Oxford Review of Economic Policy, Volume 28, Number 1, 2012, pp. 164–179

Protecting forests, biodiversity, and the climate: predicting policy impact to improve policy choice

Alexander Pfaff* and Juan Robalino**

Abstract Policies must balance forest conservation's local costs with its benefits—local to global—in terms of biodiversity, the mitigation of climate change, and other eco-services such as water quality. The trade-offs with development vary across forest locations. We argue that considering location in three ways helps to predict policy impact and improve policy choice: (i) policy impacts vary by location because baseline deforestation varies with characteristics (market distances, slopes, soils, etc.) of locations in a landscape; (ii) different mixes of political-economic pressures drive the location of different policies; and (iii) policies can trigger 'second-order' or 'spillover' effects likely to differ by location. We provide empirical evidence that suggests the importance of all three considerations, by reviewing high-quality evaluations of the impact of conservation and development on forest. Impacts of well-enforced conservation rise with private clearing pressure, supporting (i). Protection types (e.g. federal/state) differ in locations and thus in impacts, supporting (ii). Differences in development process explain different signs for spillovers, supporting (iii).

Key words: biodiversity, deforestation, conservation, climate change, impact evaluation.

JEL classification: Q24, Q28, Q38, Q57, Q54, Q56, O13, O21

I. Introduction

Forests provide important habitats for a large amount of Earth's biodiversity. While forest cover is now increasing within some developed countries, tropical forest—where areas most rich in biodiversity are found—has been destroyed at a significant rate over

* Duke University, e-mail: alex.pfaff@duke.edu

** CATIE/EfD, e-mail: robalino@catie.ac.cr

For funding that supported our own analyses which are summarized here, we gratefully acknowledge the IAI (Inter-American Institute), the Tinker Foundation, the World Bank, and the Swedish International Development Cooperation Agency (Sida) through the Environment for Development Initiative (EfD). Among many people we thank for comments are Paul Ferraro, Subhrendu Pattanayak, Eustaquio Reis, and Jeff Vincent. We are also grateful to the editors of this special issue, to two referees, and, not least, to participants in many related seminars over time, most recently: AERE/ASSA Denver, AERE Seattle, University of Wisconsin's LTC, Heartland Workshop at University of Illinois, Stanford, Oregon State University, AAG, University of Tennessee, and the Universidad de los Andes in Colombia. We thank Diego Herrera, Catalina Sandoval, and Laura Villalobos for a great deal of excellent help over many years.

doi:10.1093/oxrep/grs012

recent decades. Policies for reducing the loss of such forests are, therefore, one important part of global efforts to minimize biodiversity loss. Forest protection is also valuable for climate stability. Initiatives for 'reduced emissions from deforestation and degradation' (REDD) have motivated critical consideration of a range of policies relevant for forest loss (Pfaff *et al.*, 2011). Policies that would generate REDD would often, but not always, be a positive force in the protection of biodiversity.

Public policy to protect forest starts from a recognition that private actors' incentives to conserve do not generally reflect forests' full social values. While a large city that is downstream from a specific forest might value the forest's hydrological services, private landowners upstream may ignore such values in deciding whether to clear. Divergent incentives to protect biodiversity are even more striking. Citizens around the world may value the existence of a species but such values are likely to have marginal influence, if any, on private land-use decisions to preserve forest habitat.

A central objective of public forest policy is for private actors to consider these societal values. That is a big challenge. At the national level, policy-makers themselves must consider significant trade-offs when making decisions about whether to protect forests or to allow their conversion. Furthermore, optimal national policies may not reflect the global value of forests. As many forest services are global public goods, optimal forest conservation is inevitably an international issue.

From any public perspective, an issue for optimal policy is that private incentives to clear vary dramatically across forest locations. Thus the impact of public policies to prevent deforestation also varies across forest locations, as it depends upon the rate of private deforestation that is blocked. Policy impacts on development also vary by location. Conservation and development needs can only be sensibly balanced once spatial variation in policy impacts is understood. If it is not, then the result could be development policies with large conservation losses for small economic gains, as well as conservation policies that generate large economic losses for small conservation gains.

We argue for integrating the consideration of location in policy planning in the following three ways, in order to help to predict policy impacts on deforestation and, thereby, improve policy choices:

(i) policy impacts vary by location because baseline deforestation varies with the characteristics (market distances, slopes, soils, etc.) of the locations in a landscape;
(ii) different mixes of political-economic pressures drive the final locations for different policies; and
(iii) policies trigger 'second order' or 'spillover' effects, which are likely to differ by location, too.

We provide empirical evidence that suggests that each of these three considerations is important, by reviewing recent high-quality evaluations of the forest impacts of policies including protected areas, payments for ecosystem services, and development policies such as investments in roads. Forest impacts of well-enforced conservation rise with private clearing pressure, supporting (i). Protection types (e.g. federal versus state) differ in locations and, thus, in impacts, supporting (ii). Differences in development process can explain the different signs for spillovers, supporting (iii).

Section II lays out a conceptual framework, with three issues to consider in assessing policy impacts. Its core is a standard landscape model which illustrates variation in private deforestation pressure across the locations, or specific sites, within a landscape.

Private deforestation pressure not only directly affects conservation impacts but is also linked to both political economy and spillovers. Evidence in sections III, IV, and V supports foci (i), (ii), and (iii), respectively. Section VI concludes.

II. Conceptual framework: three issues for assessing policy impact

In this section, we briefly summarize some theoretical perspectives on private and public choices that are relevant for the impacts on deforestation of both conservation and development policies. We do so in three parts, starting with our version of a standard model of private land-use choices that vary significantly across the landscape. This variation directly implies varied policy impacts; specifically, policy impact on deforestation is a function of where the policy is in the landscape. The second part adds political economy, which influences the typical location for a given policy. The third part adds private and public responses to a policy, which generate additional impacts.

(i) Issue 1—private deforestation pressure, by location

Private land-use decision-making often implies varied deforestation pressure across a landscape. From von Thunen (1966) to the 'monocentric model' of urban land use, many landscape analysts assert that clearing pressure falls as we move outwards along a road leading from a market centre (a city, in Figure 1 where the '0' axis hits the left axis). Transport costs imply that, all else equal, moving to the right profits fall from agricultural production whose output is to be sold in the city. If all land is originally forested and only transport matters, then forests stand farther from market (in Figure 1, forests remain to the right of where the 'Expected Profits' line crosses the '0' axis).

Of course, factors other than transport also affect relative profits from agriculture versus forests: e.g. high slopes near markets may stay forested; and good soils far from market may be cleared. From an analyst's point of view, some of these factors are observed, while others are unobserved as there are limits on all datasets. The empirical analyses we review do include observed factors. However, Figure 1 does not explicitly depict them, focusing on representing unobserved factors in the form of a distribution, or varying density, of land parcels around the expected-profits line.

Conservation's short-run forest impact, by location

Conservation policies are intended to keep an existing forest standing. This may not always work (see the discussion within section VI about critical issues of monitoring and enforcement). Further, even if all forests in a policy's boundary do remain standing, that need not imply impact. The impact of even such perfect protection equals the baseline deforestation rate that is avoided; thus, if private land use would also have featured standing forest, the policy did not have impact.

More generally, a conservation policy's impact equals the private or 'baseline' deforestation rate that would have arisen without the policy minus the deforestation rate observed with the policy. Within Figure 1, if transport cost is a significant factor in the private ('baseline') rate of clearing, then even a fully forested conservation area far to the right may not have much impact on forest.

Development's short-run forest impact, by location

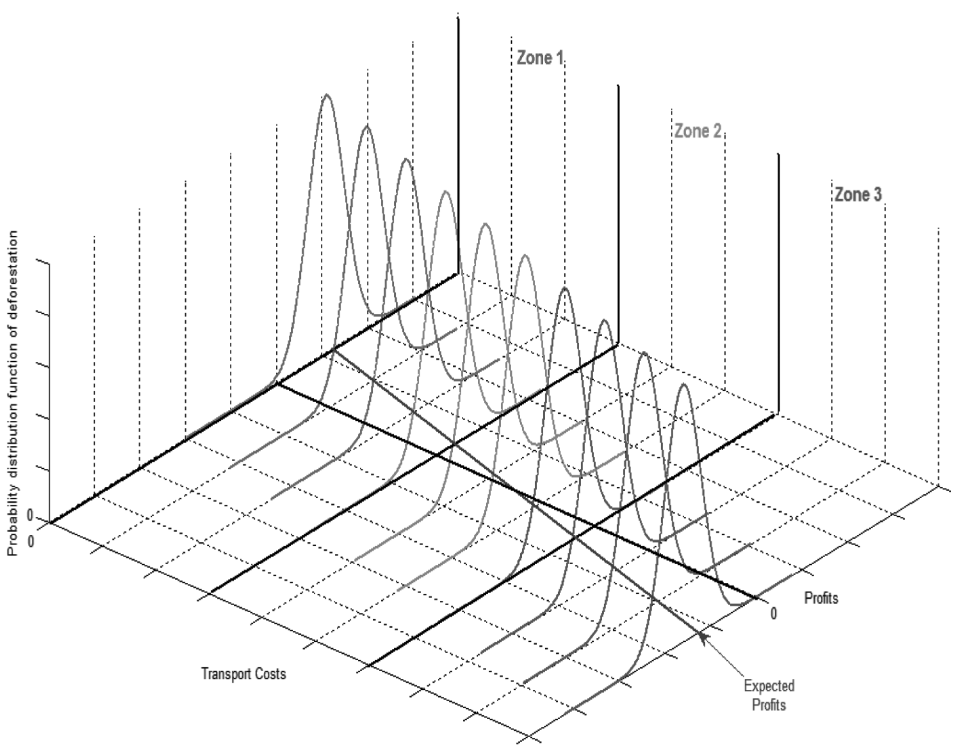
Development policies, such as subsidies or road investments, increase profits from cleared land. Our model predicts that their impacts vary non-monotonically with private deforestation pressure (unlike conservation policy's impacts, which were just seen to rise and fall with private clearing). New roads may not generate significant deforestation if private clearing pressure is already high. Greater impacts of such new development policies upon deforestation are more likely where past private pressures were intermediate and where many parcels remain at the margin of profitability (Pfaff *et al.* (2012*a*) discuss how this relies upon details of the distribution assumed in Figure 1).

Perhaps not intuitively, new roads within pristine forests, beyond the frontier, have a low impact. They raise parcel profits but still a large fraction does not reach the point of being worth clearing. However, we emphasize this is a short-run result, holding all other relevant conditions constant. Below, we consider dynamic development processes in which other conditions will change. Even if a new road has had little impact in earlier years, it may lead to additional investments. That may imply higher long-run impacts, e.g. if the new road investments follow the old roads.

(ii) Issue 2—political pressures that affect policies' locations

If a policy's forest impacts vary by location owing to private deforestation pressure, as in our model, then the distribution of conservation's locations across the landscape

Figure 1: Varied private deforestation pressure across a landscape



determines average impact. If most conservation is far from market, or more generally near little deforestation pressure, then average impact is relatively low. That holds even if impacts would be higher in other locations.

There are reasons to suspect that development trade-offs push conservation towards low pressure. Land with a high opportunity cost in production, i.e. where agricultural profits would be high, is expensive to buy for conservation. And when public lands are being allocated, without a price, those lobbying for allocation for production may lobby more intensely when the profits are high.

Importantly, though, we might expect that not all conservation decisions are made the same way. As noted, the incentives for national actors likely differ from those for global or for local actors. Thus, the mix of pressures brought to bear upon location of policy could vary by decision-maker. Incentives also may differ as a function of the nature of the conservation action; for instance, the trade-offs inherent in creating an exclusive reserve likely differ from those for multiple-use areas. Thus, the suite of political-economic influences on location could also vary by the decision type.

(iii) Issue 3—spillovers from private and public responses, by location

Total impact of a conservation policy is more than the impact within the boundary of that policy. Once such a policy is established in a given location, relevant private actors are likely to respond, affecting both forest and socioeconomic outcomes in areas proximate to newly conserved areas. For instance, people and capital might pursue tourism-based opportunities created by a new park. Alternatively, migration and investment may shift away from areas previously thought attractive if an exclusive reserve signals that a government will make no further development investments.

Public actors trying to advance development are, in turn, likely to respond to all private actions, including not only migration and investment but also, often, lobbying for more public assistance. For example, new roads and health clinics may follow upon the tourism generated by a new park. Private actors may then respond to the new roads and to additional public development policies. Such path-dependent spatial dynamics affect long-run impacts of conservation and development.

Importantly for our focus, such second-order or spillover effects likely differ across locations, too. For instance, the level of tourism that is generated by a conservation policy varies significantly. Also, spatially path-dependent development dynamics concern developing frontiers and thus are most likely to be relevant within areas characterized by low past private deforestation pressure, with rather different spillovers from what we might expect for areas of high prior development.

III. Policy impact varies with private deforestation pressure

This section, along with the two that follow, presents our review of recent high-quality evidence concerning conservation and development policies' short-run impacts on tropical deforestation. Before presenting this evidence, though, we highlight a critical feature of high-quality evidence: outcomes for policy locations are compared to outcomes in *similar locations* without any policy. That approach is suggested by our land-use model and is incorporated in the evidence we review. In this section, we present evidence that policy impacts vary with private deforestation pressure.

(i) Improved policy-impact estimates, by location

Controlling for private deforestation baselines, by location

In our model, expected deforestation without any policy varies across locations in the landscape. That variation has implications for empirically evaluating the impact of a forest-relevant policy, as impact estimates result from comparing the outcomes with policy to outcomes without policy. Once policy is established, no longer do we actually observe what would have happened without a policy. Thus, to estimate impact, we estimate what that 'baseline' outcome would have been.

A simple method would be to use the average deforestation rate on all land without any policies to estimate that unobserved baseline for lands that have a policy, e.g. all of the protected lands. However what if policy is far from private deforestation pressure, e.g. to the right in Figure 1? Then using the average unprotected land will overstate the deforestation that policy has avoided. Generally, high-quality evidence should compare parcels that are in the same 'zone' in Figure 1. Since private deforestation pressure levels are actually multifactorial and do not appear on maps, one might measure characteristics such as the distances to roads and cities, slope, and soil quality, then use those data to estimate the private deforestation rate had there been no conservation policy.

Most of the evidence we cite uses matching methods for such 'apples-to-apples' (same pressure) comparisons. That proceeds as follows. For any parcel with policy, e.g. within a protected area, one searches through the unprotected lands for the parcels with the most similar characteristics. The average deforestation outcomes for these 'most similar' unprotected lands (perhaps adding a regression to control for imperfect similarity, i.e. differences in characteristics across the groups) provides an estimate of the baseline private deforestation rate that policy avoided for that parcel. As there is no best definition of 'similar', one checks for robustness to definitions of similarity.

Allowing for varied impacts, by location

Once impacts are well estimated, it is also important to allow for varied impacts across locations. For instance, perfect protection may accomplish more to the left within Figure 1 than to the right. Since for integrated spatial policy planning we want to know each policy's impacts *by location*, we have focused our empirical review upon the analyses that explicitly distinguish sub-samples. Matching can easily be applied separately to parcels near to, and far from, deforestation pressure.

(ii) Policies' short-run forest impacts vary with private deforestation pressure

Evidence on conservation impact, by location

In a review of protection-impacts literature, Joppa and Pfaff (2010*a*) highlight a lack of explicit matching of baseline private deforestation pressure, based on measured location characteristics. Many researchers have compared clearing in protected areas to clearing on all unprotected sites or to clearing of the 'spatial buffer'. Most of the evidence that we cite below has used matching, based upon measured location characteristics, in order to control for baseline private pressure.

An early paper in terms of explicit focus on varying impacts is Pfaff *et al*. (2009), on effects of protected areas in Costa Rica upon 1986–97 deforestation. Deforestation avoided by the areas further from pressure—as delineated using various proxies—is often not statistically significant, while areas closer to private pressure (e.g. cities, roads) avoid deforestation well above average. Also, protection on lands with relatively high slopes did not avoid any deforestation, statistically speaking, while protection on lower slopes is estimated to have avoided significant deforestation.

One might not expect Costa Rica to predict all other settings. In fact, the nature of these results, as well as the model in Figure 1, characterize the global results for protection's varied impacts. Joppa and Pfaff (2010*b*) use global datasets for 2000 and for 2005 to check the very same issues within each of well over 100 countries (every country listing over 100 square kilometres of protected area). Naturally, the experience of each country differs. Yet the median and average results strongly support the results that conservation's forest impacts vary with private deforestation pressure.

Policy choice in light of such knowledge will have most impact on future deforestation frontiers. Thus, it is worth checking whether such results hold where most deforestation is going to occur. For instance, considering the entire Legal Amazon region of Brazil, Pfaff *et al*. (2012*b*) find that protection's impacts on 2000–4 and 2004–8 deforestation are higher if nearer to pressure.

All of the same logic should apply just as well to an increasingly common conservation policy, payments for ecosystem services (PES). Costa Rican evidence for PES confirms that private pressure affects forest impact. Arriagada *et al*. (2011) find that when a non-governmental organization (NGO) helped target deforestation pressure, the avoided deforestation was higher. Pfaff *et al*. (2012*c*) find that PES impact varied considerably across agency offices. For Mexico's hydroservice-payment programme, Alix-Garcia *et al*. (2012*a*) highlight that PES impact was higher where poverty rates were lower.

Evidence on development impact, by location

Our model predicted lower short-run forest impacts of new development policies both nearest to, and farthest from, private clearing pressure, with higher impacts for intermediate pressure levels. In a limited empirical work on spatially varying impacts, our review finds support for our model. Again, though, we emphasize this is a short-run result (see development dynamics in section V).

Empirical tests of such predictions are quite limited but some do exist for new road investments. Nelson and Hellerstein (1997), for central Mexico, consider the existence of prior roads, which we view as a proxy for location in a higher pressure area. They find this influences new road impact. Andersen *et al*. (2002) use another proxy for private deforestation pressure: prior forest clearing. For the Brazilian Amazon, they find that more prior forest clearing lowers a new road's impact. Delgado *et al*. (2008), for an Amazonian region, also find new road impact is lower where prior development was higher. Those results are consistent with our model's high-pressure prediction.

Yet, our model predicts a non-monotonic relationship between private pressure and the impact of new development policies, such as new road investments, i.e. the relationship changes in its sign. Pfaff *et al*. (2012*a*) test this using disaggregated data (census tracts) for the Brazilian Amazon. Studying deforestation during 1976–87, i.e. for a relatively early decade in the development of this forest frontier, they confirm the model's low–high–low prediction for impact given pressure. Thus, new roads' impacts are lower both close to and far from baseline deforestation pressure.

As development unfolds, i.e. studying deforestation for 1986–92, much of this result still holds, but we also see changes which suggest the importance of unobserved shifts in drivers over time. Defining lower or higher prior private pressure using prior deforestation, which results from the influences of all factors, Pfaff *et al*. (2012*a*) again confirm all the model's short-run predictions. However, defining lower private pressure using only the absence of any prior road investments, i.e. a definition that can miss the evolution over time of unobservable deforestation drivers, new roads' impacts for defined 'low private pressure' look more like those for intermediate pressure.

IV. Policy impact varies with political-economic pressures

The evidence that deforestation impacts of conservation policies vary significantly, by location, implies that the distribution of conservation locations will determine the average policy impact. This section continues our review of evidence, focused on our second issue for assessing impact: the differing mixes of political-economic pressures that affect policies' impacts through location.

(i) Evidence on average conservation locations and impacts

For Costa Rican protected areas, Andam *et al*. (2008) demonstrate the importance of biases in the average location of conservation policy towards locations with low private deforestation pressure. Protected lands are significantly further from roads and cities, and are also on higher slopes than is the median or average unprotected forest parcel. This fact is not reflected when the forest outcomes within protected areas are compared to the outcome for an average unprotected parcel; that comparison suggests over 40 per cent of protected forest would have been cleared without a policy. Yet if comparing with *similar* unprotected parcels, estimated impact is in the order of only 10 per cent. This result makes it clear that average location's influence on average impact can be enormous.

Considering whether this result is representative for other contexts, Joppa and Pfaff (2010*b*) find exactly the same pattern globally, for the median country and on average for over 100 countries (location bias in protected networks for these countries is documented in Joppa and Pfaff 2009). Joppa and Pfaff (2010*b*)'s matching estimate of protection's average impact is less than half the estimate generated when ignoring the bias in location. Sims (2010) finds similar bias and results for Thailand, while for the Brazilian Amazon Pfaff *et al*. (2012*b*) generate similar conclusions.

The distribution of PES conservation policies has also, on average, been biased to low pressure. For Costa Rica's early PES, Robalino and Pfaff (2012*a*) find a bias, countrywide. Other analyses find that PES participants differ from others in characteristics that affect land use (see, for example, Ortiz *et al*. 2003; Miranda *et al*., 2003; Zbinden and Lee, 2005). For Mexican PES, Munoz *et al*. (2008) suggest that early hydro-services payments were located in lower pressure areas and, as a result, had low deforestation impact on average. It is worth noting, however, that the same agency shifted this PES policy to address these biases within location by targeting a higher risk of deforestation.

(ii) Evidence on political-economic variation, by decision-maker and type

Below, we ask whether different decision-makers' incentives affect such biases in policy location and whether even for the same decision-maker, location incentives differ across decision types. These empirical examples consider only a few of the many possible examples of such differences yet they provide important demonstrations of the relevance of political economy to forest impact.

Locations by whom

Any global actor providing funding in order to incentivize actions for biodiversity will, in the end, fund a local actor. Which actor is an important choice. To the top or the bottom is a key question: should the funding all go through the federal actor(s) or, instead, go directly to more local actors? That could affect impact if the actors have different goals and would choose different locations.

For example, typical public-economic modelling distinguishes between federal and state motives. States put greater weight on local development opportunity costs, relative to benefits from forest. A reason is that some of the benefits of standing forests flow to people who are outside the state. Thus, we might predict that state conservation locations would be further from private pressure.

To test this, Pfaff *et al*. (2012*d*) examine location choices for Brazilian Amazon protected areas to compare the locations of federal conservation policies to the locations of state conservation. They find that, as is predicted by public-economics perspectives concerning important differences between these decision-makers, the average federally protected area is located closer to private deforestation pressure, and is estimated to avoid more deforestation, than the average state area.

Locations for whom

Conservation–development trade-offs appear in another form if we consider types of protection. One globally relevant distinction is between the categories of 'strict', i.e. excluding extraction, and 'multiple-use', which in various ways allows some extraction inside of the protected area. Clearly more deforestation occurs inside multiple-use areas, suggesting they have lower impacts. Yet reviewing the evidence suggests that location choice is critical and may reverse this ranking. Quite clearly, multiple-use protection goes to different locations, compared to strict protection. Specifically, on average the strict protection is found further from private deforestation pressure. That suggests multiple-use areas have higher impacts, and the data suggest this effect dominates.

For the whole Brazilian Amazon, Pfaff *et al*. (2012*d*) find that among federally protected areas (that have higher impacts—see above), multiple-use areas have greater impacts than strict areas. In the Amazonian state of Acre, multiple-use areas are closer to roads than is strict protection (see, for example, Delgado and Pfaff (2008) for a study of a specific case, Chico Mendes Extractive Reserve). Pfaff *et al*. (2012*e*) find this to be so significant that it outweighs the legal internal deforestation, i.e. whatever political economy permits multiple-use areas to occupy higher-pressure locations reverses the intuitive ranking of impact, in that the multiple-use areas avoid more deforestation. These deforestation results are consistent with Nelson and Chomitz (2011)'s global fire analysis; looking across many countries, they find that the multiple-use areas have greater average impact, again due to location. It appears that protection type generally affects location, and thus impact.

V. Policy impact varies with policy spillovers, by location

In this section, we consider the additional second-order or spillover effects of a policy that result from the private and public responses to the policy once it has been announced and established. Again our overall theme is variation in impact across locations. That applies to spillover effects, as a result of the fact that across locations different private and public processes drive responses.

(i) Private responses to conservation policy, by location

In this sub-section, we consider various forms of private responses to public conservation policy. First, we consider evidence concerning effects on the forest outcomes outside policy boundaries. Second, we review results about spillovers from conservation policy to socioeconomic outcomes.

Evidence on forest spillovers (including 'leakage'), by location

Protection may affect forest not only inside its boundaries but also on neighbouring lands. As the mechanisms through which protection can affect neighbouring deforestation locations are various, and can be simultaneous, the net spillover can vary. Public protection can promote neighbouring forest by attracting tourism that supports private forest, or reduce it if crop markets are local and the reduction of output by protection raises crop prices and profit from clearing (Robalino, 2007). For empirical consideration of forest spillovers, Robalino and Pfaff (2012*b*) examine net effects of *private* land use on neighbouring land use in Costa Rica. Spillovers mimic the initial land use: clearing increases neighbour clearing; and conservation increases neighbouring forest conservation.

Of course, the spatial spillovers to neighbouring forest from public protection choices may differ. The area in question is usually larger, and public conservation could be seen as longer lasting. For Costa Rica, an early rigorous estimate of such spillovers found no significance (Andam *et al*. 2008), yet with multiple mechanisms at play that could reflect both positive and negative effects. Robalino *et al*. (2012) consider implications of mechanisms by which impact can vary by location. They look around the roads near protected areas and distinguish the area near a park entrance, where tourism may be a much more significant force than near a boundary where nobody enters. Around the roads, they do find significant deforestation 'leakage', i.e. higher deforestation in the adjacent areas than would be expected without protection. However, net effects are insignificant even around roads when near to entrances, consistent with private forest conservation in tourism.

In principle, all of the logic above should apply to payments for environmental services as well. PES implementation also raises another potential mechanism, i.e. the effects upon expectations. Should neighbours become aware that it is possible to receive payment, owing to PES in the area, their expectations of the future streams of revenues from forest could rise, discouraging clearing. Anecdotes from Costa Rica support this possibility. And even when little impact is found within PES boundaries, analyses suggest spillovers when coarser units that blend paid and neighbouring lands are used (Sanchez *et al*. (2007) and Arriagada *et al*. (2011) find slightly higher total impact).

For Mexican PES, Alix-Garcia *et al*. (2012*a*) test directly whether and when any leakage occurs, distinguishing increased deforestation on unpaid property owned by those who receive payments from increased total deforestation in regions where there are high levels of programme participation. Evidence of both types of 'leakage' was found and the magnitude and direction of the spillovers varied across locations. Additional deforestation was higher within poor communities, consistent with credit constraints, while in wealthier communities other deforestation was lowered. Another case of spatially varying spillovers in Mexico is provided within Alix-Garcia *et al*. (2012*b*). They find that new income from Oportunidades, a conditional-transfer programme randomly applied in poor communities, increased deforestation on average and more so in more isolated communities.

Finally, such spillovers are also relevant in developed countries, as seen in debate about leakage within the US Conservation Reserve Program (Wu, 2000). Challenges in choosing empirically appropriate comparisons are highlighted by concerns about identification (Roberts and Bucholtz, 2005), although spillovers are suggested also by others using different analytical approaches (see Sohngen *et al*., 1999; Sedjo and Sohngen, 2000; Sedjo, 2005). It is argued that with global markets in forest products, alongside a lack of coordination between governments, leakage could significantly undermine national deforestation reductions (Gan and McCarl, 2007).

Evidence on socioeconomic spillovers, by location

Private responses, such as discussed above, surely could affect more than rates of deforestation. Theoretically, conservation policies could have important distributional effects through prices, for example. Wages can fall if the demand for agricultural workers decreases (Robalino, 2007). However, policy can also have positive economic effects on local tourism income (Sims, 2010). Once again, then, the signs of net spillovers are ambiguous and they can vary across locations.

In Costa Rica and Thailand, protected areas' locations were poorer than their national averages. As above, though, choosing comparisons from similar locations helps to isolate policy's impact. By controlling for confounding influences in this way, it has been shown that protection can have positive effects upon consumption and can lower poverty levels (Sims, 2010; Andam *et al*., 2010). A similar study exists for Bolivia (Canavire and Hanauer, 2012), finding that protected areas have reduced poverty significantly (a finding which is robust to different ways of measuring poverty). Gains can result from increased tourism around protected areas and are likely to vary by location. Sims (2010) finds the largest net impacts at intermediate distances from major cities in Thailand.

We would like to understand the channels through which such effects may arise (Hanauer, 2011). One approach is to focus on particular variables linked to poverty, such as employment or wages. For instance, parks have had positive effects on wages and employment in Costa Rica, implying that at least part of spillover benefit is being channelled through labour markets (Villalobos, 2009; Robalino and Villalobos, 2010). Using another statistical method, Hanauer (2011) finds similar results for Costa Rica; nearly half the poverty reduction in a previous study is due to tourism. We also want to look for variation across locations. The studies for Costa Rica find big wage effects only close to the parks' entrances, suggesting a link to tourism (Robalino and Villalobos, 2010).

(ii) Public–private development–conservation dynamics

Above, we consider varied private land, labour, and investment responses to conservation policy. Here, we consider development policies, which both drive private choices and respond to them. For example, like protected areas, new road investments can attract or repel capital and labour. In the case of development policies, though, the next public policy may follow private responses; e.g. additional roads, as well as health clinics and schools, may follow upon private migration.

In general, when considering where to put a development investment, private responses are key. For instance, it would make no sense to build a road where one is sure nobody will ever venture. Further, if private actions reveal willingness to invest in the development of particular locations, then the expected marginal development gains of putting public infrastructure there seem higher. These stories imply that the private and public decision rules interact in the development process.

Evidence on roads responses

If such dynamics were to occur, then one natural empirical focus would be the private responses. For instance, following development policies, one could track flows of people and investments. Unfortunately, for the forested developing countries the data requirements could be a challenge. Yet, if public policies follow in turn upon the private response to initial shifts in public policies, one could instead examine the reduced-form relationship in which new policies follow upon old.

Pfaff *et al.* (2012*f*) study the reduced-form implication in examining road investments over time. Breaking Brazilian Amazon roads into initial investment as well as further investment over time, they study where road investments go as a function of the prior road investments up to that point. They find paving investments tend to follow unpaved roads, i.e. initial directions are continued. They also find paving investments tend to go where there are prior neighbouring unpaved roads. Within more pristine areas, unpaved investments follow prior neighbouring-area paved roads, further suggesting dynamics. These results suggest long-run road impacts are above short-run.

Some additional results concerning neighbouring forest outcomes are consistent with such dynamics. Pfaff (1999), for instance, found at a decadal scale that neighbouring deforestation is significantly higher next to counties with roads. Greatly improving on this evidence using more precise data, Pfaff *et al*. (2007) test for impacts of road investments on deforestation in neighbouring counties that do not receive any road investment. Consistent with a model of development that spreads out from initial access roads, these new roads significantly increased the neighbouring deforestation.

More evidence on forest spillovers ('blockage'), by location

Should such public–private development dynamics be common in countries with tropical forest, then the possibility exists of an additional longer-run impact of protected areas on deforestation. Protection on a frontier could signal to private actors that the state will not be investing further in that area to stimulate development (though if a park has tourism, that can go the other direction). Such expectations could affect labour and capital movements, discouraging such private response. Private non-responses, in turn, discourage public investments (justifying expectations, *ex post*).

Thus, while above we showed that protection had little impact when far from roads, here we add that if a road would have been built, *but was not, due to protection*, it implies additional impacts. Put another way, it would illustrate another mechanism for positive forest spillovers from policy. For the Brazilian Amazon, Pfaff *et al*. (2012g) provide the only evidence we know on this topic. For deforestation in 2000–4 and in 2004–8, they find that the land next to protected areas features not higher deforestation than the estimated baseline ('leakage'), but lower ('blockage'). Such a result could arise owing to inadequate control for isolation of protected areas. Yet, if it were due to poor control, the result should appear larger the farther are areas from prior development. In fact, the locations closer to prior roads show greatest 'blockage'. This suggests further impact.

VI. Conclusion

Policies must balance forest conservation's local costs with its benefits—local through global—in terms of biodiversity, mitigation of climate change, and other eco-services such as water quality. Both challenge and opportunity are implied by variation across locations in some key trade-offs. We argued for considering location in three ways to help predict policy impacts and improve policy: (i) policies' impacts vary by location with the rates of private deforestation that policies block; (ii) different mixes of political-economic pressures drive the final location for different policies; and (iii) policies trigger second-order or spillover effects that are likely to differ by location as well.

Two additional considerations for policy impact, which are likely to vary with location within a landscape, are monitoring and enforcement. These were not featured in the studies we reviewed; however, they could have been responsible, in part, for some observed variations across space. For instance, Sims (2010) finds impacts of protection in Thailand to be slightly lower near cities, in contrast to the results for Costa Rica and consistent with weaker enforcement in Thailand. To explain enforcement-based spatial variation in impact, Albers (2010), for instance, models a game between protected-area managers and neighbouring villagers. Monitoring by local stakeholders could also be part of the explanation for the relatively high impacts of multiple-use protection. That is consistent with work by Albers and Robinson (2011) on locals having a stake in protection.

With biodiversity as a focus, the benefit from one unit of forest is another key spatial variation. Critical variations include species' estimated densities and the values people place upon species. Where species are dense and valuable affects the targeting of parks or roads; even for short run, e.g. when clearing impacts beyond the frontier may be low, benefits nonetheless could be high.

Biodiversity's need for effective habitat may also suggest another lens for measuring benefits, focused not only on total forest loss but also on remaining forests' spatial patterns or fragmentation. For example, for the Mayan forest, Conde and Pfaff (2008) find lower impact of new roads farther from current threats. Thus, in the short run, a new road in an isolated area may clear fewer trees. However, such an intrusion in an otherwise uninterrupted large area of forest could matter more for species outcomes. Conde (2008)'s work on effective jaguar habitat shows that a road within a pristine forest might not lead to much clearing but can still significantly affect species presence. Such concerns also matter for protected areas, which may have an impact on fragmentation too. Sims (2011) finds evidence that protected areas reduced fragmentation of forests in Thailand, while Albers and Robinson (2012) provide a review of work on spatial pattern in forest extraction.

These additional considerations help to emphasize the core theme of our review of the evidence, which is that conservations policies' impacts vary significantly across locations in the landscape. We provided empirical evidence demonstrating that all three of our considerations are important. Forest impacts of well-enforced conservation rise with private clearing pressure, supporting (i). Protection types (e.g. federal versus state) differ in locations and, thus, in impacts, supporting (ii). Differences in development processes explain the different signs for spillovers, supporting (iii). This support for our conceptual framework suggests that an understanding of the spatial variation in policies' forest impacts is required for conservation and development to be sensibly balanced.

References

Albers, H. J. (2010), 'Spatial Modeling of Extraction and Enforcement in Developing Country Protected Areas', *Resource and Energy Economics*, **32**, 165–79.

— Robinson, E. J. Z. (2011), 'The Trees and the Bees: Using Enforcement and Income Projects to Protect Forests and Rural Livelihoods Through Spatial Joint Production', *Agricultural and Resource Economics Review*, **40**(3), 424–38.

— — (2012), 'A Review of the Spatial Economics of Non-timber Forest Product Extraction: Implications for Policy', *Ecological Economics*, forthcoming.

Alix-Garcia, J., Shapiro, E., and Sims, K. (2012*a*), 'Forest Conservation and Slippage: Evidence from Mexico's National Payments for Ecosystem Services Program', *Land Economics*, forthcoming.

— McIntosh, C., Sims, K. R. E., and Welch, J. R. (2012*b*), 'The Ecological Footprint of Poverty Alleviation: Evidence from Mexico's Oportunidades Program', *Review of Economics and Statistics*, forthcoming.

Andam, K., Ferraro, P., Pfaff, A., Robalino, J., and Sanchez, A. (2008), 'Measuring the Effectiveness of Protected-area Networks in Reducing Deforestation', *Proceedings of the National Academy of Sciences of the United States of America*, **105**(42), 16089–94.

— — Sims, K., Healy, A., and Holland, M. (2010), 'Protected Areas Reduced Poverty in Costa Rica and Thailand', *Proceedings of the National Academy of Sciences of the United States of America*, **107**(22), 9996–10001.

Andersen, L. E., Granger, C. W.J., Reis, E. J., Weinhold, D., and Wunder, S. (2002), *The Dynamics of Deforestation and Economic Growth in the Brazilian Amazon*, Cambridge, Cambridge University Press.

Arriagada, R., Ferraro, P., Sills, E. O., Pattanayak, S. P., and Cordero, S. (2011), 'Do Payments for Environmental Services Affect Forest Cover? A Farm-level Evaluation from Costa Rica', *Land Economics*, forthcoming.

Canavire, G., and Hanauer, M. (2012), 'Estimating the Impacts of Bolivia's Protected Areas on Poverty', Discussion Paper Series, Bonn, IZA.

Conde, D. A. (2008), 'Road Impact on Deforestation and Jaguar Habitat Loss in the Mayan Forest', PhD thesis, Duke University.

— Pfaff, A. (2008), 'Sequenced Road Investments and Clearing of the Mayan Forest', presentation from Conde's PhD thesis at North Carolina State University.

Delgado, C., and Pfaff, A. (2008), 'Will Nearby Protected Areas Constrain Road Impacts On Deforestation?', presentation at NASA LBA conference Amazon In Perspective, Manaus, based upon C. Delgado's Duke MEM project at the Nicholas School of the Environment.

— Conde, D. A., Sexton, J. O., Colchero, F., Swensen, J. J., and Pfaff, A. (2008), 'Deforestation Dynamics in Response to the Evolution of the Western Amazonian Inter-Oceanic Highway', a working paper based upon C. Delgado's final MEM project, Duke University.

Gan, J., and McCarl, B. (2007), 'Measuring Transnational Leakage of Forest Conservation', *Ecological Economics*, **64**, 423–32.

Hanauer, M. (2011), 'Causal Mechanisms of Protected Area Impacts', Working Paper.

Joppa, L., and Pfaff, A. (2009), 'High & Far: Biases in the location of protected areas', *PLoS ONE*, **4**(12), doi: 10.1371/journal.pone.0008273

— — (2010*a*), 'Re-assessing the Forest Impacts of Protection: The Challenge of Non-random Protection and a Corrective Method', *Annals of the New York Academy of Sciences*, **1185**, 135–49.

— — (2010*b*), 'Global Park Impacts: How Could Protected Areas Avoid More Deforestation?', *Proceedings of the Royal Society B*, doi:10.1098/rspb.2010.1713

Miranda, M., Porras, I., and Moreno, M. (2003), 'The Social Impacts of Payments for Environmental Services in Costa Rica: A Quantitative Field Survey and Analysis of the Virilla Watershed', London, International Institute for Environment and Development.

Munoz, C., Guevara, A., Torres, J. M., and Brana, J. (2008), 'Paying for the Hydrological Services of Mexico's Forests: Analysis, Negotiations and Results', *Ecological Economics*, **65**, 725–36.

Nelson, A., and Chomitz, K. (2011), 'Effectiveness of Strict vs Multiple Use Protected Areas in Reducing Tropical Forest Fires: A Global Analysis Using Matching Methods', *PLoS ONE*, **6**(8), e22722.

Nelson, G. C., and Hellerstein, D. (1997), 'Do Roads Cause Deforestation? Using Satellite Images in Econometric Analysis of Land Use', *American Journal of Agricultural Economics*, **79**, 80.

Ortiz, E., Sage, L., and Borge, C. (2003), 'Impacto del Programa de Pago de Servicios Ambientales en Costa Rica como Medio de Reducción de la Pobreza en los Medios Rurales', Serie de Publicaciones RUTA, San José, Unidad Regional de Asistencia Técnica.

Pfaff, A. (1999), 'What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data', *Journal of Environmental Economics and Management*, **37**(1), 26–43.

— Robalino, J. A., Walker, R., Reis, E., Perz, S., Bohrer, C., Aldrich, S., Arima, E., Caldas, M., Laurance, W., and Kirby, K. (2007), 'Road Investments, Spatial Intensification and Deforestation in the Brazilian Amazon', *Journal of Regional Science*, **47**, 109–23.

— — Sánchez-Azofeifa, G. A., Andam, K., and Ferraro, P. (2009), 'Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica', *B.E. Journal of Economic Analysis and Policy*, **9**(2), available at: http://www.bepress.com/bejeap/vol9/iss2/art5

— Amacher, G. S., and Sills, E. O. (2011), 'Realistic REDD: Understanding and Improving Domestic Policy Impacts on Forest Loss', Duke University, mimeo.

— Robalino, J., Walker, R., Perz, S., Laurance, W., Bohrer, C., Robalino, J. A., Aldrich, S., Arima, E., Caldas, M., and Kirby, K. (2012*a*), '"Clean Development" From Infrastructure Location: Spatially Varied Road Impacts on Brazilian Amazon Deforestation', Duke University, mimeo.

Pfaff, A., Robalino J., Herrera, L. D. *et al*. (2012*b*), 'Might REDDer Be Better? Protected Areas' Highly Varied Forest Impacts in the Brazilian Amazon', Duke University, mimeo.
— — Sanchez-Azofeifa , G. A. (2012*c*), 'Changing the Deforestation Impacts of Ecopayments: Evolutions (2000–2005) within Costa Rica's PSA', Duke University, mimeo.
— — Herrera, L. D. *et al*. (2012*d*), 'Decentralization Given Environment-Development Tradeoffs: Federal versus State Conservation and Impacts on Amazonian Deforestation', Duke University, mimeo.
— — Lima, E., and Sandoval, C. (2012*e*), 'Estimating Avoided Deforestation by Protection Type: Can Governance plus Location Equal Forest plus Livelihoods?', Duke University, mimeo.
— — Walker, R. (2012*f*), 'Spatial Transport Dynamics on the Brazilian Amazon Frontier: roads Follow Roads, Making Long-run Impacts Higher than Short Run', Duke University, mimeo.
— — Herrera, D. (2012*g*), 'Protected Areas' Forest Spillovers in the Brazilian Amazon: what might explain "blockage"?', Duke University, mimeo.
Robalino, J. (2007), 'Land Conservation Policies and Income Distribution: Who Bears the Burden of our Environmental Efforts?', *Environment and Development Economics*, **12**(4), 521–33
— Villalobos, L. (2010), 'Evaluating the Effects of Land Conservation Policies on Labor Markets using Matching Techniques', CATIE, mimeo.
— Pfaff, A. (2012*a*), 'Ecopayments and Deforestation in Costa Rica: Countrywide Analysis of PSA's Initial Years (1997–2000)', CATIE, mimeo.
— — (2012*b*), 'Contagious Development: Neighbor Interactions in Deforestation', *Journal of Development Economics*, **97**, 427–36.
— — Sanchez-Azofeifa, G. A., Villalobos, L. (2012), 'Evaluating Spillover Effects of Land Conservation Policies in Costa Rica', CATIE, mimeo.
Roberts, M. J., and Bucholtz, S. (2005), 'Slippage in the Conservation Reserve Program or Spurious Correlation? A Comment', *American Journal of Agricultural Economics*, Agricultural and Applied Economics Association, **87**, 244–50.
Sanchez-Azofeifa, G., Pfaff, A., Robalino, J., and Boomhower, J. (2007), 'Costa Rica's Payment for Environmental Services Program: Intention, Implementation and Impact', *Conservation Biology*, **21**(5), 1165–73.
Sedjo, R. (2005), 'Global Agreements and US Forestry: Genetically Modified Trees', *Journal of Forestry*, **103**, 109–13.
— Sohngen, B. (2000), 'Forestry Sequestration of CO2 and Markets for Timber', Discussion Papers, Resources For the Future.
Sims, K. RE. (2010), 'Conservation and Development: Evidence from Thai Protected Areas', *Journal of Environmental Economics and Management*, **60**, 94–114.
— (2011), 'Do Protected Areas Reduce Forest Fragmentation? A Microlandscapes Approach', Working Paper, Amherst College, December.
Sohngen, B., Mendelsohn, R., and Sedjo, R. (1999), 'Forest Management, Conservation, and Global Timber Markets', *American Journal of Agricultural Economics*, **81**, 1–13.
Villalobos, L. (2009), *The Effects of National Parks on Local Communities' Wages and Employment in Costa Rica*, CATIE.
von Thunen, J. H. (1966), 'Der Isolierte Staat in Beziehung der Landwirtschaft und Nationalokomie', in P. Hall(ed.), *The Isolated State*, Oxford, Pergamon Press.
Wu, J. (2000), 'Slippage Effects of the Conservation Reserve Program', *American Journal of Agricultural Economics*, **82**, 979–92.
Zbinden, S., and Lee, D. R. (2005), 'Paying for Environmental Services: An Analysis of Participation in Costa Rica's PSA Program', *World Development*, **33**(2), 255–72.