Environmental Science & Policy 57 (2016) 122–130

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

Do timber plantations contribute to forest conservation?

Romain Pirard[a,*], Lise Dal Secco[a], Russell Warman[b]

[a] Center for International Forestry Research (CIFOR), Situ Gede, Bogor Barat 16115, Indonesia
[b] University of Tasmania, Private Bag 78, Hobart, TAS 7001, Australia

ARTICLE INFO

Article history:
Received 24 April 2015
Received in revised form 11 December 2015
Accepted 19 December 2015
Available online 7 January 2016

Keywords:
Timber plantations
Forest conservation
Forest transition theory
Wood production
Forest plantations

ABSTRACT

For some time there has been a proposition in forestry and nature conservation disciplines that timber plantations can potentially support natural forest conservation outcomes when wood logged in extensive natural forests is substituted by wood production from smaller areas of intensive timber plantations. Here, we have called this the *plantation conservation benefit*. We review evidence from the literature of this intuitively appealing proposition, both empirical and theoretical, and add emphasis on methods (theoretical modelling, econometrics and descriptive statistics) in order to explicitly address causative mechanisms and potential negative or positive feedback processes. This understanding is critical to developing effective policy. We find a convergence of conclusions of reduced degradation of natural forests associated with the expansion of timber plantations, but also potential increased deforestation due to either lower market value of natural forests in the absence of logging, or displacement effects. Yet, a main limitation of studies is the lack of consideration of the role of policies and institutions beyond market drivers, especially in econometric studies. We conclude on the need for integrated policy approaches applied simultaneously to both natural forests and plantations to maximize the potential benefit.

1. Introduction

Globally, deforestation and forest degradation continue to happen at a large scale, with wood extraction a significant cause (Dudley et al., 2014). This has major implications for biodiversity, ecosystem services and local communities and economies—solutions are critically sought.

This paper takes a global look at the role that highly productive timber plantations could play in addressing these problems. We review the hypothesis that natural forest degradation can be reduced by substituting wood extraction from natural forests with wood cultivated in timber plantations,[1] what we have called the *plantation conservation benefit*. It will try to answer the question: 'Is the substitution of wood from timber plantations good for forest conservation?' This question has a global scope, which means not only that it could apply to any geographical area in the world, but also that plantation development and forest conservation can be related while taking place at different locations.

Given the logical simplicity of the plantation conservation benefit hypothesis it is not surprising that this idea has a long lineage. Foresters of the early twentieth century were recognizing the potential for high productivity plantations to alleviate pressure on natural forests in order that other non wood values could be advanced (Bennett, 2010). Sedjo has advocated the idea for many decades (see Sedjo and Botkin, 1997; Sedjo and Lyon, 1983) as has Leslie (2005), a leading international forester. In more recent decades the hypothesis has been indirectly expressed through national forest policies where policy makers have become aware of the limitations of their natural forests to satisfy wood needs and meet other values at the same time. They have seen supporting plantation expansion as a way to provide opportunities to reduce pressure on natural forests (Bull et al., 2006).

The development of the plantation conservation benefit hypothesis has in part been supported by the very obvious expansion of the global plantation estate. Wood volumes coming from these sources have been growing over the last few decades

* Corresponding author.
E-mail addresses: r.pirard@cgiar.org (R. Pirard), dalsecco.lise@gmail.com (L. Dal Secco), russell.warman@utas.edu.au (R. Warman).

[1] We use the term 'timber plantations' to refer to trees planted for the purpose of wood production, including pulpwood plantations and other fast-wood plantations producing biomass for energy. Here it is intended to capture the full range of scales from vertically-integrated industrial plantations to smallholder plantings of trees outside of forests. These would align with the categories 'productive plantation' and 'trees outside forests' referred to in Carle and Holmgren (2008).

http://dx.doi.org/10.1016/j.envsci.2015.12.010

(Brown, 2000; FAO, 2010). Jürgensen et al., (2014) found that, conservatively, 33% of the world's industrial roundwood was produced in plantations in 2012. The combination of an expanding global plantation estate and ongoing improvements in productivity to the existing estate point to future plantation wood supplies two to four times higher than current levels by the middle of this century.[2]

Here, we undertake the first exhaustive review of the published evidence on this topic in order to draw lessons for more comprehensive studies on the issue as well as to synthesize results available at this point.

2. Theoretical background

The dramatic growth in plantation wood sources along with concern about the wellbeing of the world's natural forests has led to the development of a simple proposition that if wood can be produced from plantations than natural forests can be relieved of degradation pressure from logging. This substitution, physical but also economic, allows the plantation conservation benefit to accrue to the natural forests. In this section we challenge the foundations of this hypothesis and point to some of its key assumptions that tend to remain implicit.

Before proceeding with the enquiry, we note that the plantation conservation benefit hypothesis shares conceptual space with land sparing/sharing arguments, that respectively refer to (i) enhanced agricultural productivity per hectare to limit the size of the total area under cultivation and hence pressure on natural ecosystems, and (ii) agriculture undertaken in possibly less productive ways but integrated with the provision of ecosystem services across the landscape such as in agroforestry systems (Fischer et al., 2011; Phalan et al., 2011). Conceptually the plantation conservation benefit is an example of land sparing, and some authors note the similar patterns between efficiency drivers in agriculture and forestry (Victor and Ausubel, 2000).

2.1. The causality trap: lessons from the forest transition theory

The basis of the argument can be misleading and self-fulfilling when one looks for empirical evidence. The observation of the concomitant establishment of plantation estates with lower degrees of natural forest degradation or deforestation may look like a convincing observation that backs the argument. Yet, the correlation itself is not evidence of a causal–effect relationship, and statistics must be interpreted with caution.

Indeed, another theory that has been demonstrated empirically in many regions and over centuries explains the transition from high forest cover countries to subsequent stages of increasing and decreasing rates of deforestation until plantations and semi-natural forests develop to fill the gap (Mather, 1992). In other words, this "forest transition theory" is based on the identification of a pattern that provides plantations the historical role to take over natural forests (for both wood production and environmental services) once deforestation has reached an unsustainable level. This forest transition can follow various paths, and some have insisted on the difference between a transition due to economic development and one due to the scarcity of forest resources (Rudel et al., 2005). Whichever path is followed is not the point here, rather we focus on the fact that plantation establishment may actually take on the role of a "gap-filler" in response to a series of stages that contribute to the decline of natural forests as a source of wood products.

If this theory is to be accepted, and once again it is backed by evidence in a number of countries that have already gone through all stages such as Europe or North America, then it has substantial implications for the argument. Indeed, having plantations filling a gap once resources have been depleted to a significant extent, or having plantations anticipating this scarcity and substituting actively for the traditional source of supply, are two very different stories. In other words, the argument that plantations might support forest conservation holds in the second case (active role) but maybe not in the first case (passive role). One could thus ask the question: how can models and empirical studies tell the difference?

A first observation is that for plantations to have an active role, their development has to be part of a conducive and purposeful policy framework. Indeed, in the other case where they have a passive role, they develop in reaction to market signals as wood scarcity provides incentives with increasing prices.[3] We are interested in their potential active role, as its analysis and associated recommendations will support the design of suitable policies in order to tackle the pressing issue of degradation and deforestation. This is the time for proactive policies to make a difference as we do not have the luxury to wait for markets to do so.

A second observation is that it is theoretically possible to determine if plantations have started to develop before the situation would require production from alternative sources to natural forests. For instance, their production costs would be higher than those for natural forests when these costs are calculated by removing all subsidies or taxes that are intended to promote plantations over natural forests. Yet in practice it might be difficult to tell which subsidies or taxes serve this purpose or others, for instance energy subsidies.

A third observation is: a passive role for plantations is not equivalent to no role at all. Indeed, even if they do not trigger forest conservation on purpose and only result from an increased scarcity of natural forests with economically feasible wood production, they could still be viewed as preventing a near-to-absolute depletion of natural forests. In other words, they would still play a role and have plantation conservation benefits.

2.2. The argument relies on key assumptions

There are a number of underlying assumptions to the development of a plantation conservation benefit hypothesis. Firstly, it is assumed that natural forest logging is causing forest degradation. There is considerable evidence that wood extraction from natural forests contributes to forest degradation, especially in the tropics (Putz et al., 2012). This evidence of degradation is also supported by patterns of wood extraction from natural forests which have tended to exhibit non sustainable patterns (Shearman et al., 2012; Warman, 2014). There are other significant threats to the world's forests such as deforestation for agriculture (Gibbs et al., 2010) and poaching of wildlife (Robinson and Bodmer, 1999), although there are often strong interconnections between logging and these other threatening processes, particularly the impact of logging roads on these causes (Laurance et al., 2009). While there is strong evidence to support this assumption, sustainable forest

[2] See Jürgensen et al. (2014) for a review of recent forecasts of future plantation wood production.

[3] It must be noted that scarcity can be hidden by a specific policy context that removes expected market signals, as with the case of the pulp and paper sector in Indonesia where pulpwood plantations have developed more slowly than expected because of perverse incentives and the capacity of the main groups to influence policies and to guarantee their renewed access to shrinking resources (Pirard and Irland, 2007).

management (SFM) is intended to manage forests for wood production without causing forest degradation. However, while implementation of SFM at a national policy level has made some progress, it is still limited in reach, especially in the tropics and developing world (FAO, 2015). In addition, where it is applied its effectiveness remains contentious (for example see Lindenmayer and Laurance, 2012) and its application can have the effect of limiting the potential supply of wood from natural forests (the impact of protecting Spotted Owl in Pacific North West of the United States is a dramatic example, Murray and Wear, 1998).

A second assumption that is often implicit in these analyses is treatment of all natural forests as if they have equal conservation value. While this assumption can be workable when the option of comparing small areas of highly productive plantation established on land already cleared of forest is considered, it becomes problematic when the plantations themselves are established or managed in such a way that they have negative impacts on natural forest conservation values—in the most extreme case when they are established through conversion of healthy natural forest. While the negative impacts on biodiversity resulting from conversion can be obvious (Bremer and Farley, 2010), the net benefit at a larger scale could still be positive if the new plantations' productivity is of such a magnitude that it offsets the losses against reduced logging impacts across a larger area of natural forest. Estimating net cost/benefit outcomes of such trade-offs is especially complex when impacts on different natural forest and forest values are weighed up.

A third assumption is that wood from plantations is an effective substitute for wood from natural forests. The qualities of wood vary considerably between species and even within the same species across growing conditions and because of individual tree genetics and so wood types in plantations and natural forests are rarely perfect or near perfect substitutes. However, ongoing evolutions and capacity for adaptation of new processing technologies along the value chain in response to changing wood supplies (e.g. McKeever, 1997; Meil et al., 2007) including a shift to engineered and reconstituted wood products, makes the distinction between species and between natural forests and plantations less relevant.

A fourth assumption is that negative impacts created by the displacement of activities to other countries do not offset the positive domestic impacts on conservation. The case of Vietnam is interesting with the implementation of an ambitious program to establish five million hectares of plantations relying on smallholders and at the same time a moratorium on production from natural forests. Yet it was demonstrated that successes recorded within the boundaries of the country were less obvious when displacement effects were accounted for (Meyfroidt and Lambin, 2009). Indeed, more forest degradation and/or conversion took place in other countries in the region, e.g. Cambodia, in order to fill the supply gap created by policies in Vietnam, although the responsibility of the plantation expansion is only partial according to this same study. Other studies have found leakage of forest harvest can occur when logging is limited in natural forests (Meyfroidt et al., 2010; Murray et al., 2004). So this process of leakage must be clearly understood and accounted for when analyzing the plantation conservation benefit hypothesis. Otherwise, the negative impacts are ignored and the benefit of the active role of plantations is not validated.

A fifth assumption is that mature plantations will be used as a priority whenever available in order to save threatened natural forests. Unfortunately this is not necessarily the case. The political economy of forest management will not always act towards such obvious solutions, for example in the 2000's hundreds of thousands of hectares of standing industrial plantations remained untapped in the Indonesian provinces of Kalimantan while there was continued conversion of natural forests in Sumatra to supply pulp mills (Pirard and Cossalter, 2006).

3. Methods and results

3.1. Corpus and article classification

Our analysis is based primarily on a literature review, then extended to a discussion with regards to the limitations of existing studies and recommendations for both policies and future

Table 1
Distribution of the reviewed documents based on type of method and scale of application.

Method	Scale		
	Local	National	Global
Discussion			Sargent (1992) Victor and Ausubel (2000) Cossalter and Pye-Smith (2003) Binkley (2005) Paquette and Messier (2009) Friedman (2005)
Descriptive statistics		Clapp (2001) Binkley et al. (2005)	Sedjo and Botkin (1997) Sedjo (1999) Waggener (2001) Tomberlin and Buongiorno (2001) Sedjo (2001) Bowyer et al. (2005) Ince (2010) Warman (2014)
Theoretical models	Köhlin and Parks (2001) Linde-Rahr (2003) Jumbe and Angelsen (2011)	Hamilton (1997)	Von Amsberg (1998) Sohngen et al. (1997) Sohngen et al. (1999) Sembres et al. (2011) Heilmayr (2014)
Econometric models	Köhlin and Parks (2001) Linde-Rahr (2003) Jumbe and Angelsen (2011) Ainembabazi and Angelsen (2014)		Sembres et al. (2011) Heilmayr (2014)

research. Our objective has been to include all relevant literature using Web of Science, Scopus and Google Scholar databases and search engines with the following keywords: “plantations”; “planted forests”; “forest degradation”; “forest conservation”; “degradation”; “pressure”; “deforestation”. Generally-speaking articles adopt a social science perspective with economics and policies as the main entry points; and the ecological component is limited to the productivity aspects.

We proceeded with a screening of the abstracts to identify eligible articles, i.e. those addressing productive timber plantations specifically. We excluded oil palm and rubber plantations as they deal with different products and markets, hence lack relevance for the plantation conservation benefit hypothesis. We also excluded studies that focus on conversion of natural forests in the plantation establishment process, as our analysis is about the substitution effect between sources of timber supply and indirect effects.

Twenty six highly relevant studies were eventually reviewed that either specifically engaged the topic of the relationship between shifting wood production and forest conservation or provided specific empirical analysis that spoke to the topic in their findings. They were subsequently sorted according to the type of analysis and the scale they were applied to (Table 1). Indeed, this classification leads to an identification of results patterns. It is also a way to strengthen our conclusions as it helps to identify the most robust results, as well as the more limited methods. Lastly, this classification enables the identification of the main gaps in the literature with resulting recommendations for future assessments.

Consequently, four main categories of studies were considered: discussion papers, theoretical models, econometrics, and descriptive statistics. The “discussion papers” are general and tend to remain relatively superficial without empirical evidence, and were thus only used to feed the theoretical background section. Our approach differs from a meta-analysis as no statistics are provided based on the corpus, but we pay more attention to the methodological differences between studies in order to explain differing results.

3.2. Descriptive statistics: plantations are taking over

Descriptive statistics reflect on and organize data in order to describe phenomena and conduct ex post analysis to see if patterns in data fit expectations of the theory. Their main limitation is their inability to infer causative relationships as they do not consider alternative situations (or counterfactual scenarios) to assess impacts; they can only indirectly point to the possibility of the substitution effect that underpins the plantation conservation benefit. What they do point to are trends in wood production over time and parallel changes in removal of wood from natural forests from production and the increasing share of supply from plantations. But they do not say much about the role played by the ‘forest transition theory’ in such a substitution, and in turn whether plantations had an active or passive role in the process (see Section 2.1).

For example, the analysis by Warman (2014) finds that wood production from natural forests peaked in 1989, with subsequent stagnant growth in demand and growing volumes of timber plantations filling the gap between total demand and shrinking natural forest wood supplies. Scenarios for the future are also produced to explore the case further, such as those by Warman for the period 1945–2030, where projections are either based on historical trends or on the design of various scenarios of growth in plantation area associated with the review of outlook studies. Such projections point to a pattern of declining wood production from natural forests, but remain speculative because of many unknown factors such as the capacity of investors to finance the expansion of the plantation estate and/or an increase in the productivity of existing estates, and the evolution of demand.

Productivity is stressed by these descriptive statistics. With about a third of the total global industrial wood demand met with industrial plantations, but only a fraction of all forested areas are under this type of management,[4] the contrast is striking. In part this divergence in productivity reflects changes in how natural forests are valued. Because natural forests provide a greater range of goods or services in addition to provisioning services, and societal demand for these is growing, it is suggested by these authors (e.g. Binkley, 2005) that they will increasingly lose their competitive edge to plantations for wood production.[5]

3.3. Theoretical modelling: land rents and price effects

A majority of the references that we find in the literature present theoretical modelling efforts at local and global levels, rather than national scale. They are useful in their capacity to test a number of assumptions with empirical simulations, although this is neither a requirement nor systematic in the reviewed articles. Their interest is also largely in their consideration of counterfactual scenarios as this approach leads to a comparison of a world with or without plantation expansion. The factors behind the impacts on forest conservation have more chances to be elucidated in these circumstances, because the reasons for moving in one or the other direction in terms of impacts must be formulated explicitly as part of the mechanics of the models.

The body of theoretical modelling work is highly heterogeneous. In particular the focus can be on the local scale with a study of households’ behaviour with respect to fuelwood collection, or on the global scale with forecasts of demand and supply from various sources and following the logic of general equilibrium analysis. Further distinctions within these broad sub-categories can be made depending on the inclusion of a demand elasticity (how consumers react to lower prices), the capacity of a model to allow for direct land competition between agriculture and forestry, the existence of different forest classes with associated productivity, or the recognition of spatial location of various sources, just to give a few examples. Models that operate at a global scale tend to emphasize price effects and provide insights that can be missed in descriptive statistics.

Crucial here is the spatial economics of the Von Thunen framework (see Nelson, 2002) which considers the role of land rents and impacts of shocks and policy changes on these. This model is deterministic as decisions are assumed to depend on the expected returns of land uses: changes in land rents induce changes in land use. The closer the land to cities and their markets, the more intensive the land use for higher-value purposes and perishable goods, which results in agriculture close to markets, low-intensity forestry far away, and timber plantations in between (the shorter the rotation the closer to markets). Its application to the plantation conservation benefit hypothesis suggests a key role played by the price elasticity of demand. Indeed, when markets exhibit a high demand elasticity, the prices for forest products will be more stable in a period of timber plantation expansion, and the changes in land uses will be of less importance. In other words, with increased overall demand for wood products and hence sustained demand for wood from natural forests, the prices will

[4] It is estimated there are between 50 and 200 million ha of productive plantations depending on the definitions and scope (Del Lungo et al., 2006; Indufor, 2012), out of 4 billion ha of forests worldwide.

[5] For example plantation productivity could be growing at 3% per an annum Binkley (2003) and Brazilian plantation analysis indicates an average MAI for its eucalypt plantations of 26 m^3/y/ha in 1990, 30 m^3/y/ha in 2000 and 40 m^3/y/ha by 2012 (Gonçalves et al., 2013).

Table 2
Main results for each article of the sample (except for discussion-type articles).

Reference	Main result
Local	
Ainembabazi and Angelsen (2014)	The introduction of commercial timber plantations has reduced the natural forest production by 15.5% compared to the counterfactual situation
Jumbe and Angelsen (2011)	A one hectare increase in plantations area reduces by 2% the fuel wood collection in customary forests
Linde-Rahr (2003)	Wood from plantations and from natural forests are substitutes: a one unit decrease in the shadow wood price from plantations decreases the share of collection from open access forests by 0.3 units
Köhlin and Parks (2001)	Village woodlots reduce wood extraction from natural forests by 13% Plantations should not be settled too close or too far away from natural forests
National	
Binkley et al. (2005)	United States plantations will be able to respond to the entire increase in timber demand. Demand pressure on natural forest will be halved
Clapp (2001)	Chile plantations captured traditional markets supplied by natural forests but it did not reduce logging in natural forests because of a new external demand
Hamilton (1997)	Indonesia moderate demand increase and high dependence on timber plantations for wood supply will reduce deforestation
Global	
Heilmayr (2014)	Plantations lead to lower areas of logged natural forests, yet this positive impact is mitigated when the elasticity of demand is high
Warman (2014)	Wood supply from natural forests has peaked and supply from planted forests is growing
Sembres et al. (2011)	Plantations increase deforestation rate in countries with high agricultural rents. They reduce this rate in countries with low agricultural rents
Ince (2010)	Emerging role of plantations in timber production
Bowyer et al. (2005)	Emerging role of plantations in timber production
Sedjo (2001)	An innovation shock implies an increase in plantations' establishment that relieves pressure on natural forests
Tomberlin and Buongiorno (2001)	Wood supply from plantations unlikely to be enough to reduce pressure on natural forests by 2010
Waggener (2001)	Removal of natural forests from production and emerging role of timber production from plantations
Sedjo (1999)	Increase in global wood production over time comes mostly from plantations
Sohngen et al. (1997) Sohngen et al. (1999)	More plantations reduce long term price levels by 12% and thus reduce harvest in remote old-growth forests by 15% compared to the baseline scenario
Sedjo and Botkin (1997)	Placing only 5% of the current forest area under intensive plantations would be enough to meet the demand for wood products
Von Amsberg (1998)	With an inelastic demand, the increase in timber supply induced by plantations creates a real drop in timber prices that leads to less degradation of natural forests

remain stable as will returns to land for natural forests under production. It implies that forest degradation might continue but forest conversion might be (partially, and in relative terms) avoided.

Related to this observation, studies based on theoretical modelling are potentially problematic as the design of the model can to a large extent determine the outcome. This points to a critical phenomenon that might significantly shape the expected impacts of the expansion of plantations. Indeed, some models do not account for the competition among land uses and hence fail to account for the impact of the establishment of plantations on displacement of the other land uses. This is a key and very tangible aspect to understand the impacts of plantations, as their expansion could displace agricultural activity that in turn leads to the conversion of natural forests. This can occur immediately as plantations are established, but could also occur during later surges in demand for food. This is not always reflected by the models, with misleading results as reduced degradation is shown but the other side of the story is left aside, namely deforestation risk.

Studies at the household level are devoted to wood extraction as a source of forest degradation. The models look at decisions made by households among a previously identified set of sources: no impact is expected to happen beyond this area and trade is not addressed. The models rely on the maximization of the utility of individuals to simulate choices in terms of wood sources, and this utility is calculated based on observable parameters, especially distance and associated requirements in terms of time and overall cost of transportation.

3.4. Econometric modelling: rebound effects and risks of deforestation

Econometric studies are mostly used to test the theoretical models that were presented in the previous section. These econometric studies point to some elements of context and the extent of their influence on the impacts of plantations on forests, e.g. land rents, or the price elasticity of demand. This elasticity, which is a critical element of the analysis, is usually determined through global trade analysis. Models show that positive impacts on the conservation of natural forests are very much dependent on a low elasticity that prevents demand from soaring when markets are supplied with new sources of wood. Otherwise, a rebound effect (Greening et al., 2000) is expected because consumers have a tendency to buy more when prices decline and goods become affordable.

These models also have the benefit of pointing out another consideration of the plantation conservation benefit hypothesis, which is that degradation can lead to deforestation. This aspect is addressed in numerous studies about the processes of deforestation across the tropics (Geist and Lambin, 2001)—notably, the construction of road infrastructures for the management of forest concessions that boost investments in the area. It means in turn that any effort to tackle degradation through logging might also lead to avoided deforestation.

But there is the other side of the coin: when natural forests are not logged for timber production (in a sustainable way), their economic value is lower and they might be threatened for this exact reason, as long as land ownership and government regulations enable changes in land use. Indeed they become more prone to conversion as they are less competitive against agricultural rents. In this respect, a lot seems to depend on whether agricultural rents are high (high risk, negative impacts) or low (low risk and overall positive impacts more likely). Arguably, this varies a lot with the geographical areas. Indeed where agricultural rents are relatively low and natural forests are under little pressure or even expand, such as Europe or North America, reducing logging activities is unlikely to lead to conversion. But in other areas where agriculture expands rapidly in forested areas, usually in tropical zones, this assumption might hold true.

At the household level, for fuelwood extraction, various econometric methods are applied, ranging from binary or multinomial qualitative models to impact evaluation with difference-in-difference. Overall, a lot seems to depend on the characteristics of households – in particular the level of education of the household's head, the livestock endowment, the size of the household or its distance to the various sources of fuelwood – and the characteristics of plantations such as size and location.

All in all, econometric models attempt to capture the causal relationship between plantation establishment and the conservation of natural forests. One of the main advantages of these models is the possible introduction of interactive variables that enable the identification of certain elements of context that condition the plantation conservation benefit. However, several methods, such as instrumentation or the use of Generalized Method of Moments (GMM),[6] could be envisaged to better treat the potential endogeneity bias caused by reverse causality (Table 2).

4. Discussion

4.1. Findings so far: a variety of methods, issues and findings

It appears that depending on the methods, results may differ and point to complementary or contradictory impacts in terms of forest conservation. Therefore, by placing studies in several categories based on the methodological approaches applied for each of them, we could separate more or less rigorous and reliable studies from a methodological point of view. Indeed about half of the articles included in our corpus are either of a discussion (no specific evidence produced) or descriptive statistics (no modelling of interactions or the factors of change) type, which means that they have limited value in providing new evidence in support of causative relationships. This is important because ignoring these causative relationships significantly affects the relevance of knowledge for policy making. For instance, it is simplistic to consider one fixed demand and one given rate of expansion of tree plantations, and then deduce the area of natural forests that can be spared from degradation and/or conversion. Nevertheless, these studies are useful for underlining trends in productivity and spatial location of the plantation estate.

Theoretical models are powerful tools. First, they can be applied at a global or national level and build on the spatial economy Von Thunen framework, also integrating the issue of global trade that proves critical in an era of globalization with high risks of displacement effects. Second, they are applied to study household strategies and behaviour for fuelwood collection. They show that household characteristics play a significant role for predicting the outcomes of the establishment of tree plantations devoted to energy production in rural areas. The respective locations of the forest and plantation, along with size and species composition, are critical factors that determine their relative access and associated transportation costs, which in turn lead to forest conservation or, on the contrary, to business-as-usual forest degradation. But their limited scope on fuelwood extraction necessarily limits their lessons to a specific, yet very substantial issue in some developing countries.

Insights from econometric models refer to several key determinants of impacts: most importantly the price elasticity of demand and the level of agricultural rents. Indeed, if the demand for wood products is very sensitive to price fluctuations on the markets, then a rebound effect can be expected that could partially or fully offset the positive impacts. This is to be taken seriously, as this rebound effect has been observed for other products historically in line with the conceptualization by Jevons (1865) for the case of coal. The ability for rebound to occur will depend on what is driving the substitution. A rebound effect is most likely if the cost of plantation wood is competitive and pulls prices down.

The issue of agricultural land rents can be understood as follows: when wood products originate from additional timber plantations, the full sustainable production potential of natural forests (maximum sustained yield) might be untapped as demand is satisfied. A perverse effect can occur if agricultural rents are high enough in forested areas and standing natural forests lose part or all of their market value (not accounting for the range of non-market environmental services they still provide), and this in turn leads to their conversion to other land uses. The key caveat on this scenario is that the forested land has to be subject to property rights that do not restrict its use or saleability, however in many cases around the world the forests are owned by governments (up to 80% of the world's forests White et al., 2006) or are on private land that can be subject to regulatory restrictions on its use (e.g. threatened species legislation or slope protection regulations).

Our review highlighted the importance of careful consideration of the type of impacts on forest conservation. While the focus tends to be on degradation arising from logging, the interconnected processes being reviewed (particularly displacement of activities due to scarcity of land) can also lead to deforestation. Impacts then need to be divided into more or less degradation and deforestation. As a matter of fact, most studies and the terms of the debate lack clarity on this distinction, and many remain ambiguous with respect to the nature of the impacts on forest conservation that they analyse.

4.2. Policy implications

Two significant negative outcomes have been identified in relation to the plantation conservation benefit—the rebound effect on wood markets and the alteration of land rents for forests. These have significant implications for policy design. One implication of this is that policies are required to secure positive impacts for forest conservation through the avoidance or mitigation of the rebound effect. In part this can be achieved by placing restriction on natural forest harvest—for example by regulating and enforcing sustainable forest management, sustainable allowable annual cuts or complete bans on natural forest logging. In this scenario policy restrictions on natural forest logging can act in the same way that other biophysical limits to natural forests do by creating a restricted supply and raising wood prices, thus increasing the comparative advantages of plantation wood. The limitation to this approach is that in one country with trade connections this demand can be shifted to forests abroad—at best supporting plantation development there, at worse shifting to alternative natural forest sources.

Similar challenges exist for addressing deforestation resulting from high agricultural rents creating a risk of forest conversion. Regulations and law enforcement are obvious solutions but can be politically difficult to implement, the more so when the effect can be that part of the benefit is lost to deforestation elsewhere in the world. Furthermore, as pressure on forested land increases then policy makers can be tempted to undo regulations such as moratoriums or protected areas. For instance Mascia and Pailler (2010) show the multiplicity of downgrading, downsizing or even degazettement of protected areas worldwide. The market forces can also by themselves lead to low levels of enforcement, as illustrated by the high levels of degradation in conservation areas in Indonesia (Gaveau et al., 2012). Consideration needs to be given

[6] The general idea is to introduce lagged variables as instruments in the equation. This method enables to account for endogeneity caused by simultaneity bias, reversal causality and omitted variables (Arellano and Bond, 1991; Blundell and Bond, 1998).

to managing users' demand for agricultural or wood products to avoid pressure on conversion-prone areas. In addition, there is a need for plantations to supply wood for the full range of wood demands, including unique timber species so that plantations do not simply replace the demand for low value fibre supplies. When major changes happen such as China phasing out commercial logging in the country's natural forests with about 50 million m^3 of lost annual harvests, plantations have to be able to take over, in order to prevent leakage of logging effort to natural forests elsewhere.

In developing policy there is the need to consider the scale at which the policy is being directed and to recognize different processes by which the promise of the plantation conservation benefit might be achieved. Binkley (2005) notes that at a global scale the approach is to achieve significant substitution of plantation wood in order to reduce threats to the world's remaining areas of primary forests in particular. At a national scale he notes that policies can be directed towards an integrated suite of natural forest protection measures and plantation estate establishment. This approach allows individual countries to secure plantation conservation benefits without them coming at the cost of higher dependence on imports of wood products to maintain domestic wood-based industries and the associated jobs. And then he notes the local opportunities for conservation outcomes that can be achieved when plantation estates incorporate best practice features such as riparian forest reestablishment, set-asides of HCVF areas, and sensitive site rehabilitation with natural forest.

The role of subsidies is ambiguous because on the one hand they give plantations an active role in conservation as their establishment can occur before natural forest scarcity reaches a critical level; but on the other hand they can artificially lower prices and hence may have repercussions for rebound in wood demand, lower production costs in remote forests or even for agriculture leading to forest conversion (e.g. energy subsidies). But incentives can take other forms, such as regulatory restrictions on natural forest logging and deforestation, construction of infrastructures in places dedicated to plantations, or distribution of rights on degraded state land for plantation establishment. All of this, of course, requires effective enforcement, but generally-speaking governments should consider an integrated policy approach of both regulating natural forest wood extraction and supporting plantation establishment. These policies could also include alternative ways of deriving value from natural forests, such as tourism or payment for ecosystem services. Australia provides an example of where a degree of plantation conservation benefit can be seen. Overlapping policies of increasing natural forest protection and plantation establishment have been implemented with a mix of policy approaches (Ajani, 2011), including subsidies (Ferguson, 2014). Over the last thirty years Australian wood production has shifted significantly to plantations while increased conservation reserves and other logging restriction on natural forests have been implemented while increasing Australia's overall wood production levels.

Another potential limitation to the plantation conservation benefit model is that if implementation of low impact logging regimes such as SFM and certification act to increase costs, then plantation sourced wood could end up competing with wood from those more sustainable sources, hence shifting remaining natural forest logging to places without those restrictions. Such a process would be consistent with the market processes described with searches for lowest cost wood supplies directing where wood is sourced (especially if substantial certification premiums do not materialize). In such a scenario, plantation wood would be acting to shift wood production to remaining primary forests with high standing volumes or concessions without SFM. In this scenario it becomes critical to develop policy that protects those natural forests with the highest standing volumes (particularly primary forests) from this perverse outcome. Such moves would both support the expansion of plantation and give light footprint logging regimes their only real chance of being viable.

4.3. Future research needs: the way forward

Further improvement in findings should take heed of the limited aspects covered by the research, several methodological weaknesses and problems related to the availability and quality of data used. We noticed that econometric models in this domain face some critical limits because of the endogeneity bias (caused by potential reversed causality) that can hardly be avoided. Here, we think in particular about the theory of the forest transition and especially the forest scarcity path (see Section 2.1). Econometric models should also account for the time lags between the establishment of plantations and their harvest anywhere from several years to several decades later, depending on the sites, species, quality and nature of products.

We also noticed the relative neglect of several important factors, such as market segmentation, public support policies, and leakage/displacement effects. These should be better, and systematically, integrated in the models to strengthen the results. With the intensification of international trade and better connectivity between places of production, processing and consumption, leakage and displacement effects also deserve more consideration in all studies in this field.

Modelling in its various forms, and the primacy of economic aspects and dynamics in many approaches, entail some limitations that relate to policies (see Section 5.3). In many countries government policy and ownership of forests is highly influential in plantation establishment and forest designation. While this tends to be covered better at national levels, it also means that global modelling could tend to overplay the role of markets influences and underplay political and social influences. For example Friedman (2005) notes that ownership of forests makes a difference when natural forests are publicly owned and can be managed by effective governance so that there is considerably more scope for the plantation conservation benefit to occur. But more generally this raises the need to consider the complexity of the social, political and institutional dimensions of wood production and forest conservation. The relatively simple or one dimensional land use change assessment that is represented in discussion of the plantation conservation benefit hypothesis fails to incorporate multiple intersecting and influential processes.

Data issues were also identified especially for running models on a global scale. This would include the need for specific data collection of plantation estate and production data. Such requests have been made before (e.g. Warman, 2014) and the FAO has in part responded with its recent review of international data on plantations (Jürgensen et al., 2014). At this stage a key limitation continues to be the patchy data collection at national levels. In part the difficulties of getting full national datasets will be advanced by consistent application of definitions such as adoption of work such as that of Carle and Holmgren (2008) that effectively captures the spectral nature of forests and non-forest wood sources. In addition to formal data collection the quality of independent spatial data continues to improve as witnessed by emerging initiatives such as Global Forest Watch.

5. Conclusion

The limited research to date generally supports the idea that growing supplies of plantation sourced wood can reduce pressure on natural forests for wood extraction. However, there are significant limitations to published results, which we have

demonstrated in this article by making distinctions based on methodological approaches with associated strengths and weaknesses. In particular, we pointed to limitations in the identification of all explanatory variables as well as cause–effect relationships.

The literature also points to a number of potential negative outcomes for forest conservation that could arise from plantation wood sources affecting markets in wood and land. One is the potential rebound effect; another is deforestation resulting from the lower market value of non-producing natural forests. In all cases we suggest that policies need an integrated approach utilizing both regulation of natural forest use and plantation support policies to manage and reduce the potential of these negative feedbacks. Land use planning remains critical for plantations to play an active role in conservation in order to accelerate successful forest transitions; otherwise they are likely to play a mere passive role, simply reacting to market signals when over harvest and forest scarcity make them necessary to take over wood supplies.

It is also clear that there are a number of important distinctions that need to be made in analyzing the plantation conservation benefit. These are; considering the relative roles of wood for pulp, biomass and solid wood applications, whether the conservation impact being considered is forest degradation or deforestation, and taking into account the relative conservation values in the forests being considered (including distinctions of primary and secondary forest, the latter referring to natural forests subjected to logging) but also various environmental impacts of plantations depending on their design and integration in the landscape. All of these must also be carefully considered in relation to the scale at which the analysis is conducted—findings at a generalized global scale might not be applicable in all countries or regions and vice versa. Failure to clearly account for each of these considerations in any analysis of the plantation conservation benefit can lead to individual studies that confuse rather than clarify the processes.

Although the general corpus broadly supports the existence of the plantation conservation benefit, opinions diverge on the desirability of working to retain natural forests for timber production—some support strong levels of protection to give priority to environmental services while others contend that well-designed and enforced regulations enable the combination of timber extraction and the provision of most ecosystem services. We do not take position on this issue in this article, but would like to draw the reader's attention to the fact that lowering of demand for natural forest wood can lower natural forest land rents so that they become subject to conversion pressure, mainly in the absence of any regulatory process to prevent this. This leads to consideration of the range of current and emerging ways of bringing value to natural forest lands to support their retention and management, including developing alternative market signals such as ecotourism, payments for ecosystem services, better integration of local communities in the management of adjoining forest areas, as well as sustainable forest management for wood production. The key challenge is that for any of these approaches to work, a reasonable degree of effective regulatory systems, including enforcement, is needed. And yet the problem mainly arises if there is an absence of regulatory capacity (or willingness) to prevent the deforestation in the first place (another possibility is that regulations change over time to adapt to a changing economic context with higher returns from conversion to other land uses and allow deforestation). The wicked problem nature of this dilemma suggests that there is unlikely to be a silver bullet solution or approach to optimizing benefits and reducing negatives to the plantation conservation benefit where regulatory systems are ineffective.

It is likely that approaches designed for addressing complex problems such as adaptive management and tackling underlying reasons for failure in effective regulatory systems are needed to fully realize the potential of the plantation conservation benefit and to avoid its potential negative effects. It still might be possible that there is a demand for slow grown woods with qualities not easily replicated in plantations. These will by their nature need to be managed on very long rotations of several decades to centuries and are unlikely to ever form more than a very limited portion of total roundwood demand—in effect a boutique natural forest harvest sector for long rotation small volume high value log extraction. It is also possible that a greater portion could be satisfied by natural forest production if certification premiums are substantial enough to compensate for much higher production costs—although this remains highly speculative based on experience so far.

The responses that will be made to these challenges, and the evolution of the values that society attributes to natural forests with resulting demands for better natural forest management, will largely determine the extent to which the plantation conservation benefit can be realized. While the broad trends point to an eventual separation of much wood production out of natural forests into plantations (that would be qualified as 'wood cultivation'), issues of wood qualities, regional and national forest types, land demands and varying social demands from forests mean it is unlikely to be a complete transition of neat simplicity. What is clear is that the plantation conservation benefit contains obvious significant opportunities for meeting societal demand for (and benefits of) wood while improving the chance of natural forests being able to deliver other demands for their many unique and valued non timber services.

Acknowledgements

Funding for this article has been provided by DfID through the KNOW-FOR grant, MTO 069018. The third author's contribution was supported by a scholarship from the University of Tasmania.

References

Ainembabazi, J.H., Angelsen, A., 2014. Do commercial forest plantations reduce pressure on natural forests? Evidence from forest policy reforms in Uganda. For. Policy Econ. 40, 48–56.
Ajani, J., 2011. Australia's wood and wood products industry situation and outlook. Working Paper, Fenner School of Environment and Society. The Australian National University.
Arellano, M., Bond, S., 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev. Econ. Stud. 58, 277. doi:http://dx.doi.org/10.2307/2297968.
Bennett, B.M., 2010. Locality and Empire: Networks of Forestry in Australia, India, and South Africa, 1843–1948, PhD thesis. University of Texas.
Binkley, C.S., 2003. Forestry in the long sweep of history. In: Teeter, Lawrence Dale, Cashore, Benjamin William, Zhang, Daowei (Eds.), Forest Policy for Private Forestry: Global and Regional Challenges. CABI, Oxon, pp. 1–8.
Binkley, C.S., 2005. The environmental benefits of tree plantations. J. Sustain. For. 21 (4), 5–14.
Binkley, C.S., Aronow, M.E., Washburn, C.L., New, D., 2005. Global perspectives on intensively managed plantations: implications for the Pacific Northwest. J. For. 103 (2), 61–64.
Blundell, R., Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. J. Econ. 87, 115–143.
Bowyer, J.L., Howe, J., Guillery, P., Fernholz, K., 2005. Fast-Growth Tree Plantations for Wood Production—Environmental Threat or a Means of 'Saving' Natural Forests? Dovetail Partners Inc., White Bear Lake, MN.
Bremer, L.L., Farley, K.A., 2010. Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. Biodivers. Conserv. 19 (14), 3893–3915.
Brown, C., 2000. The Global Outlook for Future Wood Supply from Forest Plantations. FAO, Forestry Policy and Planning Division, Rome.
Bull, G.Q., Bazett, M., Schwab, O., Nilsson, S., White, A., Maginnis, S., 2006. Industrial forest plantation subsidies: impacts and implications. For. Policy Econ. 9 (1), 13–31.
Carle, J., Holmgren, P., 2008. Wood from planted forests: a global outlook 2005–2030. For. Prod. J. 58 (12), 6–18.
Clapp, R.A., 2001. Tree farming and forest conservation in Chile: do replacement forests leave any originals behind? Soc. Nat. Resour. 14 (4), 341–356.
Cossalter, C., Pye-Smith, C., 2003. Fast-Wood Forestry: Myths and Realities, vol. 1. CIFOR, Bogor, Indonesia.

Del Lungo, A., Ball, J., Carle, J., 2006. Global planted forests thematic study. Results and analysis. Planted Forests and Trees Working Papers FP38E. FAO, Rome.
Dudley, N., Jeanrenaud, J.P., Sullivan, F., 2014. Bad Harvest: The Timber Trade and the Degradation of Global Forests. Taylor & Francis.
FAO, 2010. Global Forest Resources Assessment 2010: Main Report. Food and Agriculture Organization of the United Nations, Rome.
FAO, 2015. Global Forest Resources Assessment 2015: Synthesis Report. Food and Agriculture Organization of the United Nations, Rome.
Ferguson, I., 2014. Australian plantations: mixed signals ahead. Int. For. Rev. 16 (2), 160–171.
Fischer, J., Batáry, P., Bawa, K.S., Brussaard, L., Chappell, M.J., Clough, Y., Daily, G.C., Dorrough, J., Hartel, T., Jackson, L.E., 2011. Conservation: limits of land sparing. Science (New York, NY) 334 (6056), 593.
Friedman, S.T., 2005. Environmental aspects of the intensive plantation/reserve debate. J. Sustainable For. 21 (4), 59–73.
Gaveau, D., Curran, L.M., Paoli, G.D., Carlson, K.M., Wells, P., Besse-Rimba, A., Ratnasari, D., Leader-Williams, N., 2012. Examining protected area effectiveness in Sumatra: importance of regulations governing unprotected lands. Conserv. Lett. 5 (2), 142–148.
Geist, H.J., Lambin, E.F., 2001. What drives tropical deforestation. LUCC Rep. Ser. 4, 116.
Gibbs, H., Ruesch, A., Achard, F., Clayton, M., Holmgren, P., Ramankutty, N., Foley, J., 2010. Tropical forests were the primary sources of new agricultural land in the 1980 and 1990. Proc. Natl. Acad. Sci. 107 (38), 16732–16737.
Gonçalves, J.L.d.M., Alvares, C.A., Higa, A.R., Silva, L.D., Alfenas, A.C., Stahl, J., Ferraz, S. F.d.B., Lima, W.d.P., Brancalion, P.H.S., Hubner, A., 2013. Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. For. Ecol. Manage. 301, 6–27.
Greening, L.A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption – the rebound effect – a survey. Energy Policy 28 (6), 389–401.
Hamilton, C., 1997. The sustainability of logging in Indonesia's tropical forests: a dynamic input–output analysis. Ecol. Econ. 21 (3), 183–195.
Heilmayr, R., 2014. Conservation through intensification? The effects of plantations on natural forests. Ecol. Econ. 105, 204–210.
Ince, P.J., 2010. Global sustainable timber supply and demand. In: Rowell, Roger M., Caldeira, Fernando, Rowell, Judith K. (Eds.), Sustainable Development in the Forest Products Industry. Universidade Fernando Pessoa, Porto, Portugal, pp. 29–41.
Indufor, 2012. Strategic Review on the Future of Forest Plantations, Helsinki.
Jevons, W.S., 1865. The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of the Coal-mines. Macmillan.
Jumbe, C.B., Angelsen, A., 2011. Modeling choice of fuelwood source among rural households in Malawi: a multinomial probit analysis. Energy Econ. 33 (5), 732–738.
Jürgensen, C., Kollert, W., Lebedys, A., 2014. Assessment of Industrial Roundwood Production from Planted Forests, FP/48/E, FAO Planted Forests and Trees Working Paper. Food and Agriculture Organization of the United Nations, Rome.
Köhlin, G., Parks, P.J., 2001. Spatial variability and disincentives to harvest: deforestation and fuelwood collection in South Asia. Land Econ. 77 (2), 206–218.
Laurance, W.F., Goosem, M., Laurance, S.G., 2009. Impacts of roads and linear clearings on tropical forests. Trends Ecol. Evol. 24 (12), 659–669.
Lindenmayer, D.B., Laurance, W.F., 2012. A history of hubris—cautionary lessons in ecologically sustainable forest management. Biol. Conserv. 151 (1), 11–16.
Leslie, A., 2005. What will we want from the forests. ITTO Trop. For. Update 15 (1), 14–16.
Linde-Rahr, M., 2003. Property rights and deforestation: the choice of fuelwood source in rural Viet Nam. Land Econ. 79 (2), 217–234.
Mascia, M.B., Pailler, S., 2010. Protected area downgrading, downsizing, and degazettment (PADDD) and its conservation implications. Conserv. Lett. 4 (1), 9–20.
Mather, A.S., 1992. The forest transition. Area 24 (4), 367–379.
McKeever, D.B., 1997. Engineered wood products: a response to the changing timber resource. Pacific Rim Wood Market Rep. 123 (5), 15.
Meil, J., Wilson, J., O'Connor, J., Dangerfield, J., 2007. An assessment of wood product processing technology advancements between the CORRIM I and II studies. For. Prod. J. 57 (7–8), 83–89.
Meyfroidt, P., Lambin, E.F., 2009. Forest transition in Vietnam and displacement of deforestation abroad. Proc. Natl. Acad. Sci. U. S. A. 106 (38), 16139–16144.
Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. Proc. Natl. Acad. Sci. 107 (49), 20917–20922.
Murray, B.C., McCarl, B.A., Lee, H.-C., 2004. Estimating leakage from forest carbon sequestration programs. Land Econ. 80 (1), 109–124.
Murray, B.C., Wear, D.N., 1998. Federal timber restrictions and interregional arbitrage in US lumber. Land Econ. 74 (1), 76–91.
Nelson, G.C., 2002. Introduction to the special issue on spatial analysis for agricultural economists. Agric. Econ. 27 (3), 197–200.
Paquette, A., Messier, C., 2009. The role of plantations in managing the world's forests in the Anthropocene. Front. Ecol. Environ. 8 (1), 27–34.
Phalan, B., Onial, M., Balmford, A., Green, R.E., 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333 (6047), 1289–1291.
Pirard, R., Cossalter, C., 2006. The revival of industrial forest plantations in Indonesia's Kalimantan provinces. Will They Help Eliminate Fiber Shortfalls at Sumatran Pulp Mills or Feed the China Market? No. 37, CIFOR Working Paper Center for International Forestry Research (CIFOR).
Pirard, R., Irland, L.C., 2007. Missing links between timber scarcity and industrial overcapacity: lessons from the Indonesian Pulp and Paper expansion. For. Policy Econ. 9 (8), 1056–1070.
Putz, F.E., Zuidema, P.A., Synnott, T., Peña-Claros, M., Pinard, M.A., Sheil, D., Vanclay, J.K., Sist, P., Gourlet-Fleury, S., Griscom, B., 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conserv. Lett. 5 (4), 296–303.
Robinson, J.G., Bodmer, R.E., 1999. Towards wildlife management in tropical forests. J. Wildl. Manage. 63 (1), 1–13.
Rudel, T.K., Coomes, O.T., Moran, E., Achard, F., Angelsen, A., Xu, J., Lambin, E., 2005. Forest transitions: towards a global understanding of land use change. Glob. Environ. Change 15 (1), 23–31.
Sargent, C., 1992. Natural forest or plantation? In: Sargent, Caroline, Bass, Stephen (Eds.), Plantations Politics: Forest Plantations in Development. Earthscan, London, pp. 16–40.
Sedjo, R., 2001. The economic contribution of biotechnology and forest plantations in global wood supply and forest conservation. Proceedings of the First International Symposium on Ecological and Societal Aspects of Transgenic Plantations, College of Forestry, Oregon State University.
Sedjo, R., 1999. The potential of high-yield plantation forestry for meeting timber needs. In: Boyle, James Reid, Winjum, Jack K., Kavanagh, Kathleen, Jensen, Edward C. (Eds.), Planted Forests: Contributions to the Quest for Sustainable Societies. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 339–359.
Sedjo, R., Botkin, D., 1997. Using forest plantations to spare natural forests, Environment. Sci. Policy Sustain. Dev. 39 (10), 14–30.
Sedjo, R., Lyon, K.S., 1983. Long-term forest resources trade, global timber supply, and intertemporal comparative advantage. Am. J. Agric. Econ. 65 (5), 1010–1016.
Sembres, T., Kontoleon, A., Brown, C., 2011. Understanding the impact of timber plantations on tropical deforestation: a cross country analysis.
Shearman, P., Bryan, J., Laurance, W.F., 2012. Are we approaching 'peak timber in the tropics? Biol. Conserv. 151 (2012), 17–21.
Sohngen, B., Mendelsohn, R., Sedjo, R., 1999. Forest management, conservation, and global timber markets. Am. J. Agric. Econ. 81 (1), 1–13.
Sohngen, B., Mendelsohn, R., Sedjo, R., Lyon, K., 1997. An Analysis of Global Timber Markets. Resources for the Future Washington, District of Columbia, USA.
Tomberlin, D., Buongiorno, J., 2001. Timber plantations, timber supply and forest conservation. In: Palo, Matti, Uusivuori, J., Mery, G. (Eds.), World Forests, Markets and Policies. Springer, Netherlands, pp. 85–96.
Victor, D.G., Ausubel, J.H., 2000. Restoring the forests. Foreign Affairs 127–144.
Von Amsberg, J., 1998. Economic parameters of deforestation. World Bank Econ. Review 12 (1), 133–153.
Waggener, T., 2001. Role of Plantations as Substitutes for Natural Forests in Wood Supply-Lessons from the Asia-pacific Region. Department of Environment and Natural Resources, pp. 277–295.
Warman, R.D., 2014. Global wood production from natural forests has peaked. Biodivers. Conserv. 23 (5), 1063–1078.
White, A., Sun, X., Canby, K., Xu, J., Barr, C., Katsigris, E., Bull, G., Cossalter, C., Nilsson, S., 2006. China and the Global Market for Forest Products, Transforming Trade to Benefit Forests and Livelihoods. Forest Trends, Washington, D.C.