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REVIEW

Perverse Market Outcomes from Biodiversity Conservation Interventions

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Abstract

Conservation interventions are being implemented at various spatial scales to reduce the impacts of rising global population and affluence on biodiversity and ecosystems. While the direct impacts of these conservation efforts are considered, the unintended consequences brought about by market feedback effects are often overlooked. Perverse market outcomes could result in reduced or even reversed net impacts of conservation efforts. We develop an economic framework to describe how the intended impacts of conservation interventions could be compromised due to unanticipated reactions to regulations in the market: policies aimed at restricting supply could potentially result in leakage effects through external or unregulated markets. Using this framework, we review how various intervention methods could result in negative feedback impacts on biodiversity, including legal restrictions like protected areas, market-based approaches, and agricultural intensification. Finally, we discuss how conservation management and planning can be designed to ensure the risks of perverse market outcomes are detected, if not overcome, and we address some knowledge gaps that affect our understanding of how market feedbacks vary across spatial and temporal scales, especially with teleconnectedness and increased international trade.

Introduction

With increasing global population and affluence, the global demand for timber, food, and other natural resources is rising, with crop demands projected to increase by 100–110% from 2005 levels by 2050 (Tilman *et al.* 2011). Meeting this demand will drive further forest degradation from logging and deforestation for agriculture and timber plantations, especially in the tropics (Hansen *et al.* 2013). Habitat loss in the tropics is the biggest driver of biodiversity and ecosystem function losses (DeFries *et al.* 2004). There is thus an urgent need to better manage tropical land-use change to reduce the loss of biodiversity and ecosystem functions, while addressing the issue of rising timber and food demands, for instance, via changing diets or reducing food waste (Erb *et al.* 2016).

Management strategies are commonly implemented to reduce conversion of natural habitats to other land uses, and therefore to stem the loss of biodiversity. These include legal restrictions on land-use by establishing protected areas (PAs) (Oliveira *et al.* 2007), market-based conservation efforts such as certification and payment for ecosystem services (PES) schemes (Chobotová 2013), and improvements in technology and agricultural intensification (Tilman *et al.* 2011).

Often, however, there are indirect and unintended consequences of conservation measures. Trade-offs are inevitable with changes in land use (DeFries *et al.* 2004), and this includes when implementing conservation efforts. Many unintended consequences are often overlooked when assessing the effectiveness of biodiversity conservation actions (Larrosa *et al.* 2016), in part because indirect environmental and ecological impacts of land-use changes and conservation actions typically occur over longer time-scales and larger distances than directly measured outcomes. Unintended consequences can have positive or negative effects on the overall (net) outcomes of interventions. Positive feedback effects include protection or restrictions on wildlife harvests diminishing demand (Pain *et al.* 2006) and unintended crowding-in effects from market-based conservation policies (Wunder 2013). By contrast, negative feedbacks could include demand driving leakage of deforestation into unprotected areas in response to establishing PAs (Ewers & Rodrigues 2008) and an increase in demand brought about by improving cost-efficiency of agriculture (Rudel *et al.* 2009).

Given that negative feedbacks compromise conservation efforts, we focus on their emergence via the influence of market forces. Knowledge of the socio-ecological system responses is crucial for decision makers to minimize negative unintended feedbacks. Typologies that classify feedbacks between deletion (removal of pre-existing feedbacks), addition, and flows (changes in magnitude of pre-existing feedbacks) have recently been developed (Larrosa *et al.* 2016). Under this typology, market feedbacks could be considered flow feedbacks and PAs establishment addition feedbacks.

Market feedbacks in response to the initial conservation intervention can undermine conservation efforts (Armsworth *et al.* 2006), and although important, they are often not considered in policies (Jantke & Schneider 2011; Miller *et al.* 2012; St John *et al.* 2013). Understanding how agents in a market respond to policy changes is very important in determining whether a certain scheme will have the intended consequences, or instead be counterproductive (Galaz *et al.* 2015). Changes in policy typically affect the incentives of agents, resulting in changes in their behaviors. In many cases, the reaction of agents to the new incentives resulting from policies in biodiversity conservation will have a large influence over whether the policy is successful, or if perverse incentives will lead to damaging unintended consequences instead. Arguably, unintended consequences of environmental and conservation policies through these channels have not attracted sufficient scrutiny to date (Milner-Gulland 2012). It is therefore essential to understand how a policy will alter the pattern of incentives of agents in the market. Indeed, successful policies will be designed to ensure the incentives of agents in the market are compatible with the intended aims of the policy.

In this review, we focus on the potential perverse market outcomes of conservation efforts. We first develop a theoretical model to explain how market regulations respond to conservation efforts. Reframing conservation in an economic context allows us to understand how market feedbacks could lead to perverse outcomes. We then apply the framework to different conservation interventions and discuss how conservation policies and management practices might be adapted to minimize the risk of negative consequences.

Economic underpinnings of unintended consequences via market feedbacks

Conservation places restrictions on resource use

Conservation interventions can be viewed as external impacts on the resource market (e.g., timber), which can result in a shift in the equilibrium or lead to disequilibrium. In many cases, conservation actions revolve around restricting access to a resource. Placing logging bans and quotas on timber harvests, for example, restricts trade of the commodity (i.e., timber). Establishing PAs also restricts land availability and access to resources. Imposing such restrictions limits the quantity of supply (q_1, Figure 1A), and the market is no longer in equilibrium. The market responds with a rise in the price to p_1, above the initial equilibrium level, at which suppliers would like to offer more than q_1 to the market (q_1, Figure 1A). This represents the basic economic model of a quota (Goolsbee *et al.* 2016).

However, there is some question about the effectiveness of such policies in practice. For instance, applications of this theory to include leakages (Murray *et al.* 2004; Jonsson *et al.* 2012) involve the expansion of supply back toward the quantity at the free-market equilibrium. Related arguments of how illegal trade can expand consumption in the presence of import quotas have also been established in the international trade literature (e.g., Falvey 1978). In other words, some of the restriction in quantity due to the quota may be undone by illegal trade. Perverse "illegal" (black) market incentives reduce the impact of the conservation policy.

The imposition of a quota also produces an artificially high price in the formal market, meaning that inefficient (high-cost) suppliers can co-exist with efficient ones. This presents the question—which suppliers supply the formal market and which supply the black market? In addressing this question, we highlight a novel further possible perverse impact of a quota policy. Compared to a free market where efficiency considerations determine which firms supply the formal market, the allocation of supply rights under a quota policy is now determined by the regulatory authority. With high prices within the formal market, there is less incentive to be efficient, and inefficient suppliers could end up supplying the market. If the regulatory authority does not observe efficiency and

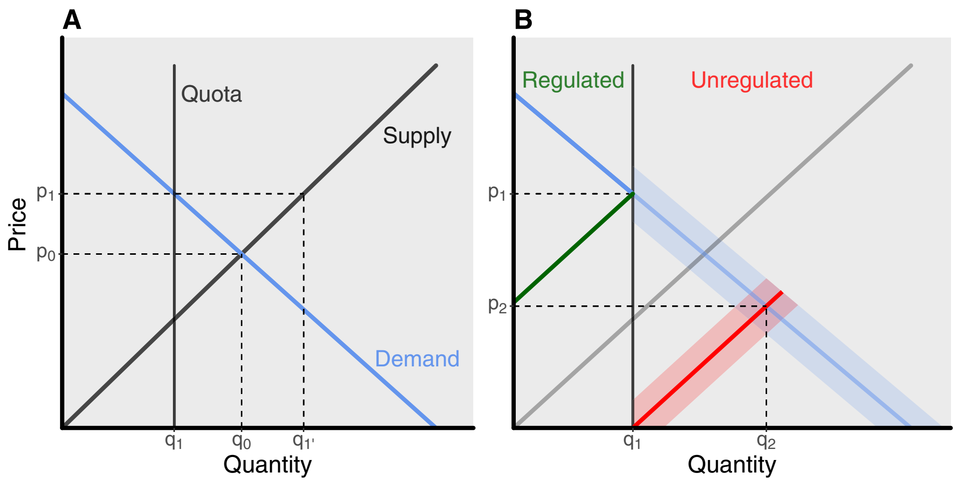

Figure 1 Conceptual framework describing possible effects of an output quota (A) on the creation of an illegal market (B). (A) The market is initially in equilibrium at (q_0,p_0). Setting a quota restricts the quantity of resource traded to q_1 raising the price to p_1. Firms can respond to this disequilibrium by creating an illegal market. Assuming, for simplicity, there are no additional costs to illegal supply relative to regulated supply, firms will expand supply through the illegal market moving up the supply curve beyond q_1 with total supply rising toward the pre-quota level, q_0. (B) If, for instance, the inefficient firms (green) supply the formal market, supplying q_1, and the efficient firms (red) supply the illegal market, supplying q_2-q_1, the creation of the illegal market can result in an overall increase in the quantity traded ($q_2 > q_0$) despite the quota. We might also expect shifts in demand and supply (shaded) within the unregulated market due to externalities.

allocate supply rights to the most efficient firms, or, if the authority is able to exploit the power of allocating rights to pursue their own agenda (e.g., corruptly supplying rights to "friendly", possibly high-cost, firms), then one perverse result of the imposition of a quota might be a decline in market efficiency. In such a case, the inefficient firms supply the formal market and the efficient firms supply the unregulated market—there is a reorganization of supply (Figure 1B) akin to the rationing rules on the demands side used, for instance, in Davidson & Deneckere (1986). The total output across the formal and black markets in this case could be greater than under the initial equilibrium before the quota was introduced (q_2, Figure 1B). The quota might be ineffective in terms of reducing trade, and may even result in an increase in trade.

The degree to which the quantity traded exceeds the quota will depend on which firms supply each market, as well as the costs and benefits to firms and consumers from trading in the illegal market. For instance, supply in the illegal market will shift downward, reducing the leakage effect, if the costs associated with supplying the legal market are lower than supplying the illegal market. However, where the legal market has high costs associated with meeting regulatory standards, by avoiding these costs, firms trading in the illegal sector might offset extra costs associated with the illegal market (e.g., concealment costs).

Improving land-use practices and efficiency to reduce land-use

Conservation measures could also involve improving efficiency and technology through agricultural intensification and new crop varieties, to reduce the pressure to convert more land. While the direct impact of such measures could be an increase in production with a reduced need for land, there may also be unintended consequences. Although there is uncertainty as to whether intensification would improve the cost-efficiency of production, if improved, it could lead to a decrease in the costs of resources: suppliers are willing to supply more at any given price. This is associated with a rightward shift in the supply curve and consequently, in the equilibrium (q_0,p_0 – q_2,p_2, Figure 2), resulting in an overall increase in resources being traded (e.g., Villoria *et al.* 2014). The size of this shift in equilibrium does depend on the price elasticity demand of the product—with a more pronounced effect in the case of an elastic demand (where demand varies strongly with prices). Conservation measures aimed at regulating the supply of, for instance, agricultural production might instead put additional pressure on remaining available resources.

These perverse outcomes could be exacerbated in markets where the global demand is supplied though multiple substitutes, such as different types of vegetable oil crops (e.g., oil palm, rapeseed). Assuming markets for both commodities are the same (perfect substitutes),

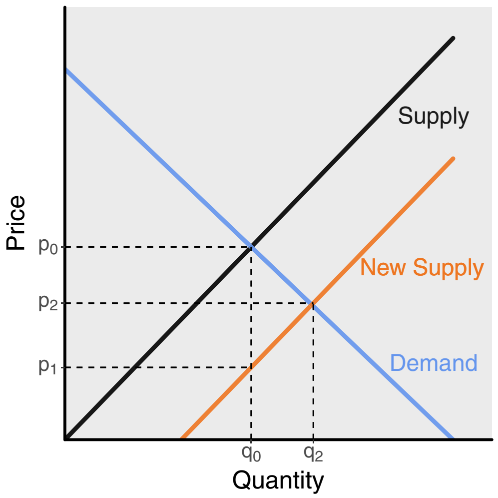

Figure 2 Conceptual framework describing how prices and quantities of resources traded vary when crops are improved. Agricultural intensification can shift supply rightward (black to orange) resulting in an overall shift in equilibrium from (q_0,p_0) to (q_2,p_2).

initial equilibria for both commodities should also be identical (q_0p_0, Figure 3A). Improving yields in one crop lowers prices for any given quantity proportionally, represented by a shift in supply curve from Supply$_A$ to Supply$_{AInt}$, and causes a shift in equilibrium from q_0p_0 to q_Ap_A (Figure 3B). Additionally, we can expect decreased demand for the less efficient substitute, denoted by the downward shift in Demand$_B$, and a decrease in quantity of crop B (from q_0 to q_B): consumers are likely to favor the cheaper crop beyond price p_A. We can therefore expect higher quantities of crop A traded, and a surplus of crop B not traded. Overall, however, there could still be a net increase in agricultural land use (deforestation for crop A – forest recovery on abandoned land from crop B), and a net loss of old-growth forests across a larger region (Carrasco *et al.* 2014).

Examples of conservation measures and market feedbacks

Legal restrictions on land use

Legal protection and restrictions on land use are widely implemented globally and include establishing PAs and regulating logging and other resource harvest quotas. Such conservation measures rely on regulation by an authority, usually governmental, to ensure the impacts on ecosystems and biodiversity are minimal, or at least compensated. However, legally enforced (i.e., sufficiently funded) conservation policies are often only effective within their designated areas, typically at local spatial scales, and could lead to a displacement of destructive activity and land use into unprotected and unregulated areas (Ewers & Rodrigues 2008).

Establishing PAs could be effective in directly reducing human impacts within targeted forests, but in many instances might be driven more by markets than by conservation or ecological considerations (Rayner *et al.* 2014). Many PAs lack additionality because they are situated in locations passively protected by their distance to markets, unproductive soils, steep gradients, etc. The establishment of PAs in economically valuable areas could increase land prices across remaining areas (Polasky 2006), and shift deforestation and land-use changes into unprotected forests instead. This could create incentives for an unregulated market with consequences as outlined in the framework (Figure 1B).

In the tropics, such leakage effects result in high rates of clearing and degradation of forested areas surrounding PAs. For instance, while deforestation rates in the Peruvian Amazon were as low as 2% within PAs, they were up to 18 times higher outside PAs (Oliveira *et al.* 2007). Similarly, protection of mature forests in Costa Rica reduced the rate of mature forest loss by 50%, but resulted in cropland expansion redirected into unprotected natural habitats, including wetlands, native reforestation, and young secondary forests, due to the lack of legal protection of these areas (Fagan *et al.* 2013). Furthermore, import of timber and agricultural products into the country increased, displacing land-use change internationally (Jadin *et al.* 2016). Another potential perverse outcome is an acceleration of land-grabs before regulations are put in place. This situation was observed in Tanzania where accelerated land conversion occurred in anticipation of PA expansion (Baird *et al.* 2009).

Legal restrictions against resource extraction, much like PAs, can also have displacement effects into unregulated areas, rather than decreased harvests as intended: a similar restriction to a quota is placed on resource quantity, which could result in an informal market arising with a re-organization of supply and expansion of total output (Figure 1B). Reduction in deforestation rates across multiple countries was, for instance, associated with displacement via international trade (Meyfroidt *et al.* 2010).

Basic economic principles can be used to show how endogenous market feedbacks (i.e., changes within the market, Figure 1) could undermine conservation efforts and benefits, and change conservation priorities (Murray *et al.* 2004; Armsworth *et al.* 2006). More recently, studies have integrated sub-models of resource extraction and biodiversity impacts, fluctuations in household utility and market prices, and spatially explicit distributions of biodiversity and resources to highlight the impacts on land-use change (Bode *et al.* 2015; Renwick *et al.* 2015).

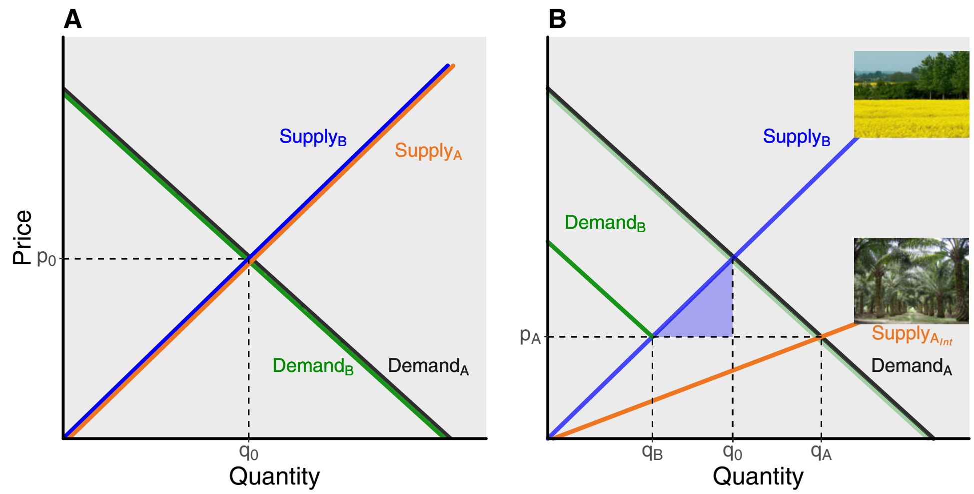

Figure 3 Conceptual framework describing the possible effects of agricultural intensification on demand and land-use of substitute crops (B). (A) Assuming, for simplicity, that demand and supply conditions of each commodity are identical, both markets will have the same initial equilibrium (q_0,p_0). (B) Agricultural intensification of one crop (A, orange) can increase amount traded, from q_0 to q_A. Additionally, demand for the substitute crop B could decrease (green), as consumers are likely to favor the cheaper substitute above price p_A. Amount of crop B traded decreases to q_B, resulting in either a surplus (shaded region) not traded. This surplus will ultimately lead to either innovation to use the surplus, or land abandonment from crop B. Improving oil palm yields (pictured lower inset) in the tropics, for example, could lead to a decreased demand in rapeseed oil (upper inset), allowing secondary forest regrowth in temperate regions, but the increased demand for palm oil could increase tropical deforestation.

Market-mediated conservation measures

Market-based approaches to conservation policies are increasingly seen as efficient, effective means of managing resources, while promoting conservation (Chobotová 2013). The impacts of biodiversity are controlled through use of markets, and practices that promote conservation are incentivized over practices with negative environmental outcomes. These could be used as complements to legally mandated conservation measures (Lambin *et al.* 2014). Nevertheless, as highlighted in our framework, these approaches still allow a quota to be set: a governing authority defines a formal, regulated market and determines who supplies within this market, potentially re-organizing supply with possible perverse consequences (Figure 1B). Furthermore, market-based measures revolve around incentivizing suppliers of the formal market, and do not necessarily penalize suppliers of the informal market. Much like legally mandated measures, market-based interventions could favor an unregulated market (with uncertified resources at lower prices, q_2p_2, Figure 1B) alongside the regulated market (with certified resources at higher prices, q_1p_1, Figure 1B). These perverse outcomes can occur at both local and transnational scales, because policies are typically narrowly focused and do not account for their wider consequences.

PES schemes, such as the United Nations' Reducing Emissions from Deforestation and forest Degradation (REDD+), although not widely implemented, are increasingly popular (Wunder 2013). They provide a means of internalizing the externalities from loss of ecosystem services and enhancing conservation efforts by compensating suppliers who help improve or protect ecosystem services via habitat protection or restoration.

PES schemes could promote more sustainable practices within the market, and allow authorities to decide who supplies the regulated market. However, this neither directly reduces the overall demand for a resource, nor does it penalize suppliers to the informal market. The incentive of supplying the informal market could therefore remain high (Figure 1B), and the market might favor suppliers of the informal market—we could ultimately witness a displacement of land-degrading activity into areas not regulated by the PES scheme. This leakage effect could be exacerbated as prices within the regulated market increase (p_1, Figure 1B).

Perverse incentives could also occur within PES schemes if they are not implemented and managed well (Wunder 2013). When suppliers are only rewarded by favorable practices within designated areas (e.g., for additional management practices like afforestation), we could observe a leakage of effect, where destructive activity displaced into areas not enrolled in PES schemes but belonging to the same owner are neglected (Atmadja & Verchot 2012). Managing PES schemes also becomes increasingly difficult in situations where a single approach is implemented to achieve multiple objectives: PES schemes are frequently also viewed as poverty alleviation and development tools (Daw *et al.* 2011).

Sustainability certification schemes (hereafter certification schemes) and eco-labeling (e.g., Rainforest Alliance, Roundtable on Sustainable Palm Oil) rely on consumer activism and pressure on companies to improve business practices and ethics, thereby promoting sustainability in the global supply chain. Forestry certification schemes like the Forest Stewardship Council (FSC) are among the most developed schemes (Auld *et al.* 2008): the amount of FSC-certified forests has increased to over 186 Mha in the span of about two decades (FSC 2016), and some studies have reported improved forest health in FSC-certified forests (e.g., Kalonga *et al.* 2015).

Certification schemes, however, have the potential to create similar effects in terms of a re-organization of supply and associated consequences for expansion of output as those arising from a quota. For instance, if the scheme gives certified suppliers exclusive access to the consumers with a high willingness to pay (q_1, Figure 1), but is not tied to firm efficiency, then less efficient firms could end up among the suppliers in the certified market, displacing efficient firms into the uncertified market. Indeed, certification usually results in a rise in price of certified commodities (from p_0 to p_1, Figure 1B), thereby restricting access to wealthier consumers. Prices of certified timber within Malaysia, for instance, were up to 56% higher than uncertified timber (Kollert & Lagan 2007). Therefore, only relatively wealthy consumers can afford certified products, while less wealthy purchasers continue buying unregulated and uncertified products (q_2p_2, Figure 1B). Additionally, if prices of certified-sustainable goods are too high, the market demand could be lower than the supply and we could observe lower uptake than expected (Edwards & Laurance 2012). FSC schemes, for example, have increased in popularity over the last decade, but were concentrated in newly developed countries across the tropics, and usually do not include developing nations with larger native forests (Auld *et al.* 2008).

Importantly, because certification schemes do not penalize the informal market (i.e., no additional costs for supplying the unregulated market), we can expect the unregulated market to thrive. While certification schemes like FSC directly reduce poor logging practices within certified forests (formal market; from q_0 to q_1, Figure 1B), they could also result in leakage of (illegal) logging into unmanaged forests (from q_0 to q_2, Figure 1B), making the overall management of resources and deforestation more difficult. Indeed, illegal timber products account for 50–90% of forestry products across the tropics (Nellemann 2012). Similar leakage effects could also emerge from other certification schemes. RSPO certification might be effective in promoting sustainable agricultural practices within certified oil palm plantations, but we could also witness a leakage effect not only affecting unprotected forests, but also production of other crops. RSPO certification across Indonesia led to increased conversion of existing rice cropland (Koh & Wilcove 2008) and jungle rubber plantation (Warren-Thomas *et al.* 2015) into oil palm plantations, resulting in an indirect displacement of efforts and habitat conversion in Indochina.

Biodiversity offsets and other trading schemes

Biodiversity trading schemes could be classified as market-driven measures to reduce biodiversity loss, but have also been passed as legislations in some countries. These are typically enforced on companies and developers to allow for economic growth and development, while indirectly reducing human pressures on biodiversity and the environment (Froger *et al.* 2015). Such schemes have been legislated in a number of countries (e.g., Australia) or regions (e.g., California), and widely embraced and adopted by private land developers and companies, including mining and oil companies (Edwards *et al.* 2014), as a means of measuring and reducing their impact on biodiversity loss.

Biodiversity offsets and trading schemes, in essence, place restrictions on some areas (reserves) while allowing others to be converted for use. Fundamentally, these methods mimic legally mandated conservation efforts (e.g., PAs), where the amount of land use is restricted (Figure 1A). Such offsets can only be effective at a very local level (i.e., within reserves themselves), and reserves need to have higher conservation values than areas being converted to achieve a no-net loss outcome. Enforcing restrictions on land-use, as with other conservation measures, does not affect the demand for land, timber or nontimber forest resources, and could result in a displacement of efforts outside the managed (regulated) area. Where reserves are of high economic value, land purchases in biodiversity offsetting programs could also alter supply and demand of resources, resulting in increased land rent and therefore biodiversity loss in unprotected areas (Armsworth *et al.* 2006).

Land sparing and high-yielding crop varieties

The land-sparing versus land-sharing framework, which considers the trade-offs between agricultural or timber demands and the desire to protect biodiversity, has been widely applied in the debate of how best to meet growing resource demands (Phalan *et al.* 2011). Notwithstanding the limitations of both strategies (Fischer *et al.* 2011; Erb *et al.* 2016), a large number of data-based assessments suggest that the land-sparing approach of high-yield farming with habitat conserved elsewhere, if managed correctly with strong governance and effective protection of remaining forests, might be more effective in promoting biodiversity conservation while meeting demand (Phalan *et al.* 2011; Erb *et al.* 2016). Agricultural intensification is a necessary condition for land-sparing, but not a sufficient condition for reducing the need to convert more forest to farmland (Erb *et al.* 2016).

Agricultural intensification, however, does not reduce the incentives associated with expansion; agricultural area has been observed on occasion to increase with intensification (Ewers *et al.* 2009; Rudel *et al.* 2009). Projections of land-use changes have also suggested the possibility of further loss of forests with improved crop yields (Kaimowitz & Angelsen 2008; Phelps *et al.* 2013; Villoria *et al.* 2014). This is especially so in passive land-sparing scenarios, where remaining forests are not managed or protected effectively, and hence easily targeted for agricultural expansion (Phalan *et al.* 2016). A rebound effect known as Jevon's paradox could arise, where the increased efficiency and reduced costs of crop production instead lead to increased demands. The magnitude of this effect could vary, depending on elasticity demand of the product (Hertel 2011; Villoria *et al.* 2014). For agricultural intensification to be effective in reducing land-use change, an active land-sparing framework is necessary, with heavy reliance on the role of PAs and effective governance (Phalan *et al.* 2016), which many countries might lack (Fischer *et al.* 2011).

Increasing agricultural productivity could make crops cheaper and more profitable to produce over time, and increase its uses and demand as a cheaper substitute for other less cost-efficient crops (Villoria *et al.* 2014), even at transnational scales (Figure 3). If this results in favoring more cost-efficient tropical crops (e.g., oil palm), this could then exacerbate agricultural expansion across the tropics (Carrasco *et al.* 2014). There could be an increase in land abandonment and reforestation within low-profit areas, i.e., a decrease in land use from q_0 to q_B (Figure 3), but this is coupled with increased expansion and deforestation (q_0 to q_A, Figure 3) within areas of higher market value. The benefits of increased forest regeneration in marginal areas for agriculture across the Neotropics (e.g., highlands), for instance, would be outweighed by the negative impacts on biodiversity from increased deforestation in the lowland tropical forest (Aide *et al.* 2013).

Managing the effects of market outcomes

Assessing perverse outcomes in studies

Conservation interventions need to work toward incorporating steps to monitor and minimize perverse outcomes (Larrosa *et al.* 2016), but little has been done to overcome these outcomes. Some studies have, however, looked into incorporating and evaluating unintended feedbacks into their analyses of PAs and incorporated spatial information, theoretical models, and biodiversity maps to project spatially explicit predictions of areas more vulnerable to leakage (Bode *et al.* 2015; Renwick *et al.* 2015). Others have identified and measured leakage of conservation policies such as REDD+, using econometric or general equilibrium models (e.g., Murray *et al.* 2004; Gan and McCarl 2007). These models center on identifying the market feedbacks incurred from the conservation action, and understanding how they translate into indirect impacts on resources, i.e., through the unregulated market.

A number of factors also need to be considered when assessing, predicting, and managing these perverse outcomes. Since costs associated with land-use change vary across space due to multiple factors (social, political, and environmental), we would also expect the magnitude of market outcomes and impacts on biodiversity to vary between regions (Armsworth *et al.* 2006; Chaplin-Kramer *et al.* 2015) and across different spatial scales. While some studies acknowledge this, few have incorporated spatial information in their models (e.g., Bode *et al.* 2015). Not accounting for spatial variation results in often-erroneous assumptions of homogeneity across landscapes.

As with spatial scales, actions tend to be implemented across short timescales, but the effects of land conversion and land use are long term: time lags in responses and impacts on habitat and biodiversity (e.g., extinction debts and forest regeneration) might not be captured in static analyses (Ghazoul *et al.* 2015). Displacement costs of policies and actions could at times be intergenerational (Roca 2003), and while the immediate effects of some measures might seem positive, by not making assessments over longer temporal scales we do not consider other socio-economic factors and market feedbacks that might be detrimental (Hill *et al.* 2015). The benefits of PES schemes and other long-term measures are also often based on the assumption that other conditions in the market are constant, but land-use regimes could be implemented alongside other regulations and socio-economic changes and shocks (Müller *et al.* 2014), which will impact on the effectiveness of the regime. More emphasis needs to be placed on dynamic effects in planning long-term measures.

Another aspect of market-based outcomes often not addressed in studies is the interaction between distant parts of the world (teleconnectedness; Carrasco *et al.* 2014). Given the importance of global markets and transnational trade, overlooking the effects of teleconnectedness could lead to a considerable underestimation of the indirect impacts on land-use change (Renwick *et al.*

2015): since legislations, policies, and other conservation measures are usually localized, studies tend to focus only on local and national effects. The consequences of these conservation policies and actions are, however, usually spread across much larger spatial scales and between countries and continents (Liu *et al.* 2013). Reducing land-use in one area, without a reduction in resource demand, could lead to agricultural expansion and land conversion in another, and countries with large gains in forest cover might observe increases in imports of wood and agricultural products (Gan & McCarl 2007; Meyfroidt *et al.* 2013). For instance, regulations to increase forest regeneration within Vietnam (Meyfroidt & Lambin 2009) and China (Viña *et al.* 2016) led to an increased import of timber products. Projections of land-use changes should also account for the possible influence of alternative and complementary markets. Oil palm, for instance, can be a cheaper substitute to other oil-producing crops, including soy and rapeseed, and changes in prices and quantities of one crop could affect demands of each substitute crop (Figure 3), and ultimately increase land-use across the tropics (Carrasco *et al.* 2014).

Reducing the risk of perverse incentives within formal markets

Our framework also helps highlight how policies might be designed to help mitigate these unwanted effects. Conservation policies should recognize where conditions and incentives exist for officials to be corrupt regarding the selection of suppliers and make this a focal point for anti-corruption investigation. Policies also need to implement mechanisms to increase transparency and address information asymmetries by employing competitive tendering mechanisms allowing the efficient firms to reveal themselves (Smith & Walpole 2005). Third-party auditing, for instance, may be a potentially effective means of increasing transparency and minimizing probability of leakage and of perverse behavior within the formal market (Cook *et al.* 2016). Measures like these would limit the potential for corruption to dictate the exploitation of land and resources.

Reducing the risk of informal markets emerging

Our framework also points at the emergence of an informal market as an important source of perverse outcomes from conservation efforts (Figure 1B). Conservation policies therefore need to be more inclusive of the entire market to identify and manage leakage effects; the quota-policy framework only pays attention to the formal market. Conservation policies that, for instance, incorporate and account for trade and import of agricultural and forestry products represent a step toward being more inclusive and could potentially minimize the likelihood and scale of leakage. Effective spatial planning and targeting specific areas to intensify agriculture, while ensuring designated areas are kept protected for conservation, is another way to minimize leakage effects (Phalan *et al.* 2016).

Managing conservation efforts should also focus on minimizing the risks of informal markets emerging. This involves a thorough understanding and projection of price and market condition changes in response to the initial conservation measure, as well as a working knowledge of the various actors in the formal and informal markets. Monitoring changes in prices of resources and understanding how they relate to emerging illegal markets is one way to better pre-empt and manage unintended feedbacks. Efforts toward better detection and punishment of illegal market operations will increase the costs of these trades and this will reduce the viability of suppliers in this market reducing the extent of the leakage (a downward shift in the supply curve in the unregulated sector in Figure 1B).

It is also important that we identify and monitor the key actors most likely to supply the informal market, and potential leakage sinks. This should allow for the more efficient detection of unintended and deleterious changes in land use. Measures to detect leakage should also focus on flows of unregulated or illegal products: trade flows may be used as a means of identifying transnational leakage and displacement of deforestation practices in response to conservation efforts (Meyfroidt & Lambin 2011). Achieving this can be challenging: illegal timber, for instance, is often laundered through legal plantations and mills (Nellemann 2012). Using satellite imagery could be another way of monitoring areas more likely to be cleared, and minimizing displacement and leakage effects. Empirical studies suggest, for instance, that buffer zones and forested areas surrounding PAs are more prone to being cleared (Pfeifer *et al.* 2012), and focusing monitoring efforts in such areas could lower the chances of forest loss. Spatially explicit econometric analyses might also be effective in identifying key areas likely to undergo land conversion. Importantly, monitoring and management should not be restricted within national boundaries, but should also include transnational leakage.

Conclusion

Most conservation measures tend to focus only on the primary and direct outcomes on nature and biodiversity, while indirect consequences are overlooked. This could lead to an overestimation of the true effects of the intervention, and the promotion of conservation actions that yield minimal to no overall conservation benefit: rather than reducing biodiversity loss, they could instead be counterproductive. Applying economic principles, we highlight the possible perverse consequences that are often not accounted for. This allows us to acknowledge these counterproductive impacts and, ideally, to seek ways to mitigate these effects through further regulations or extending the spatial extent of action, working toward optimal management strategies. Appreciating, if not understanding, the vulnerability and sensitivity of biodiversity conservation efforts to market feedbacks is a first step toward designing and managing conservation interventions more effectively.

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