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Agriculture and deforestation: What role should REDD+ and public support policies play?

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HIGHLIGHTS

AGRICULTURE IS CENTRAL TO REDD+ When over 83% of new cropland areas in the tropical zone came at the expense of natural forests over the 1980-2000 period, and when the food challenge is becoming increasingly urgent, the REDD+ mechanism must find the means to tackle this sector of activity.

LITTLE PROOF EXISTS IN PRACTICE TO CONFIRM THE BORLAUG HYPOTHESIS (LAND SPARING)
This hypothesis indicates that an increase in agricultural productivity per hectare makes it possible to reduce cultivated areas (and therefore the impact on forests). However, not only is the confirmation of this hypothesis uncertain according to recent articles on the matter, but its translation into economic terms also shows that it has some serious limitations.

CHANGES IN AGRICULTURAL TECHNOLOGIES HAVE DIFFERENT TYPES OF CONSEQUENCES Agricultural technologies can be changed in different ways with varying consequences for forest cover. For example, the consequences of intensifying labour or land differ considerably in terms of cultivated areas.

SUPPORT POLICIES ARE NEEDED In order to guarantee that agricultural land reforms work in favour of reducing deforestation and degradation, public support policies are needed. Most notably: (i) the dissemination of agricultural technologies, (ii) the harmonisation of sectoral public policies, (iii) Payments for Environmental Services (PES), and (iv) changes in diets to act at the level of demand.

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Introduction

Negotiations to establish a funding mechanism for the fight against deforestation and degradation in developing and emerging countries (REDD+[1]) under the aegis of the United Nations Framework Convention on Climate Change (UNFCCC) are at an advanced stage and could, in the most favourable scenario, lead to an agreement at the Conference of the Parties in Cancun in December 2010 (COP 16). The discussions conducted over several years have helped to inform a new debate on the causes of the massive degradation of tropical forest ecosystems, and in particular on the specific threat that the expansion of agricultural areas poses and will continue to pose. A recent article (Gibbs et al. 2010) thus showed that between 1980 and 2000, over 55% of new cropland areas in the tropical zone came at the expense of primary forests, while another 28% of this expansion came at the expense of secondary forests.

During the initial phase, discussions on the new international REDD+ mechanism focused on funding issues: how can sufficient financial resources be collected from donors or markets, and how can these resources be distributed to recipient countries (Pirard 2008)? We have now entered a new phase that concentrates on the content of national strategies, in other words the policies and measures that will be deployed to limit greenhouse gas emissions, and which go further than localised "projects". We will therefore ask the following question in this short essay: "Will the funding available to protect tropical forests be enough to promote the appropriate agricultural technologies, via agricultural land policies designed to disseminate them, and how will this be done?".

This question may at first sight appear inappropriate to those who have a rather restrictive vision of the functioning and objectives of the REDD+ mechanism. Indeed, if one considers that the aim of this mechanism is to set up measures to reduce emissions from forested areas as carbon stocks, and therefore to only act at the level of these forests through measures such as those to promote Reduced Impact Logging or to create exclusive protected areas, one therefore excludes from the debate any measures that apparently go beyond the perimeter of the mechanism. In reality, as argued in this text, the long-term viability of REDD+ depends on action in sectors of the economy that are accepted as having an impact on forests, of which agriculture is the most striking example (Angelsen 2009). This observation does not depend in any way on the nature of incentives distributed (such as carbon credits, bilateral official development assistance or international funding through the World Bank for example), as long as the funding is linked to a certain extent to the results obtained.

1. REDD+ stands for Reducing Emissions from Deforestation and Forest Degradation, and the addition of "+" corresponds to the inclusion of the increase in carbon stocks, for example through appropriate forestry practices or plantations. Its principle is to pay developing and emerging countries by means of contributions from industrialised countries, either through a market or a fund.

Our analysis is based on a small number of scientific articles considered to be of great importance. Some recent ones provide some extremely instructive insights into the linkages between agriculture and deforestation, and deserve greater consideration in the current debate, which is giving growing importance to agricultural policies (for example, the SBSTA body of the Climate Convention is turning its attention to the issue of agriculture as a driver of deforestation). Other, older articles lay the theoretical groundwork that we use in this analysis. This is not therefore a state of the art, but rather a vision – a proposal for an analytical and operational framework for the mechanism – that we back up using some of the references we believe to be the most significant in this field.

We will present the issue in the first section, introducing the terms "agricultural land policies" and "agricultural technologies". Next, the theoretical aspects, such as hypotheses regarding the presumed links between agricultural intensification and changes in forest cover, will be described. In the third section, the recent findings of scientific research – based on empirical facts – will be analysed in order to determine whether they confirm or contradict the theoretical assumptions. Finally, the last section will explore the implications for REDD+ and will suggest some possibilities for improving its overall effectiveness.

1. Agricultural land policies and agricultural technologies: What are we talking about?

In late 2005, Costa Rica and Papua New Guinea officially revived the idea of a mechanism to compensate for the reduction of emissions from the loss of forest cover in developing countries. This initiative, originally limited to "avoided deforestation" in the jargon of the time, met with such great success that it resulted in the emergence of a mechanism potentially encompassing forest degradation, the enhancement of carbon stocks in standing forests, conservation, sustainable management and afforestation (see the draft negotiating text for COP 16 in Cancun, FCCC/AWGLCA/2010/14).

This marked increase in the number of "activities"[2] said to be eligible for REDD+ raises certain questions and may be interpreted in different ways depending on whether it is seen as a broader way to address emissions linked to land use (but improving soil carbon sequestration in agriculture will not be included) in order to increase its efficiency, or whether this unchecked growth is seen as potentially making the mechanism more difficult to implement due to its very hazy limits (the result of tough negotiations).

This broadening of "activities" may be associated with changes in the types of action actually deployed and discussed within the framework of the mechanism. For example, "avoided deforestation" activities may include an intervention such as the creation of a protected area; "avoided degradation" activities may include an intervention such as sustainable forestry management. At first, reference was only made to "forest policy", in other words to interventions very clearly aimed at forest areas themselves. The term "forest sector" was therefore adopted in all discussion forums, although doubts exist as to its validity. Indeed, the forest sector literally includes forest exploitation and clearing activities as well as downstream transformation activities. However, we are dealing with a "phenomenon" when it comes to deforestation and degradation. This phenomenon, far from being confined to the forest sector alone, is in fact a consequence of decisions made in many other economic sectors (urban planning, agriculture, energy, etc.). Fortunately, the discussions conducted on REDD+ have eventually integrated this reality, which is essential when addressing deforestation: in other words that the policies and measures implemented within this framework should be able to include sectors (forums for decision-making and interests) that are not strictly speaking part of the forest sector.

2. This term is in fact used in negotiating texts to describe the boundaries for estimating emissions reductions. It does not mean activities in the sense of "intervention", in other words the way in which the developing countries will act to reduce emissions, through for example protected areas, population displacements, or the dissemination of low-impact farming techniques, etc.

On this subject, the most appropriate expression is apparently that of "forest-related policies", which Singer (2009) defines in his thesis as "*the product (i) of an entire system of action constituted by actors who collaborate to solve a set of collective problems and (ii) that affect forests, whether explicitly or not*". In substance, this therefore means that decisions made in the field of agriculture – for example land allocation or taxation decisions – are policies that affect forests if the context is one of expansion to the detriment of forest areas. Taxation encouraging extensive land use such as cattle ranching in Brazil (Bulte et al. 2007), or a public policy aimed at encouraging the expansion of the paper industry in Indonesia by granting tax benefits and preferential access to resources (Pirard and Rokhim 2006), may therefore be described as forest-related policies.

Agricultural land policies are just one category of forest-related policies, and are defined in this document as all policies and measures aimed at modifying agricultural practices (quantitatively and/or qualitatively) and the ownership and usage regimes for the associated land and resources. It is an accepted fact that these policies generate considerable impacts on tropical forests, with the example of extensive cattle farming in the Amazon providing an emblematic example (Bulte et al. 2007). Well-targeted action is needed to achieve the objectives set by REDD+.

A sub-component of these agricultural land policies is represented by agricultural technologies. These technologies define the organisation of agricultural production (the intangible aspect), the production technique (the technical means used) and the type of product (self-consumption, export, diversification, etc.). These technologies are extremely diversified throughout the world, and the changes to be made to them (to increase productivity or reduce the environmental impact, etc.) are potentially numerous and specific to a range of contexts.

Agricultural intensification is often seen as the main or only means of changing agricultural technologies, but is nevertheless a restrictive interpretation of the possible range of these technological changes. Indeed, agricultural intensification is often understood as the increase in inputs per hectare, especially fertilisers and capital with the mechanisation of tasks, in order to increase yields. However, we suggest considering more broadly any "improvement in agricultural technologies" with the prospect of a total factor productivity gain. It should be noted that this "total factor productivity" gain does not necessarily represent an increase in production per hectare, especially when labour is used sparingly, or when capital replaces labour (see Federico 2005 for a historical view of these changes in total factor productivity from 1800 onwards). This therefore also includes ecological intensification, based on the services provided by ecosystems when they are well managed; in other words the optimisation of their functions. It may also include a broader range of innovations making it possible to achieve not only the objective of ensuring additional production without overdoing inputs, but also other functions of agriculture when it is considered to be multifunctional. This may involve, for example, reorganising tasks or using better suited varieties. Griffon (2006) provides a convincing overview of these promising avenues, and clearly shows the differences between the green revolution in the strict sense, and what he calls the "doubly green revolution" because it gives special importance to the quality of the environment.

Changes in agricultural technologies may meet several objectives, including (i) improving the living conditions of millions of poor farmers throughout the world (according to Griffon 2006, around 600 million people whose livelihoods depend on agriculture in the developing world do not have enough food), (ii) improving the total productivity of factors of production in order to increase total food availability, which seems to be generally accepted as necessary in order to feed the planet[3], and (iii) preserving

3. Even if the estimate of a necessary 70% increase in production between 2010 and 2050 put forward by FAO is debated under certain scenarios, such as those of the Agrimonde exercise (Chaumet et al. 2009), population growth and future food transitions will require a considerable increase in agricultural production throughout the world. The issue of the geographical distribution of this growth in production (preferably in countries that are already major exporters, in countries where agriculture is not yet particularly intensive, or rather in a homogenous way between these different countries?) does not produce any convergence between scenarios.

ecosystems, especially forest ones. The combination of these three objectives is proving to be a particularly ambitious challenge, especially in terms of ensuring compatibility between the increase in production and the maintenance of forest cover.

2. Theoretical foundations: The Borlaug hypothesis as a backdrop

2.1 The Borlaug hypothesis, from physical considerations to economics

There is one recurrent question hanging over debates on the linkages between agriculture and forests, which in fact go back much further than the current climate negotiations: does an increase in productivity per hectare help to limit agricultural expansion? The fact of minimising new cropland areas by increasing yields from existing cropland is known as the Borlaug (*land sparing*) hypothesis, from the name of one of the fathers of the green revolution that took place from the late 1960s in Mexico, before being taken to Asia over the following decades.

Although the hypothesis seems rather evident when thus formulated – though we will examine in the following section the solidity of existing proof of the way it functions in practice – it is actually based on several levels of justification. These levels of justification lie mainly within the field of economics, as we will discuss. It is unwise to limit oneself to the following reasoning, whose simplicity conceals some fundamental aspects: on the one hand there is fixed global demand for food products and, on the other, food production that will increase as long as the initial fixed demand is not entirely met. If the equation could be summarised in this way, the Borlaug hypothesis would undoubtedly be confirmed. However, this is not the case.

Why? This hypothesis is in fact dependent on economic forces and phenomena, since the greater part of agricultural production is sold on markets. More and more, these are globalised markets (although regional or local dynamics persist alongside them) where the price is set by the balance between supply and global or regional demand. Consequently, the hypothesis actually depends on the investment decisions made by farmers – whether small farmers from rural areas, who often work less than one hectare per household, or pioneers providing capital and modern production techniques in order to cultivate large areas – who react to price signals while taking into account their needs, their outlets and their property rights to the land available. Over and above the physical and quantitative aspects of agricultural production requirements, the issue must be tackled via decisions and factors of an economic nature.

Seen from an economic viewpoint, the Borlaug hypothesis can therefore be reformulated as follows: an increase in yields, and therefore in production per hectare, leads to a fall in agricultural commodity prices due to excess supply over demand, and therefore in profit per hectare, and finally produces a supply adjustment through smaller growth in cultivated areas. In other words, better yields result in lower prices and less investment.

This basic framework, which is both logical and simple, can have many variations. Different modifications are possible. By way of example, a distinction can be made between the factors of production (capital, labour, land, etc.), since using more capital or more labour will generate different future investment decisions. Prices may also be artificially altered by the intervention of the competent authorities. Choices regarding public investment in transport infrastructure play a key role, and depend, *inter alia*, on the official development assistance agenda. In short, a number of variables have considerable influence over the capacity and willingness of farmers to increase cultivated areas.

2.2 Two levels of analysis, micro and macro

To tackle this complexity, we can take a simplified look at two levels of analysis for agricultural expansion according to yields: the microeconomic level and the macroeconomic level.

The microeconomic level is that of exploitation, where new cropland decisions are made by agents who are supposedly rational and well-informed – which is, incidentally, a strong assumption that is rarely borne out in reality, especially in the developing world. First, the information is not always available, and second, these agents must take into account many different constraints and objectives linked to their immediate survival. In the case of perfect markets, with the possibility of selling surplus production, theory indicates that technological progress generally leads to more land being converted to cropland and therefore to more deforestation. This has always been the case during "commodity booms" for export markets, such as bananas in Ecuador (Wunder 2003), cocoa beans in Côte d'Ivoire (Ruf 2003), and soybeans in Brazil and Bolivia (Kaimowitz and Smith 2003). We are therefore looking at a trend that apparently runs counter to the Borlaug hypothesis.

In the case of imperfect markets, the most common case and the closest to the reality on the ground, several factors are likely to moderate this tendency towards expansion. These may include the scarcity or shortage of factors of production at the local level (the labour available, for example, but also financial capital due to the remoteness and risks of rural areas), the existence of high transaction costs for the adoption of new agricultural technologies, or the presence of risks serious enough to weigh on investment or loan decisions. This list is clearly not intended to be exhaustive, as an infinite number of examples exist.

The macroeconomic level is that of the functioning of the overall system, which we can visualise at country level. For economists, this represents the issue of general equilibrium. The adoption of new agricultural technologies thus has repercussions on the economy when adopted on a scale large enough to change the terms of the supply/demand equation, or to modify the terms of trade when the products are exported. These repercussions may include a change in the relative prices of finished products or of inputs, as well as in the profitability of agriculture. But this goes even further, and human migration issues also play a key role, through the displacement of populations available, either to be recruited into agricultural work, or to directly engage in additional investment. Some examples are given in section 3.2 to illustrate this.

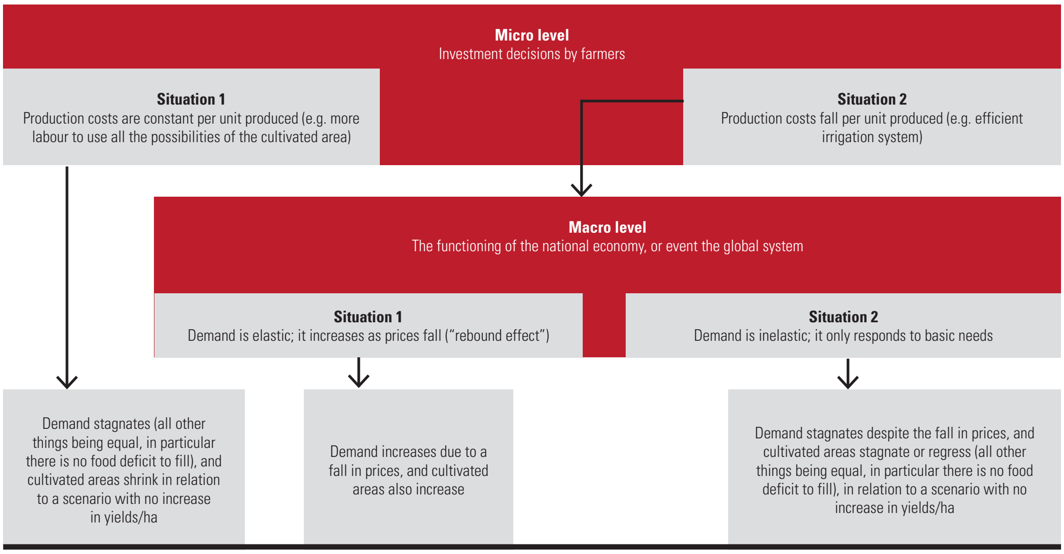
At the macroeconomic level, there is one decisive factor that is undoubtedly the most important, to which we will return later in the document. This is the elasticity of demand. Indeed, the simple interpretation of the Borlaug hypothesis is based on demand that is *fixed* at the outset. Meeting this demand, therefore, apparently means new conversions to cropland are prevented, since surplus production has no outlets. But economic theory questions this fixed demand. In reality, it is well known that the way in which this demand is met will determine its evolution: either the initial level is reached by an increase in production at constant cost, and therefore the level of demand should not vary (all other things being equal); or the initial level is reached through productivity gains, produced by the new technologies, and therefore the expected drop in prices (due to lower production costs) will generate an automatic increase in demand. Indeed, demand depends on prices and increases when prices fall. This is known as the "rebound effect", since demand rebounds (it increases) when new technologies enable productivity gains and associated price reductions in a highly competitive market. Economists call this responsiveness of demand "elasticity". Demand which is insensitive to price fluctuations is said to be "inelastic". This very specific case will only be borne out in practice for goods corresponding to basic needs or for demand that is already saturated. For example, a fall in the price of meat will generate an increase in demand for meat, but only up to a certain point, beyond which consumption can increase no more.

Figure 1 illustrates these dynamics in economic terms, and shows that the Borlaug hypothesis only works in certain specific cases, whereas in other cases economic theory forecasts different results.

Another important factor, to better understand the foundations and weaknesses of the Borlaug hypothesis, is the diversification of production. Agricultural products are extremely diverse, although food production has gradually concentrated around a smaller number of species[4].

4. To quote Esquinas-Alcazar (2005): "*Since the Industrial Revolution, rapid changes in population size, ecological degradation and globalization have led to a dramatic reduction in crop genetic diversity. Barely more than 150 species are now cultivated; most of mankind now lives off no more than 12 plant species*".

Figure 1. The Borlaug hypothesis in economic terms at the micro and macro levels



Aside from the fact that agriculture also produces non-food goods (oil for cosmetics, cotton for textiles, or biofuels, for example), food production may diversify considerably to the point of creating new demand. Not everything boils down to a question of protein or staple goods, and "luxuries" – in other words non-essential food products that are consumed in addition to daily food requirements – may also play a significant role in production. A lot therefore depends on the type of innovation and product concerning new technologies.

In this context of diversification, the Borlaug hypothesis may theoretically be confirmed for each type of agricultural product; however, it then becomes quite a challenge to make a distinction between agricultural expansion resulting from this diversification, and the slightest agricultural expansion for each product resulting from the increase in productivity.

3. Some theoretical hypotheses are confirmed empirically under very specific circumstances

This section is aimed at examining lessons from empirical research – as opposed to the previous theoretical observations – on the linkages between agriculture and deforestation. This critical review is divided into two parts, each corresponding to a specific methodological approach: first based on data from global time series, then based on local case studies. These two methodological approaches are aimed at testing two types of phenomena: the Borlaug hypothesis at a global or national scale, and the local relationships between agriculture and deforestation for a wide range of specific contexts.

3.1 Little proof exists confirming the Borlaug hypothesis

The two articles that we believe to be the most comprehensive on this matter, and which we will examine in depth in this part, were published very recently.

In the first of the two articles, Rudel et al. (2009) attempt to confirm the Borlaug hypothesis using historical data, taking into account 161 countries and 10 main crops (wheat, maize, soybean, rice, cotton, bananas, coffee, cocoa, sugar and potatoes), over the 1970-2005 period.

The authors stress the existence of two contradictory forces resulting from intensification – an incentive for each individual farmer to increase the cultivated area, but also a fall in the sales price due to excess supply which becomes an incentive to limit expansion – to justify the need to test which was historically the stronger. As they remind us, "*analysts working at the global scale have modeled the* *land-sparing effect rather than examining historical instances".*

Some methodological obstacles nevertheless initially appeared for this ambitious study. First, data on non-forest land that is not allotted to agriculture are difficult to come by. Indeed, this implies being able to distinguish between land that has been abandoned and land that is being cultivated, a distinction that most global databases do not make. Consequently, the authors have used the FAO statistical data on cultivated areas by crop type rather than satellite data. Furthermore, it must be ascertained that land abandoned because of crop intensification is not allotted to other types of crop, which would cancel out the environmental benefits. This second aspect is settled by a statistical test which, according to the authors, invalidates the hypothesis of a substitution having significant impacts on the results of the analysis.
Let us add the problem of cattle rearing, which was not addressed in the study because of the lack of data, even though it is a major cause of deforestation today. We must keep in mind that this methodological problem has not been resolved, which substantially limits the scope of the study.

The econometric study is initially conducted in a global manner. The trends for the 1970-2005 period indicate areas that grow less rapidly than the population and the per capita income. An absolute reduction is noted from 1980-85.

However, the study does not reveal a significant correlation between crop productivity and the global evolution of areas. Nevertheless, this negative correlation (which therefore agrees with the Borlaug hypothesis) exists in 34 countries considered individually from 1900-2005. The authors identify clusters of frontier countries, especially South-Eastern Europe and Central America.
Furthermore, it is interesting to note that correlations emerge when crops are analysed separately, rather than by country or groups of countries. For example, the increase in yields for wheat and coffee seems to have resulted in a reduction in areas allocated to these crops.

The value of this study lies in its capacity to conduct tests at different levels. This enables the authors to identify the areas where the Borlaug hypothesis would potentially be confirmed, in order to later study the full details that do not appear at the econometric stage. Indeed, this stage does not include all factors that played a potentially important part in the phenomenon; and it turns out that substitute imports and national land conservation programmes have played a considerable role. For example, conservation has taken root in China (the Grain for Green programme) and in the United States (the Conservation Reserve Program) since the 1990s, with impacts that are consolidated for wheat crops by the possibility of importing this product. Aspects of international economics are also critical in other cases, for example with Cuba losing its Soviet markets for sugar and seeing its cropland areas shrinking for this product, or with Mexican soybean, maize and wheat crops affected by the North American Freed Trade Agreement (NAFTA) and the appeal of US imports for these highly subsidised products.

To sum up, the authors highlight the absence of any empirical demonstration of the Borlaug hypothesis, except in certain exceptional national cases. In reality, intensification in itself does not seem to result in land sparing, unless accompanied by specific policies and measures. We will return to this important point in the last section on the implications for REDD+.

In the second article, Ewers et al. (2009) consider 124 countries and the 23 most important food crops from an energy perspective at the global level since they represent 60% of global tonnage harvested in 2000. The period considered by the analysis spans two decades, from 1979 to 1999.

The authors note at once that the Borlaug hypothesis potentially comes up against two contradictory forces[5]. First, the economic

5. The authors add a third contradictory force concerning the impacts on biodiversity – later uses of land spared thanks to agricultural intensification and consequently their benefits for fauna and flora – but which is not of interest to us within the framework of this article.

reasons linked to the "rebound effect" already mentioned in section 2.2, with the possibility that the fall in production costs may result in an increase in demand, or in supply due to higher profit per hectare; second, the possibility that agricultural subsidies will cancel out the positive effects of the increase in productivity, by creating surplus production through a diversification beyond staple crops. These two effects are studied in the article in a statistical manner, and provide some very interesting results in this respect.

Overall, the authors begin to conclude in a Borlaug hypothesis that is confirmed to a small extent, although 87 of the 96 countries that increased their productivity per hectare over the period in question also reduced cultivated areas per capita (this variable means the role of population growth can be taken into account in demand for food). Next, the authors analyse the role of the diversification of production encouraged by subsidies, making a distinction for developed countries. They actually show a significant increase in the production of non-staple crops, which tends to largely counterbalance the positive effects expected from the increase in yields. The following are singled out as representing a very substantial threat to the confirmation of the positive effects of agricultural intensification in the future: first changes in diets and increasing meat consumption; and second the development of biofuels with a view to combating climate change.

Next, the role of the food deficit at the beginning of the period is analysed, distinguishing between developing countries based on available food supply per capita. The results are ambiguous: despite following the pattern expected (the smaller the deficit, the more the Borlaug hypothesis is confirmed), the results are of marginal statistical significance. One explanation put forward by the authors is that if there is no food deficit, the "agricultural diversification" effect takes over.

3.2 Case studies show a convergence between local dynamics and theoretical lessons

This section is based on some remarkable work that was published in 2003 under the supervision of A. Angelsen and D. Kaimowitz, and which includes not only numerous case studies across three continents, but also a very comprehensive summary analysis of empirical data, putting them back into the theoretical framework.

This classic, founding work is largely influenced by the Borlaug hypothesis. It nevertheless goes further, as the technological changes considered also include reductions in yields per hectare, for example when labour or capital are maximised (thereby increasing production per unit of labour or capital, but not necessarily per unit of land). Technological change is defined as a variation in total factor productivity, without being limited to one or the other. Some factors of production are intensified, while others are spared.

Based on the many situations described and studied in the publication, the authors summarize the lessons by identifying five typical categories and illustrating the linkages between agricultural technologies and tropical deforestation[6].

The five categories are as follows:

- **The commodity boom**

The examples given support the theory that an increase in yields leads to a sudden, dramatic reduction in forest cover: bananas in Ecuador, cocoa in Côte d'Ivoire and Sulawesi, and soybean in Brazil and Bolivia. This is all the more instructive given that these cases all demonstrate very different intensities in terms of factors of production: soybean is capital intensive, cocoa is labour intensive, and bananas have changed over time.
These studies show that such impacts occur especially when five conditions coincide: (i) links with international markets to absorb

6. The sixth category corresponds to the situation observed in developed countries where the forest transition has become established as the common model (although in a very different global context, which perhaps makes the same process inappropriate at this moment in time). A concomitance was observed between the increase in agricultural productivity and the increase in forest cover, which should not eclipse certain radical changes instigated by the public authorities: extended transport networks (providing the possibility of specialising in a production and cultivating the most fertile lands first), and the rural exodus (less labour available and competition in agriculture).

supply without depressing the price (price taker), (ii) support policies, in particular for the right to land (see the Côte d'Ivoire slogan, "*the land belongs to those who work it*"), (iii) forests are accessible for cultivation, (iv) labour is inexpensive, and (v) capital is available (possibly via support policies elsewhere). Another decisive element is forest rent (see Ruf and Lançon 2004), according to which it is more attractive to convert forests than to replant previously cultivated land.

■ **Slash and burn farming**, which illustrates the appeal of extensive practices compared to intensive practices

Changes in agricultural technologies in the case of slash and burn farming – the most extensive practice of all – take several forms. These may include a new, more productive variety to limit cultivated areas (Zambia), commercial forest crops with an eventual shift to agroforestry (Borneo), or an improvement in fallowing in order to shorten crop rotations (Peru).
In the case of Zambia, the labour made available by the new variety migrated towards the copper mines rather than extending croplands, thereby making it possible to limit the agricultural expansion that would have automatically resulted from the freeing of additional labour.
In the case of Borneo, rubber plantations slowed down forest conversion by intensifying the use of cropland areas. The decisive factors that produced this result were the availability of sufficient cleared areas, the fact that little immigration was possible in these isolated zones, and finally that the law was applied in a satisfactory manner to limit the encroachment into forests. The known counter-examples are all situated in areas that are easily accessible to migrants.

■ **Permanent upland rainfed agriculture**, which show various impacts

Changes in agricultural technologies in upland rainfed crops include the use of better varieties, the dissemination of new crops, increased inputs and the use of pesticides.
In the case of Zambia, the capital-intensive technology proposed was attractive to slash and burn farmers. But its adoption was dependent on substantial public support.
In Ethiopia, treatments against the Tsetse fly made it possible to use cattle and to free up labour to convert more forest.
In Ecuador, coffee producers have intensified the labour factor – despite existing constraints on available labour – to avoid risks of income loss and to benefit from well-established markets to sell their production. This has resulted in better conservation of existing forests.

■ **Irrigated, intensive lowland agriculture**, a textbook case for testing the Borlaug hypothesis

This category includes technological change that corresponds to what happened with the green revolution: the widespread use of irrigation and pesticides to complement mechanisation.
The case of the Philippines clearly illustrates the labour part of the Borlaug hypothesis (rather than a fall in sales prices, there is an increase in labour costs, which has the same effects on profitability). Better small-scale irrigation systems were introduced, with higher labour intensity for production, which pushed up wages and made agricultural investment less attractive.
In Sulawesi (Indonesia), the result was the opposite. The dominant effect of the technological change was less labour to produce the same quantities, which made it possible to expand cocoa crops to the detriment of forest cover.
These cases are instructive from the viewpoint of the Borlaug hypothesis, as they show that markets for selling products and diversification play a key role. For example, a green revolution in the lowlands may lead to agricultural expansion at higher elevations in order to meet growing demand linked to better standards of living, for different products that are highly sensitive to a rise in purchasing power.

■ **Cattle ranching**, emblematic of Latin America

Two technology pathways are possible for this category: intensifying the use of pastures (more cattle per hectare), or enriching pastures to make them sustainable. On the latter point, it should be noted that an article recently

Figure 2. Important dimensions in the technological change – deforestation link, with tentative impacts on deforestation (excerpted from Angelsen and Kaimowitz 2003)

Reduced	Impact in deforestation	Increased
Intensive (high)	Labour and capital intensity	Saving (low)
Constrained	Farmer characteristics	Well-off
Local	Output market	Global
Yield-increasing	Technology	Cost-saving
Local segmented	Labour market	Mobile labour (migration)
Intensive (lowland)	Sectors experiencing technological change	Frontier areas (upland)
Global	Scale of adoption	Local
Short term	Time horizon of analysis	Long term

published (Rodrigues et al. 2009) showed the existence of a boom and bust situation in Brazil, where the rapid economic development initiated by cattle ranching has given way to a downturn due to the unsustainability of these practices.
This category is studied in the book using simulation methods, which provide different results that are nevertheless negative on the whole (more deforestation), for Peru and Colombia. In practice, cattle farmers generally extend pastures spontaneously following an extensive pattern if they are not obliged to intensify by the scarcity of land or by other types of intervention (such as the creation of protected areas in Brazil, see Taravella 2006).

The value of this book is that it shows that empirical case studies tend to reveal a convergence with the results formulated by theory for specific contexts (with very precise characteristics, rather than a global model as with the Borlaug hypothesis). In particular, forest cover is more likely to be affected if demand for agricultural products is sensitive to price reductions, since the environmental benefits expected as a result of an increase in productivity (and production) are cancelled out by an increase in demand. In addition, the capacity to attract migrants also tends to negate the presumed positive effect of adopting labour-intensive agricultural technologies. The respective intensities in terms of factors of production (labour, capital, land) are therefore critical. Finally, it seems that the gains obtained in a given production system are commonly reinvested in other crops – either for product diversification, or for complementarity between intensive and extensive practices – which in fact generates more deforestation.

Most of these theoretical lessons corroborated by empirical cases are summarised by the authors in Figure 2.

4. Implications for an effective REDD+ mechanism

The issue addressed in this document is a complex one, and this complexity could be better reflected in the way the question of agriculture is approached for the REDD+ mechanism at the international level[7]. Although intensification – in other words the increase in productivity per hectare - is a key variable for long-term forest conservation, the problem cannot be resolved by this alone. The scientific findings previously presented all indicate that there is no simple, unequivocal relationship between changes in agricultural systems and tropical deforestation.

However, the major trend to follow undoubtedly remains the increase in yields, without however

7. At the national level, the problem is posed in a slightly different way, especially through the national strategies that the countries participating in the World Bank FCPF (Forest Carbon Partnership Facility) must develop. Thus, agriculture is becoming more important in these national strategies, even if it is still too early to judge whether this is just for show or a real intention to act in an intersectoral manner.

basing this increase primarily on the provision of chemical inputs that increase the quantity of greenhouse gas emissions. One solution could theoretically lie in the rapid dissemination of a type of intensive agriculture in certain countries or regions – notwithstanding numerous problematic consequences, for example geographical specialisation implying a restrictive approach to the conservation of natural resources for the developing world. This option tends to maximise use of favourable agricultural conditions in certain regions, in order to indirectly preserve other countries or regions with less favourable conditions (a strategy know as "common agricultural pools")[8]. It remains to be determined how a REDD+ mechanism could represent an incentive for this global strategy, in the sense that areas that are unsuited to agriculture would see an economic advantage in reaping the benefits of REDD+ and minimising their agricultural areas, and vice versa for other regions.

4.1. Necessary public support policies[9]

A key lesson from the analysis presented in this text is the need for public support policies. This may be understood in at least four different ways.

a) Fostering changes in agricultural technologies

First, it means that we must not count on spontaneous changes in technologies that may contribute to forest conservation objectives. To explain this, it is useful to refer to the classical work by Ester Boserup (1965), which shows that spontaneous innovation generally brings about an intensification of scarce resources. This means that farmers show a strong tendency to adopt extensive systems when land is abundant in order to compensate for the scarcity of other factors of production such as labour and capital. This holds for both slash and burn farmers in Borneo and elsewhere and for cattle farmers in Latin America. Consequently, counting on the spontaneous innovation and adoption of new agricultural technologies implies accepting an increase in clearing while forest resources are abundant, and waiting until this resource is almost depleted before farmers attempt to remedy the problem! This has also been the case for bananas in Ecuador (Wunder 2003) and cocoa in Sulawesi in Indonesia (Ruf 2003), where small farmers did not adopt the new system as long as forests remained sufficiently abundant to apply the old techniques. A certain number of macro tools must therefore be implemented, for example management of the industry, taxation applied to the agricultural sector, or the creation of an area network with agencies responsible for disseminating technologies among their potential users.

b) Harmonising sectoral public policies

The second way to interpret the need for public support policies amounts to accepting the importance of harmonising measures that have a direct or indirect impact on forest cover. These are the "forest-related policies", which include all sectors of activity that have a significant impact: trade, taxation, infrastructure, regional control, and programmes encouraging human migration, etc. From reading the different references mentioned in this text, it becomes very clear that a strategy that is limited to just one sector of activity – here, agriculture – and not harmonised with the other sectors of activity, such as the construction of road infrastructure, would at best produce mixed, temporary results, and at worst be doomed to failure. Admittedly, some would argue that the "price signal" a carbon market would produce (or a different version such as multilateral and bilateral funding based on results) is itself capable of guiding decisions favourable to reducing emissions and therefore the harmonisation of policies if this harmonisation will lead to the objective being met. This idea is somewhat disconnected from reality, however, and political economy as well as governance issues must also be part of the analysis.

8. Here, it is important to note that emissions linked to the transportation of goods are not taken into account; accounting for these could partially change the final balance in terms of gains/losses of greenhouse gas emissions.

9. We use the term "public support policies" to refer to policies whose aim is to avoid the adverse effects of changes in agricultural technologies – in other words agricultural expansion to the detriment of forest cover. We do not use it in the sense generally employed in literature on carbon markets, namely that of policies that are complementary to the "spontaneous" effects of the carbon price signal.

c) Adopting the PES principle

The third way to interpret public support policies is central to our reasoning. Indeed, some major opportunities exist for giving the principle of Payments for Environmental Services (PES) the position it could well deserve in the future. This is not the place to go into detail about the mechanism, which is examined in depth in other sources (see, for example, Wunder 2005 for the canonical definition, or Pirard et al. 2010 for a critical analysis), but we can reiterate the principle behind it: the beneficiaries of an environmental service establish voluntary contracts with the providers of this service (who control the natural resource) and condition their rewards on the maintenance of the service. In the case in question, PES would consist in measures aimed at conditioning support for the adoption of sound agricultural technologies on the absence of excessive forest clearing on nearby land. Farmers and landowners would thus benefit from the possibility of using technologies capable of increasing their production and income, and at the same time the adverse consequences of forest clearing could be minimised. In other words, the principle is to benefit from REDD+ funding for an ecosystem service (climate regulation through CO_2 emissions reductions), in order to foster an agricultural revolution that would serve the interests of poor populations suffering from undernourishment on the one hand, and on the other, would avoid losing precious time in meeting the food challenge (substantially higher global food production by 2050). PES would therefore make it possible to set up contracts aimed at covering the costs of investment and of the transition towards new agricultural technologies. We define this as a support policy resulting from our analysis of the characteristics and consequences of changes in agricultural technologies from the viewpoint of changes in forest cover, because PES are then presumed to be capable of securing the positive effects (an increase in food production) while mitigating the adverse effects (expansion to the detriment of tropical forests).

d) Acting on global demand

The fourth way to interpret the need for support policies refers to the issue of demand for agricultural products. We have already explained that the elasticity of demand is a fundamental cause for the negation of the Borlaug hypothesis in practice: when production increases, demand also tends to rise in response to lower prices. This is known as the "rebound effect". It is based on the behaviour of consumers and their tendency to increase their consumption when purchasing power enables them to do so. It seems there are few remedies to this, since it is undoubtedly unrealistic to restrict consumers in their consumption choices. It is sometimes suggested that action should focus on diets throughout the world, in both developing and developed countries in order to bring demand per capita into line globally, for example by attempting to reduce the share of dairy products and meat. This is certainly necessary, but it is proving extremely ambitious. The effectiveness of educational programmes aimed at changing dietary habits in developed countries is as yet uncertain, and it is politically sensitive to recommend that people in developing countries should not copy the diets of the industrialised countries. More specific studies on food transitions nevertheless make it possible to imagine that the developing countries might not necessarily follow the same food transition as developed countries (in particular, not reaching the same very high total calorie intake per person, or the same share of animal products in this total), thanks to both nutritional policies and to cultural reasons, or because of the implementation of alternative models in the agro-food industry (Chaumet et al. 2009). Another alternative envisaged consists in setting up systems that would subject agricultural products to a kind of tax based on their carbon content, similar to commitments made under the Climate Convention (Zaks et al. 2009), but the implementation of such a system is still considered to be highly problematic.

4.2. A REDD+ mechanism focusing on results is incompatible with the need to experiment

This analysis leads us to question the ability of the REDD+ mechanism as currently discussed to satisfactorily apprehend the complexity of relations between agriculture and tropical deforestation. Here, we are not referring to the principle of national sovereignty laid down in the Climate Convention (each country being free to choose its own means of domestic action), or to the willingness of recipient countries to deploy agricultural policies that are compatible with reducing deforestation. Rather, we are referring to the fact that experimentation in the field of agricultural policies for the purpose of preserving forest ecosystems could perhaps be hindered depending on the architecture and functioning of REDD+. Specifically, it is questionable whether providing developing countries with incentives to obtain rapid, measurable results is fully compatible with the conditions for formulating effective agricultural land policies. The most important thing here is to ensure adjustments are made as the effects of changes in agricultural technologies are observed and analysed. In particular, it is highly likely that in many cases the new systems will at first generate negative impacts for forest cover, while these impacts will be reversed in the longer term. For example, an agricultural land policy consisting in providing farmers with land rights and technologies is likely to represent a strong incentive to clear forests in the short term, if support measures on regional planning are not drawn up and implemented (see, for example, Araujo et al. 2009). However, this should also help to create the conditions – relative prosperity, fewer risks, legal control of the resource making it possible to draw up PES contracts on a large scale – for an ambitious and effective long-term policy to combat deforestation. We should nevertheless keep in mind that the agricultural systems set up in this way also create irreversibilities by giving their actors greater negotiating power, which runs the risk of a lack of compliance in the long term with the initial conditions. These temporal dynamics and transitions must therefore be studied in much greater detail.

As Kaimowitz and Angelsen (2003) explain in their book, the objective could be to eventually achieve the terms of the following equation: (Win / Lose) + (Lose / Win) = (Win / Win)[10]. This equation means that the technologies that result in higher income for farmers while encroaching on the forest through the extension of cultivated areas may be combined with technologies (or rather regulations in this case) to promote conservation with negative impacts on farmers' income, in order to achieve a result that is satisfactory on the whole at all levels. This amounts to accompanying agricultural technologies that are capable of increasing yields with PES-type measures. It also implies drawing lessons from Boserup (1965) and from the spontaneous adoption of agricultural technologies that are detrimental to the environment, by promoting voluntarist measures, which may include PES within the REDD+ framework. Only time will tell if this option is realistic; as it stands, we believe it to be the most promising, combined with measures concerning global demand for agricultural products. ■

10. For each binomial (X / Y), X indicates whether the effects of a measure on farmers' income are positive (win) or negative (lose), while Y indicates whether the effects of a measure on the preservation of forest cover are positive (win) or negative (lose).

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idées pour le débat

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