rural households have many non-farm employment options. Where these conditions do not apply, as in many modern-day developing countries, low agricultural prices may not deter poor households from moving to agricultural frontier areas, since the opportunity costs of their labour are low. Similarly, the market signals provided by technological change will have a much stronger effect if they are reinforced by other policy signals, such as effective regulations restricting farmers' encroachment on protected areas.

4. A Concluding Note

After all this, we are left in a world that defies simplistic explanations but requires clear and simple policies. It is a world in which agricultural innovation has provided huge benefits and yet poses real risks. The basic Borlaug hypothesis – that we must increase agricultural yields to meet growing global food demand if we want to avoid further encroachment by agriculture – still holds. Still, that by no means guarantees that specific agricultural technologies that farmers adopt will help conserve forests. The current trend towards more global product, capital and labour markets has probably heightened the potential dangers. Technologies that make agriculture on the forest frontier more profitable and that displace labour present particularly strong risks, while technologies that improve the productivity of traditional agricultural regions and are highly labour-intensive show the most promise.

Note

1 Following Ruthenberg (1980), we include systems with short and/or rare fallows in 'permanent upland cultivation'.

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