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Assessing costs and livelihood implications

Working Paper No. 8

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Abstract

Despite recent reductions, Brazil remains among the top deforesting countries in the world, and is thus one of the countries where 'Reducing Emissions from Deforestation and Forest Degradation' (REDD) initiatives could potentially have the most tangible returns for climate-change mitigation. Economic incentives, such as payments for environmental services (PES) represent one option to induce forestland stewards under appropriate property right regimes to conserve more forests. Yet, for the large part of Amazon deforestation that occurs on non-designated public lands (*terra devoluta*) as well as on poorly delimited private land, PES will not be viable in the short and medium term. REDD will thus also require other tools, notably improved command-and-control disincentives that enforce existing forest laws more rigorously. While quite a number of studies have addressed the potential costs of using PES as a REDD vehicle, cost estimates of control-based REDD strategies are speculative at best. In this study, we develop a conceptual framework and a spatially explicit model to analyse regulatory enforcement in the context of the Brazilian Amazon. We validate the model's performance based on historical deforestation and enforcement mission data covering the years 2002-9. Based on an optimal enforcement scenario we analyse the costs of liability establishment and legal coercion for alternative REDD targets and evaluate local welfare impacts in terms of land users' opportunity costs or fine obligations depending on local compliance.

On the basis of the results, we discuss implications for the introduction of a planned national PES Program and assess alternative REDD strategies with regard to costs and welfare implications.

Our findings suggest that spatial patterns deforestation and inspection costs influence enforcement strategies and thus welfare effects of REDD interventions. Command-and-control is the most cost-effective REDD instrument from a regulator's point of view, but could cost land users over R$ 2.5 billion annually in opportunity costs and fines if the national REDD target of an 80% reduction in deforestation rates was achieved. PES incentives could reduce the social costs, but increase budget outlays vis-à-vis a command-and-control dominated strategy and both legal and institutional challenges have to be overcome to make

PES work at a larger scale. Decision-makers will thus have to innovatively combine on the ground implementation tools in order to make REDD both financially viable and socially compatible.

Keywords

Enforcement; PES; incentive; equity.

About the authors

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Contents

Acronyms

C&C	Command-and-control (mechanisms)
IBAMA	Brazilian Environmental Protection Agency
PES	Payments for Environmental Services
REDD	Reducing Emissions from Deforestation and Degradation

1 Introduction

Numerous initiatives to Reducing Emissions from Deforestation and Degradation (REDD[1]) are flowering worldwide, especially in countries with traditionally high deforestation rates, such as Brazil and Indonesia (Cenamo et al. 2009; Cerbu et al. 2011). Project-type approaches still dominate most countries' incipient REDD landscape, but REDD is generally expected to develop into an intergovernmental mechanism, implemented primarily through national policy programs (Angelsen et al. 2009).

Broadly speaking, national decision makers can resort to three complementary means to induce REDD at the local level, namely, incentives, disincentives and enabling measures. Incentives are understood here as measures designed to encourage forest conservation, whereas disincentives discourage deforestation and forest degradation. Complementary enabling measures, such as land-tenure regularization or environmental education, can help individuals to use forest resources more efficiently, thus preparing the ground for incentives and disincentives to work effectively.

Incentive mechanisms, such as like payments for environmental services (PES), are usually based on the principles of conditional cash transfer and often looked to as prime REDD on-the-ground implementation mechanisms (Blom et al. 2010; Bond et al, 2009). Ferraro and Kiss (2002) consider PES to be the most direct incentive-based conservation measure, as it represents a *quid pro quo* agreement between environmental service users and providers. As a REDD policy instrument, PES schemes would compensate land users with sufficient control over their land for the costs of avoiding deforestation. Being conditional on contract compliance, PES schemes would be enforced by reducing or suspending payments to unfaithful service providers.

Disincentive-based REDD mechanisms range from taxes, production quotas and standards to outright deforestation and logging bans, usually enforced through sanctions such as fines, expropriation or imprisonment. If bans are enforced through (*de facto* collected) fines, they

[1] The now widely adopted official acronym is REDD+, in including other than pure conservation measures, such as carbon stock enhancement. For expositional reasons, we stick to the term "REDD". Moreover, our case study focuses primarily on deforestation, which is the prime source of forest-based emissions in the Brazilian Amazon.

come to work much like taxes, representing an additional cost to production. Tax payers, too, need to be monitored with regard to their economic activities and legally pursued in case of non-compliance. Disincentive-based policy instruments thus generally involve enforcement costs. Environmental policy, especially in Latin America, has long been dominated by disincentive-based regulatory mechanisms, e.g. full or partial bans on deforestation, which however have proved hard to implement effectively (Seroa da Motta et al. 1996). Below we refer to these policy instruments as command-and-control (C&C) mechanisms.

For direct payments to be effective REDD policy instruments, individual or collective service providers must be endowed with the right to exclude others from modifying forest cover on land under conservation agreements (Wunder 2007). This minimal institutional precondition for PES generally requires spatially delimited land-tenure rights, as a means to effectively monitor and enforce PES contracts. However, tropical forest frontiers are often characterized by uncontrolled immigration waves causing spontaneous settlements with poorly regulated tenure (Geist and Lambin 2002). Börner et al. (2010) found that 67% of threatened forestlands in the Brazilian Amazon are subject to ill-defined or non-clarified tenure, thus limiting the short- and medium-term scope for PES as a REDD vehicle.

At the same time, many REDD candidate countries boast far-reaching environmental legislation restricting forest use and deforestation through C&C policies. In the Brazilian Amazon, most private and public tenure categories allow land users to deforest merely up to 20% of their forests[2]. Illegal deforestation is nonetheless widespread, because regulations are poorly enforced. According to the latest agricultural census[3] in 2006 the aggregated non-forest land uses on private properties exceeded the 20% limit in 749 out of 760 municipalities.

In the presence of widespread structural limitations for PES and incentive-based policies, and a record of grossly ineffective C&C implementation, REDD strategies that combine more effective "stick" enforcement with compensatory "carrots" could appear promising in Brazil, as elsewhere in the tropics. Indeed, the Brazilian REDD strategy presented at the Kyoto Protocol's COP15 (15th Conference of the Parties) in Copenhagen (MMA 2009) stated a clear commitment to achieving an 80% reduction vis-à-vis historical deforestation rates by

[2] The Brazilian Forest Code: Lei Federal nº 4.771/65.

[3] www.ibge.gov.br

combining existing C&C measures with a national PES initiative. Nepstad et al. (2009) have put the price tag of achieving this target at between R$13 and 36 billion[4].

However, little thought has so far been given as to how specifically such a policy mix of sticks and carrots could be designed in order to achieve cost-effectiveness and equity objectives. This is where we hope to make a contribution with this paper. We quantitatively assess the potential of C&C in achieving cost-effective and equitable forest conservation outcomes, and set this into the perspective of PES options. Specifically, we address the currently weak link between the "optimal enforcement" and the "forest resource management" literature (Robinson et al. 2010). We do so by developing a spatially explicit optimal enforcement model to assess the cost-effectiveness and equity impacts of a disincentive-based REDD policy scenario, and applying it using data on land use and forest law enforcement in the Brazilian Amazon. Based on the results, we derive the implications for integrating C&C sticks with PES carrots.

The paper is organized as follows. Section 2 presents our conceptual framework and model assumptions, and Section 3 documents data sources. Analysis and results are presented in sections 4 (cost-effectiveness), 5 (welfare) and 6 (integrating C&C and PES). Section 7 provides our main conclusions, while we discuss some of the limitations of our approach and their implications for our findings in Section 8.

[4] 2009 average exchange rate: US$1 = R$2

2 Conceptual framework

The forest and land user's perspective

Deforestation, including in Brazil, often happens because both most land users, and their corresponding national governments, have a clear economic rationale for harvesting precious timber resources and increasing their farmland by converting abundant forests (Andersen et al. 2002; Kaimowitz 2002). Many tropical land users may, nonetheless, have interest in forest conservation. Indigenous and traditional forest users could be much benefitted if REDD leads to improved frontier governance and enhanced C&C of deforestation by external migrants and entrepreneurs encroaching illegally on their land. However, we focus here on the majority of Amazon land users who, as a baseline, incrementally convert forests to farm- and pasturelands, even when this deforestation is formally illegal.

Upon deciding whether or not to deforest, land users facing C&C policies are likely to balance expected profits from illegal forest conversion against the odds of receiving a fine. Following the classical optimal enforcement model (Becker 1968), the land user's decision to deforest d depends on:

$$d_{1,0} =: \begin{cases} 0 & \text{for } r - p_{enf} F \leq 0 \\ 1 & \text{for } r - p_{enf} F > 0 \end{cases} \quad \text{(eq.1)}$$

Where r is the profit obtained per hectare of forest converted to agriculture, p_{enf} is the personal probability of deforestation being detected and effectively sanctioned, and F is the per hectare fine for illegal deforestation. p_{enf} and F are controlled by environmental authorities, and will be critical in determining land-use decisions, but must be carefully set to represent an effective disincentive (Robinson et al. 2010). Depending on the available means for legal coercion, extremely high fines can become ineffective deterrents if offenders chose to default on them, or do so because they are too poor to pay. Large fines may also encourage wasteful avoidance behaviour and increase the scope for bribe taking in weak institutional environments, thus introducing excessive social costs. Also, detection probability must be high enough for offenses not to be considered as *de facto* tolerated. In their review of the enforcement literature, and contrary to Becker's proposition, Robinson et al. suggest that effective enforcement normally requires relatively high probabilities and low fines. This is contrary to Becker's initial proposition, that optimal enforcement is best achieved by combining high fine levels and low enforcement probabilities, thus minimizing enforcement costs.

The environmental authority's perspective

Environmental authorities in charge of implementing REDD through enhanced forest conservation on the ground, will typically be up against a powerful agricultural lobby and many local land users' interest in continuously expanding the agricultural frontier. In allocating REDD budgets, welfare impacts on land users and sectoral development constraints will thus have to be balanced against cost-effectiveness criteria. A key conceptual question relates to whether the opportunity costs of land users should enter the regulator's cost-effectiveness equation (social planner's accounting). Here we argue that recipient countries under an international REDD agreement can face budgetary opportunity costs that represent an incentive to use REDD funds in order to free up resources from the national forest sector budget for investment in non-forest sectors. Looking at operational cost-effectiveness and land users' welfare effects of forest conservation as two separate performance indicators thus appears justified.

In the context of REDD, environmental cost-effectiveness (i.e., tons of emissions avoided per unit of currency invested) of a national REDD program could formally be defined as follows:

$$E_{REDD} = \frac{\sum_{t}^{T}\sum_{i}^{I}\left(D_{ti} - D_{ti}^{R}\right)B_{i}}{C_{REDD}} \qquad \text{(eq.2)}$$

where t is a period of time horizon T, i is a spatial unit of the intervention area I, D and D^R represent, respectively, deforestation without and with REDD intervention, and B represents the above-ground biomass carbon content lost per area unit in the form of CO_2 during forest degradation or conversion to other uses. C_{REDD} represents the operational costs of implementing national REDD policies. D, the baseline deforestation level, is established *ex-ante* by assessing historical trends. D^R, the *de facto* realized deforestation, is in principle established *ex post* through deforestation monitoring, but here we will model the impacts of different policy instrument on *D*. *B*, the area's carbon density, is usually determined through remote sensing analyses and selective field measurements of forest biomass content.

Effective C&C based REDD will incur operational costs in three categories: a) liability establishment, b) administrative processes, and c) legal coercion.

Liability establishment principally involves the cost of travelling to detected deforestation patches: more frequent inspections to more deforestation sites raises the probability of regulators to confront potential offenders, but also increases the costs of field presence.

Variable administrative costs arise from legal processes that result once illegal deforestation has been officially confirmed. Depending on the type of offense and legal action taken by presumed offenders, processes can run through various instances. Administrative costs can be particularly high if enforcement is effective in detecting offenses, but ineffective in following up with sanctions. Like in the Brazilian case, such an ineffective enforcement scenario tends to result in high non-compliance levels and consequently high administrative costs.

Coercive action is required if offenders choose to default on fines. The cost of effective coercive action depends on the available leverage mechanisms. In Brazil, a frequently employed and effective - though cost-intensive – measure of coercion is confiscation. A stylized representation of the three C&C cost elements is provided in equation 3, where the first term represents liability cost establishment: a cost that on average accrues in all locations with potential deforestation pressure. The second term includes coercion and administrative follow-up costs in locations, where deforestation actually occurs and liability can be established, as well as potential fine revenues:

$$C_{C\&C} = \sum_{i=1}^{I} p_{enf\,i}\left(TC_i^L\right)D_i + D_i^R\left(TC_i^C - p_{enf}F\right) + P_i c \qquad \text{(eq.3)}$$

With *I* being the total number of spatial units *i* in the study area, p_{enf} is the probability of *i* being visited by an enforcement team, *TC* represents roundtrip costs to visit *i* with superscripts *L* and *C* identifying liability establishment and coercion (i.e. confiscation) costs, respectively. *P* is the number of deforestation polygons in *i* and *c* the administrative cost of following up on the environmental offense, and *F* represents fine revenues.

Representing the land user – enforcement agency relationship by way of equations 1 and 3 rests on the assumption that the available enforcement budget is optimally allocated to cover operational enforcement costs, i.e. the level of effectiveness depends only on p_{enf}. In real world situations, multiple sources of enforcement ineffectiveness exist. For example, cross-compliance mechanisms, such as restricted credit access for land users that default on fines, do exist in Brazil, but hinge on effective local institutions that are seldom in place at the forest margins (Brito and Barreto 2006). Some implications of representing enforcement costs by way of equation 3 are discussed in section 8.

The disincentive of effective REDD-funded C&C enforcement must result in income, and thus, welfare losses compared to no additional action. The aggregate direct welfare effect of enforcement in intervention area I can be written as:

$$W_{REDD} = \sum_{i}^{I} -\left(D_i - D_i^R\right)\left(r_i\right) - D_i^R p_{enf} F \qquad \text{(eq.4)}$$

Where the first term represents income losses (uncompensated opportunity costs) for compliant land users and the second term depicts fine payment costs to non-compliant land users. That is, forestland users that would have illegally deforested in the absence of enhanced C&C can choose between two strategies, according to which of them is likely to minimize welfare losses.

Optimal enforcement at the forest frontier

According to equations 3 and 4, both cost-effectiveness and welfare effects depend on how well the disincentive is delivered on the ground (here represented by p_{enf}, a measure of enforcement probability).

To determine an optimal p_{enf} at a given location in space, consider that regulators typically face a budget constraint, so that punishing every single offender is seldom an option[5]. If the costs of field presence vary in space, a common feature of extensive forest frontiers, an economically optimal enforcement strategy would thus prioritize nearby over remote

[5] This reflects the reality in Brazil and many other Latin-American countries. Theoretically, the prospect of fine revenues could eventually make enforcement a profitable undertaking.

deforestation polygons. Maximizing deterrence may also imply prioritizing large over small deforestation offenses[6]. The regulator's objective function can thus be described as:

$$\max_{v_i} \; AREA = \sum_{i=1}^{I} \sum_{p=1}^{P} v_i s_{p,i} \qquad \text{(eq.6)}$$

Subject to:

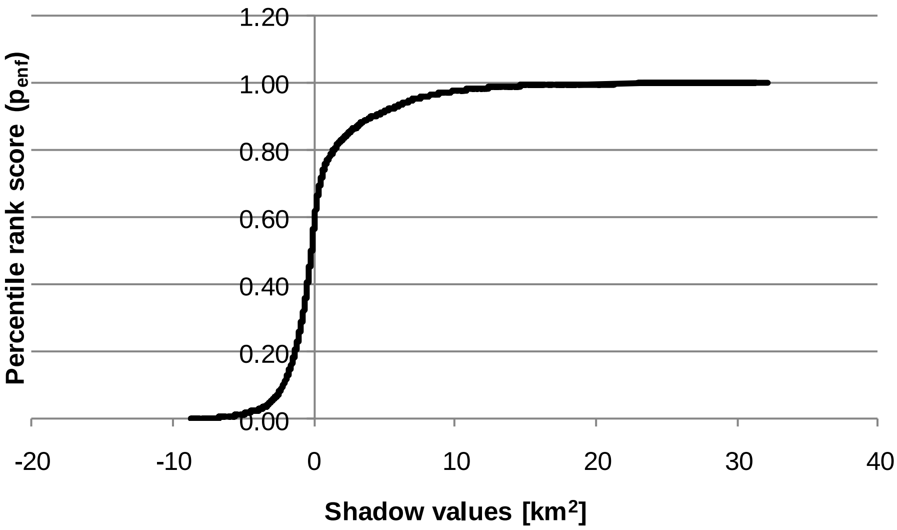
$$BUDGET \geq \sum_{i=1}^{I} TC_i v_i \, , \quad v_i \in 0,1 \qquad \text{(eq.7)}$$

Where *AREA* is the total area visit by environmental regulators, *s* is the size of deforestation polygon *p* in spatial unit *i*, and *v* a binary choice variable indicating whether a given polygon is visited by an enforcement team ($v=1$), or not ($v=0$). Maximization as a constrained linear programming problem[7] results in a shadow value for each v_i. Positive shadow values of constraints on *v* (i.e., $v \leq 1$) reflect enforcement priority levels among visited *i*, whereas negative values indicate how much additional deforestation must occur in a given spatial unit *i* for an enforcement visit to become cost-effective. If polygon size and quantity are specified as expected values for each *i*, shadow values can be interpreted as economically motivated enforcement priorities.

[6] This also reflects that the enforcement agency's objective is to maximize total area of inspected deforestation polygons in the Amazon (IBAMA personal communication, June 2009).

[7] With a high number of polygons the imprecision introduced by using a continuous constrained choice variable instead of a binary one is negligible.

Figure 1 Enforcement probabilities as a function of shadow value



Between 2003 and 2008, the Brazilian Environmental Protection Agency (IBAMA) had an average annual operational budget of approximately R$ 50 million for the Amazon region (IBAMA pers. comm. June 2009). In Figure 1, we apply this budget constraint to our spatially explicit simulation of optimal C&C enforcement in the Brazilian Amazon for a hypothetical year. For the simulation, polygon sizes (*s*) in grid cells (*i*) were set equal to average 2002-9 deforestation levels.

Applying percentile rank scores to the shadow values of the optimal solution, we obtain a vector of enforcement probabilities with p_{enf} below 0.5 for grid cells that were not included in the optimal solution of the enforcement simulation. Enforcement probabilities are somewhat stronger correlated with travel costs ($\rho_{TC,Penf} =$ -0.7) than with polygon size ($\rho_{s,Penf} = 0.63$). Validation of the optimal solution by means of a municipal-level comparison with the location of IBAMA's *de facto* enforcement missions during 2002-09 resulted in a 70% match.

Our resulting C&C strategy is responsive rather than preemptive in nature, with field interventions being planned based on observed deforestation patterns. As such, it represents quite well the strategy currently pursued by IBAMA, with enforcement teams guided by up-to-date satellite imagery and maps of past deforestation hotspots.

3 Data sources and processing

Due to widespread Amazon deforestation, Brazil has long topped the list of tropical deforestation (Hansen et al. 2008). Despite considerable reductions in recent years, deforestation rates could pick up again once the global economy recovers from the financial crisis. Today, still more than three quarters of the Brazilian Amazon are covered by forests. Modelling scenarios, however, suggest that agricultural expansion will have reduced forest cover by up to 40% in 2050 (Soares-Filho et al. 2006).

The empirical analysis in the following sections covers 4.5 million km^2 of the Legal Brazilian Amazon, drawing on data from a variety of sources (Table 1). An area of approximately 700 thousand square kilometres at the southwestern end of the Legal Brazilian Amazon was excluded due to incomplete deforestation data. The study area thus comes to represent the Amazon Biome rather than the formal Legal Amazon.

Table 1 Data sources used in this study

Data type	Source
1. Annual deforestation polygons (2002-9)	INPE-PRODES (2002-9)*
2. Municipal-level average profits from agricultural activities and timber extraction (i.e. REDD opportunity costs)	Börner et al. 2010
3. Location and size of land-reform settlements, protected areas, and indigenous territories.	IBAMA (provided in 2007)
4. Location and size of protected areas and indigenous territories	IBAMA, at: http://siscom.ibama.gov.br (accessed in 2009)
5. Costs and locations (districts) of C&C enforcement operations (2003-2008)	IBAMA records, provided in June 2009
6. Population estimates (Amazon region)	IBGE** Agricultural Census 2006

* The Brazilian Space Research Centre's (INPE) Program for the Calculation of Deforestation in the Amazon:

www.obt.inpe.br/prodes/

** The Brazilian Institute for Geography and Statistics (IBGE)

In order to estimate the travel costs of enforcement missions as a function of travel time, we used parameters derived from various interviews with IBAMA officials at their headquarters in Brasilia (September/October 2009) (Table 2).

Table 2 Field presence cost estimates

	Quantity/unit	R$[8]/unit	R$ per h
Manpower	8	3000 per month	150
Diesel	30 liters		60
Car rental	2	500 per day	125
Helicopter purchase cost	-	-	4000
Other cost (air travel, housing, etc.)			150

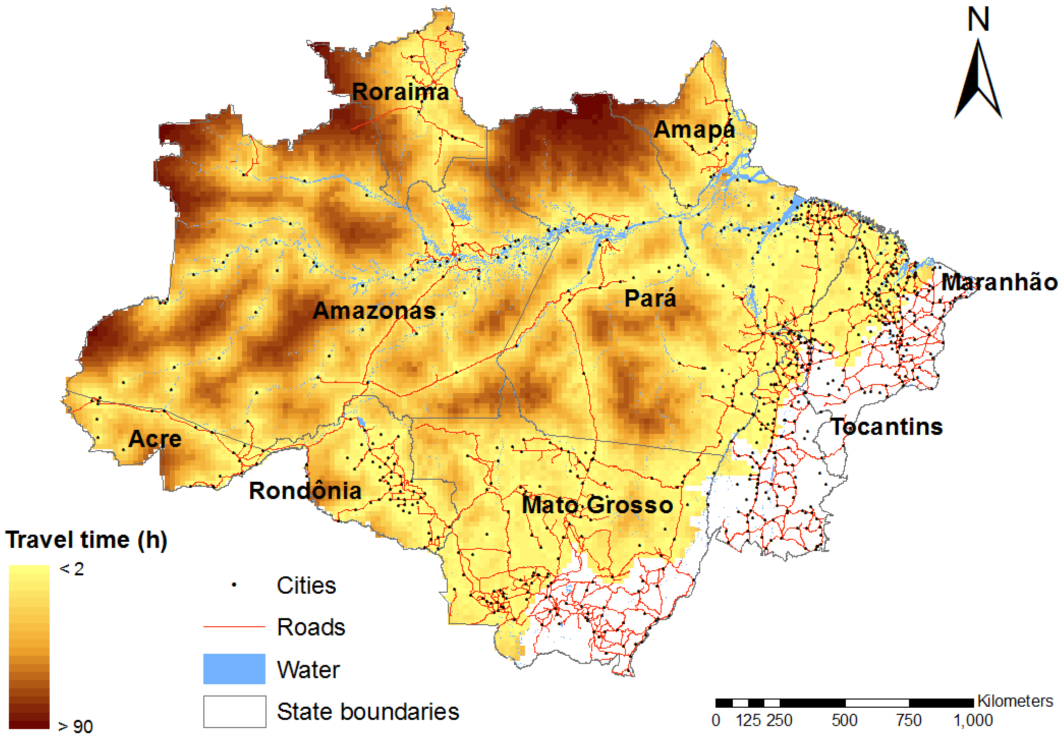
Source: Interviews with IBAMA officials (2009)

Shortest possible travel time by road and waterways was estimated from 524 Amazon municipal centres to the centre points of 11181 grid cells with a size of 400 km^2, using the Accessibility Analyst software package[9] developed by the International Centre for Tropical Agriculture (CIAT). Travel speed on waterways, unpaved and paved roads was set to 10, 25 and 60 km/h, respectively. Figure 2 shows the results, in terms of travel time from the nearest urban centre to each grid cell.

[8] R$ 1 ~ US$ 0.58 (January 2010)

[9] http://webapp.ciat.cgiar.org/access/

Figure 2 Travel time to grid cells from nearest urban center in the Brazilian Amazon (white areas excluded from the study area)



Using the parameters in Table 4, we can estimate the parameter *TC* (travel costs per polygon visit, eq. 4), with the underlying assumption that all polygons falling in to the same grid cell can be visited at the same cost. Parameter *r* (per-ha net returns to forest conversion, eq. 1) was calculated as a municipal-level average using official annual production statistics from IBGE (for methods and analysis, see Börner et al. 2010). D^s (baseline deforestation, eq. 2) and *P* (number of deforestation polygons per grid cell, eq. 4) was estimated from official deforestation data (see Table 3). Finally, parameter *c* (administrative cost per identified offense, eq. 4) was estimated on the basis of an assessment of administrative efficiency by Micol et al. (2008).

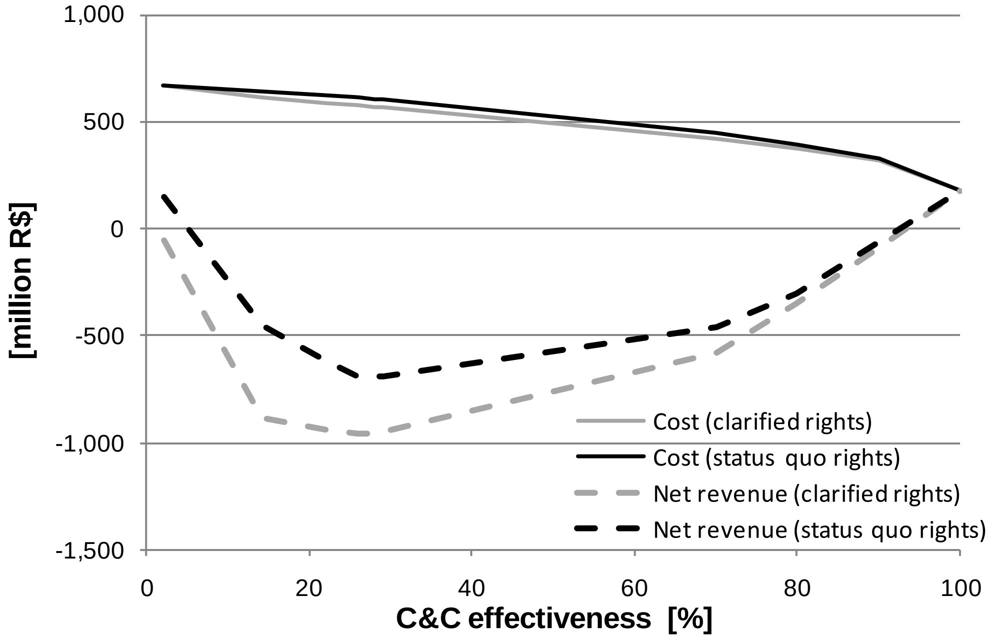
Spatial data processing involved overlays of deforestation with tenure data and zonal statistics on 100 meter resolution grids, in order to assign each deforestation polygon to a unique grid cell and tenure category. Tenure categories include land reform settlements (252,142 km^2), Indigenous Territories (970,441 km^2), Protected Areas (786,317 km^2), not officially delimited tenure (2,340,727 km^2), and others (52,579 km^2). Overlapping tenure categories (totalling 67,632 km^2 ~ 1.4% of the study area) were analysed separately.

4 Enforcement costs and REDD supply

Assessing the operational cost and effectiveness of enforcing C&C based REDD, using the model set out in section 2 (equations 2 and 3), requires probability measures for deforestation patterns in spatial units. Using spatial deforestation data, we derive expected values for annual deforestation (D^s_i) and average deforestation polygon number (P_i) in each of the 11,181 grid cells in which deforestation occurred during 2002-9. As a result, we applied the model to an average annual baseline deforestation level of 17,462 km^2, i.e. slightly lower than the 19,500 km^2 reference scenario of the Brazilian REDD strategy that is based on the period 1996-2005. Land users' opportunity costs are estimated over a 10-year planning horizon (Börner et al. 2010) and policy implementation costs and welfare effects must be interpreted as arising from the provision of a C&C disincentive over the same planning horizon.

Figure 3 depicts the operational costs and compliance effectiveness of four different C&C implementation scenarios: with and without fine revenues, and with and without fully clarified land use rights in the undelimited tenure category (see section 3). For each scenario, we look at operational costs over the full range of avoided deforestation targets, in the sense that C&C targets are enforced by increasing the level of per-hectare fines. The first scenario (clarified rights) assumes that field inspections by enforcement teams directly translates into corresponding enforcement probabilities, i.e. if an enforcement team visits a given grid cell once in ten years, then land users face a one in ten chance to be effectively fined. In the second scenario (status quo rights), we assume, more realistically, that field inspections will only be half as effective in areas with poorly defined tenure status (52.3 % of the study area) or where deforestation occurs in publicly owned strictly protected areas (7.3%), because in those cases it will typically be much more difficult to link deforestation to liable land users. During 2002-9, 68.6% of total forest loss was detected in areas with poorly delimited tenure, compared to only 1.1% in strictly protected areas.

Figure 3 Operational costs, potential net revenue and effectiveness of enforcing Brazilian forest laws, as percentage of avoided deforestation



Under the clarified rights scenario (grey lines), operational costs are slightly lower than under the status quo rights (black line) scenario, because a higher number of non-compliant land users require higher outlays for administrative and coercive action when tenure is unclear. At 80% avoided deforestation, the operational cost difference is R$ 372 versus R$ 392 million, i.e. roughly R$20 million. Hence, current efforts by the Brazilian government to increasingly clarify Amazon land tenure could also make C&C implementation more cost-effective, so that future scenarios come to lie somewhere between the status quo and clarified rights simulations.

If fines can effectively be collected (dotted-line scenarios), C&C could result in negative costs (i.e. net revenues for regulators) as soon as avoided deforestation reaches 5-10%. Well-defined tenure conditions could boost net revenues of regulatory enforcement by R$43 million at the 80% avoided deforestation target. The sharp initial decline in net enforcement costs is explained through a boost in fine revenues as per-hectare fines increase, while still affecting a large group of non-compliant land users with low opportunity cost. As compliance increases, fine revenues level off, but enforcement costs also go down, due to increasing compliance levels. In the perfect tenure scenario, a 20% reduction in deforestation rates could be achieved by setting per-hectare fines at R$1370, whereas the 80% effectiveness target requires a R$3104 fine per hectare of illegally cleared forest. In the more realistic status quo rights scenario, fine levels must increase to R$2093 and R$5509 to achieve 20% or 80% conservation effectiveness, respectively. Thus, it is notable that, under perfect conditions, improved deforestation C&C could more than pay for itself through fine collection. However, for a variety of reasons (see below), environmental authorities in Brazil have collected only 0.6% of environmental fines applied during 2005-9[10]. Hence, a realistic implementation scenario will probably come to be closer to the fully drawn than to the dotted lines.

If regulators were interested in maintaining lower fine levels (e.g. out of a recognition that high fines are less likely to be paid, Section 2), 80% effectiveness could alternatively be achieved by increasing field presence to compensate for the lower penalties. Under perfect enforcement, i.e. successfully penalizing every single offense, our model suggests that the minimum per-hectare fine level must lie at R$2450, less than half the fine level of imperfect enforcement. Perfect enforcement of the 80% effectiveness target would cost regulators R$656 million annually, but potentially still come with R$839 million in fine revenues. This represents, nonetheless, a 40% loss in cost-effectiveness, compared to imperfect enforcement.

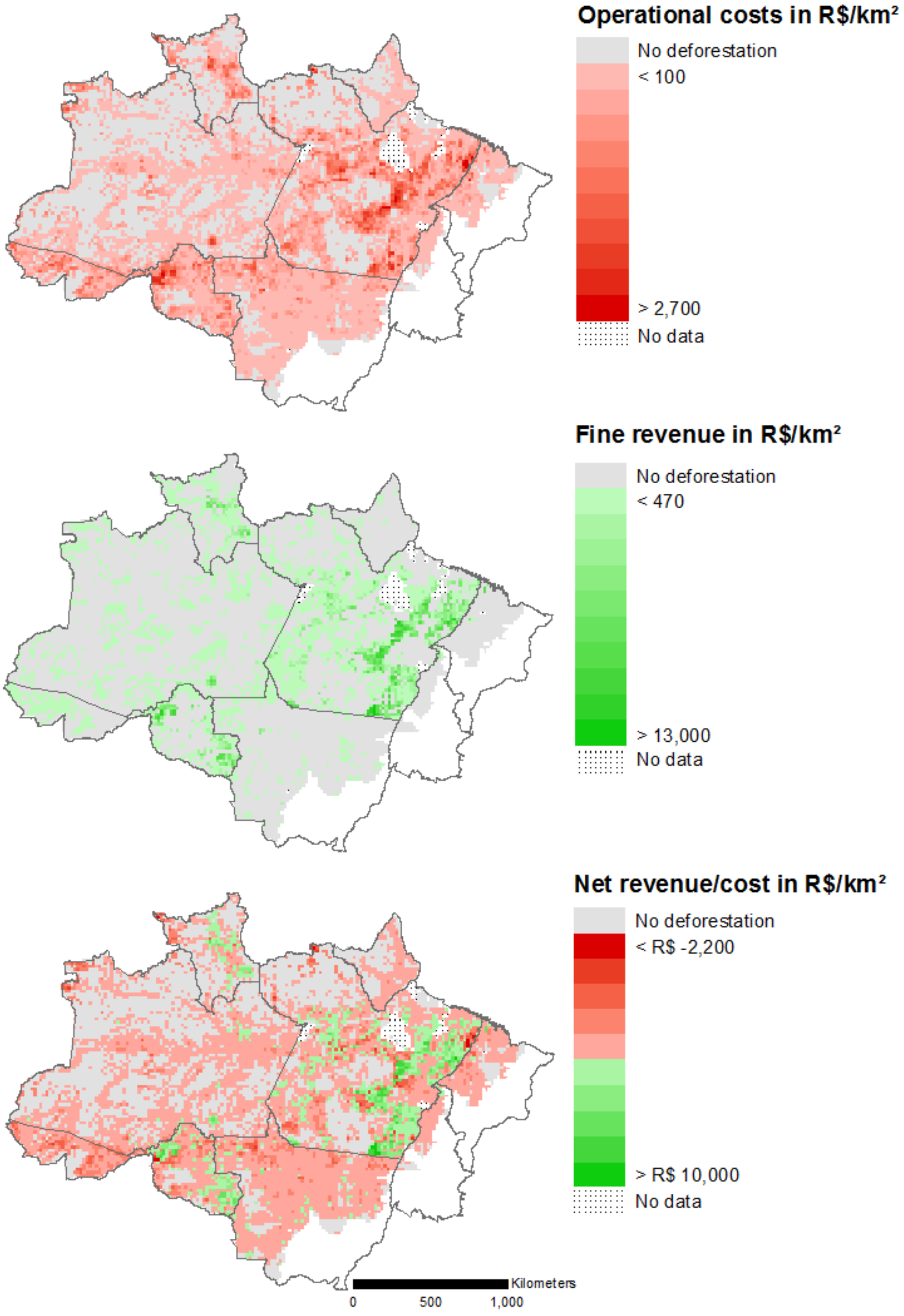
Figure 4 shows for the 80% reduced deforestation and status quo rights scenario the spatial distribution of total operational C&C costs, potential fine revenues, and the net budgetary outcome of subtracting the two. While fine revenues do compensate for operational costs at the aggregate level, operational costs are simulated to be higher than fine revenues in over 84% of the grid cells where deforestation was detected during 2002-9. Clusters of grid cells with very high operational enforcement costs and fine revenues are located primarily in the states of Pará and Rondônia and, to some extent, in Roraima. Enforcement costs are especially high in grid cells with a large number of scattered deforestation polygons, rather than few large ones.

Fine revenues accrue only where the C&C disincentive is not high enough to induce compliance. High fine revenues thus occur in grid cells that combine high opportunity costs with large deforested areas and relatively few deforestation patches. Since such locations are also prioritized by an economically optimal enforcement strategy (see Section 2), little room exists to further increase compliance here through higher field presence. Even under perfect

[10] Tribunal de Contas da União 2009 (accessed in June 2010): www.tcu.gov.br/contasdegoverno

enforcement, landowners are best served here to just pay their fines, as if it was a tax. Higher fines or equivalently deterrent cross-compliance mechanisms would then be needed to further reduce deforestation by C&C alone (see discussion in Section 6).

Figure 4 Operational enforcement costs, potential fine revenues and net budgetary gains (green areas) versus costs (red areas) of an 80% reduction in 2002-9 annual average deforestation in a scenario with *status quo* tenure conditions



5 Welfare and equity implications of enforcing REDD

In the absence of compensation mechanisms, more rigid enforcement of conservation regulations results in two types of welfare effects: non-compliant land users pay fines, whereas compliant land users suffer opportunity costs (Section 2). Table 3 separates these effects for the two alternative tenure scenarios, and for high versus low conservation target.

Table 3 Land user annual welfare losses from enforcing forest conservation targets in the Brazilian Amazon

Scenario	Total loss Million R$	Losses through fines %	Opportunity costs %
80% conservation with status quo use rights	2,850	24	76
80% conservation with clarified use rights	2,852	25	75
20 % conservation with status quo use rights	1,585	77	23
20% conservation with clarified use rights	1,829	83	17

At an elevated 80% conservation target, simulated welfare changes vis-à-vis current levels of predominantly illegal deforestation are clearly dominated by higher opportunity costs, which account for three quarters of net changes. Total welfare loss is estimated at R$2,580 annually under status quo largely unclear use right conditions -- slightly higher so under the clarified rights scenario, because fines are collected more effectively from non-compliant land users. According to official IBGE estimates this total welfare loss represents 69% of the average annual growth in value added from agriculture, forestry, and fisheries in Amazon states (or 20% of the national value added in these sectors) for the period 2002-8.

Since tenure regulation would increase the effectiveness of enforcement missions in areas that account for the major share of forest loss, fines could then be set at lower levels. With lower fines, offenses in high opportunity cost areas become profitable, whereas more effective enforcement in low opportunity cost areas with clarified tenure conditions increases compliance levels. The latter effect is slightly stronger, which is why opportunity cost related welfare losses reduce by one percentage point (about R$22 million in absolute terms) under the clarified use rights scenario.

The patterns of welfare changes in the lower 20% conservation scenario are similar, but the increase in total welfare loss when moving from the status quo to the clarified tenure scenario is much more pronounced (R$245 million as opposed to R$2 million). The reason is that tenure regulation enables fine collection from much larger number of non-compliant land users. In fact, fine payments dominate welfare losses at the low conservation target by and 83% in the perfect and (77%) in the status quo tenure simulations, respectively, due to the larger number of fine paying non-compliant land users.

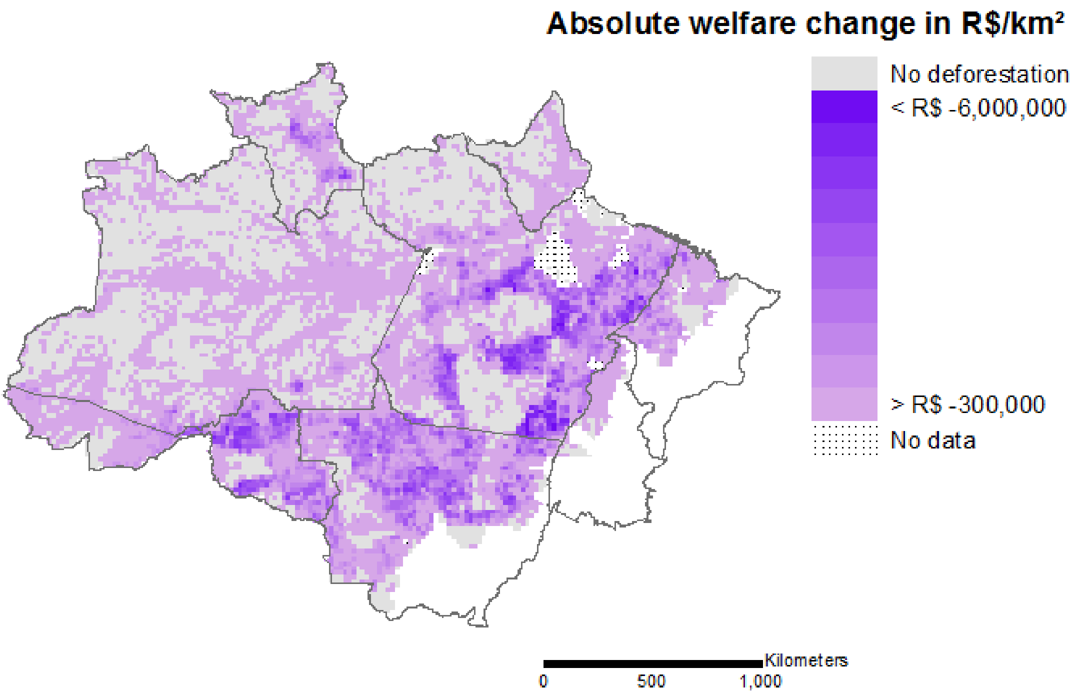
A comparison of welfare outcomes in the 20% versus 80% conservation scenario reveals that the first 20% of deforestation reduction cause a greater absolute welfare loss than moving the conservation target all the way up to 80%. This is the result of an optimal enforcement strategy that prioritizes nearby and large-scale offenses, which typically exhibit higher opportunity costs. A perfectly reasonable enforcement strategy thus comes to produce an economically inefficient outcome at the national level, because 20% conservation could have been achieved at a much smaller economic loss if low opportunity cost areas had been prioritized (for a discussion of implications for the optimal mix of REDD policy tools, see Section 6).

To assess equity outcomes, we have to look at the distribution of welfare losses. C&C induced costs reflect the distribution of deforestation pressures across tenure categories. For example, the simulated improvement in use right regulation would affect an area of approximately 2.3 million km^2 that comprises almost 55% of all deforestation patches detected between 2002-9 and caused predominantly by private (often large) landholders and occupants of public land. Under the 80% conservation target, roughly 68% of the total annual welfare loss accrues to land users that live in these areas with poorly regulated tenure conditions. Despite lower fine levels, absolute welfare loss for this tenure category increases by almost R$42 million in the regulated tenure scenario, whereas it reduces by roughly the equivalent amount in all other tenure category. Put differently, if the enforcement effectiveness loss due to unregulated tenure is compensated by higher fine levels, land users in well-established tenure categories have to face otherwise unnecessary high fine revenues.

The second largest absolute welfare loss in the 80% conservation scenario (19%) accrues to land reform settlements that comprise almost a quarter of all deforestation patches detected in the eight-year period. Tenure regulation in combination with lower fixed per-hectare fines could reduce this burden by R$20 million annually, while maintaining the 80% conservation target. Protected areas that allow sustainable use account for 6% of the total welfare loss, whereas indigenous territories and strictly protected areas would face a 3 and 1% share, respectively.

Figure 5 depicts the spatial distribution of welfare changes for the status quo tenure scenario of 80% conservation. In absolute terms, high welfare losses seem to occur above all in states with active deforestation frontiers, such as Pará, Mato Grosso and Rondônia and, to some extent, in the extreme northern Amazon at the well-connected border to Venezuela. The picture slightly changes, however, if average welfare loss per offense is considered – an indicator of individual welfare loss (not shown in Figure 5). In terms of individual welfare loss, Mato Grosso stands out as the state with the largest number of high negative value grid cells. The reason is that deforestation in Mato Grosso is generally larger scale than in most other states, hence, absolute welfare effects are distributed over a smaller number of deforestation polygons. While the state of Pará boasts 346 grid cells with absolute welfare losses above the third quartile value, the number of high value grid cells is 42% lower for average welfare loss. The inverse is true for Mato Grosso, where the number of grid cells with third quartile level average welfare loss is 37% higher than that of absolute welfare loss cells.

Figure 5 Absolute welfare change as a result of inducing an 80% deforestation target through C&C measures under *status quo* right conditions



As expected, the welfare effects of C&C induced forest conservation are thus rather unequally distributed over space, tenure categories, and individual land users. Land users that have engaged little in deforestation in the past, such as indigenous and traditional populations, would face relatively small or no welfare loss through enhanced C&C enforcement, whereas as opposed to settlers, private landholders, and occupants. Changes in the enforcement strategy do not seem to substantially alter distributional effects. For example, if each and every offense was inspected and sanctioned (perfect enforcement), the Gini coefficient of average (per offense) welfare effects would only fall slightly from 0.48 to 0.46[11].

[11] Since welfare effects are negative, larger Gini coefficients indicate higher concentration of losses in fewer grid cells.

6 Integrating REDD sticks and carrots

The analyses in sections 4 and 5 suggest that budgetary constraints probably play a minor role in preventing a policy shift towards more effective enforcement of existing environmental legislation in the Brazilian Amazon: increased enforcement could widely pay for itself, provided that fine collection becomes effective. However, an ambitious 80% reduction in deforestation will cause agribusiness and smallholders to lose out significantly, so that these groups would become key political economy barriers to REDD. Strong local political reactions against a 2008 IBAMA crackdown on illegal logging, and national-level parliamentary strength of the agribusiness lobby foreshadow that REDD is bound to encounter formidable political resistance. Using PES carrots has thus been suggested as a way to appease the losers, and thus devise a politically more viable complementary strategy for REDD on-the-ground implementation. In this section, we discuss three conditioning factors for the implementation of PES in the Brazilian Amazon.

Pre-existing environmental legislation and forest tenure

In Brazil, REDD is facing an environmental policy context where little deforestation can occur legally. As mentioned, the Brazilian Forest Code requires the majority of Amazon properties under private tenure to keep an 80% forest cover. The remaining public tenure categories typically restrict land use even further. However, since the enforcement of conservation laws has been lax over many years, illegal deforestation has been widely tolerated, and land users have come to consider tolerated deforestation an entitlement (May and Millikan, 2010). Hence, while REDD could *de facto* reduce emissions substantially, only a small share would be *de jure* additional,

A discrepancy between *de jure* and *de facto* additionality is a common feature among REDD candidate countries in Latin America (Armas et al. 2009). Hence, designing an international compensation mechanism requires carefully balancing the odds of discouraging national efforts through environmental budget substitution against the risk of losing out on substantial mitigation opportunities. For the Brazilian case, our welfare analysis above supports the notion that a politically viable national REDD approach may require budgets for compensatory measures. Given legal constraints, PES would essentially take the form of a compliance subsidy, rather than a full-blown compensation of conservation opportunity costs.

As mentioned, most threatened Amazon forests are not held under clear property rights. This would currently restrict the scope for offering conditional landowner compensations to little more than a third of threatened forests (Börner et al. 2010). Nevertheless, the federal *Terra Legal*[12] program and several state-level land survey initiatives are underway, which will elevate this scope in years to come.

Enforcement costs of PES contracts

In the literature, conservation opportunity costs are often used to roughly estimate required compensation amounts (Börner et al. 2010, Nepstad et al. 2009, Grieg-Gran 2006). Empirical assessments of PES schemes suggest that opportunity costs indeed represent the major share of total implementation costs, but transaction costs could still be significant (Wunder et al. 2008). Implications for PES-based REDD arise from our analysis of C&C with regard to contract enforcement.

Different from C&C rules, PES contracts can potentially be leveraged through the suspension of payments, but compliance still requires effective enforcement. To illustrate this, consider the following variant of equation 1 (Section 2):

$$d_{1,0} =: \begin{cases} 0 & for\ r - p_{enf}(F + PES) \le 0 \\ 1 & for\ r - p_{enf}(F + PES) > 0 \end{cases} \qquad \text{(eq.8)}$$

where *PES* depicts a conditional per-hectare compensation. Unless enforcement is perfect (p_{enf} = 1), a PES incentive that equals the land user's opportunity cost will be insufficient to avoid deforestation. Moreover, it pays off to receive PES without complying, when detection is only penalized with termination of payments. Imperfect PES enforcement thus provides an

12 The Terra Legal Program is a pragmatic attempt to regulate occupied public lands that had covered over 10 million hectares of land until the end of 2010: http://portal.mda.gov.br/terralegal/

economic incentive to pocket payments and continue business-as-usual – a potentially high loss in the overall cost-effectiveness of a national REDD scheme.[13]

The costs of enforcing PES contracts will depend on the rules regarding liability attribution and contract coercion. Like in the Mexican national PES program, contracts could potentially hold landowners liable for any loss in service provision, i.e., suspending payments even for externally caused damages such as third-party invasion or fires spreading from neighbouring plots (Muñoz-Piña et al. 2008). Nonetheless, landowners would tend to factor in these risks and only accept PES contracts with higher per-hectare payments. If fixed per-hectare payments had to be increased by 10% in the Brazilian Amazon, our spatial analysis suggests that payment costs could rise by R$687 million annually.

Alternatively, if the liability for externally induced service losses, plus the burden of proof, would lie with the environmental authority, this would involve widespread field inspections for liability establishment, similar to C&C. Based on historical Amazon deforestation patterns, the incremental cost would lie around R$300 million. Correspondingly, if payments represent only partial subsidies for the costs of complying with underlying regulations, and/or sanctions include the restitution of past payments, more field presence and administrative effort would be needed to avoid cheating, thus triggering additional costs. Hence, making PES a compliance subsidy also compromises some of its attractive simplicity.

Entitlement to PES and distributional fairness

Apart from the implications of pre-existing regulations for the additionality of PES (see discussion above), the history of land grabbing and unequal access to natural resources in the Brazilian Amazon somewhat blurs the otherwise straightforward rationale for compensation payments. Compensation typically presumes entitlement, but past deforestation has not only been largely illegal, it has also partially taken place under illegitimate land claims. The perspective of compensation payments to farmers with active deforestation records, thus understandably raises a perception of entitlement among allegedly good forest stewards, such as indigenous and traditional population groups.

13 Even elevating the risk to payback of the previously received PES amounts is generally not efficient to discourage cheating: at worst, the non-compliant land user has to return an 'interest-free loan'. The only way to deter cheating would be to threaten with penalties that exceed PES amounts, in which case PES would become more similar to C&C.

Against this backdrop it would appear politically contentious to introduce PES merely according to *de facto* additionality criteria. Just like welfare losses under improved regulatory enforcement, payments based on a historical reference scenario would then reflect the underlying distribution of assets and deforestation pressure in favour of large-scale producers (Börner et al. 2010). Any single stick or carrot approach to REDD in the Brazilian Amazon would thus ignore historically motivated perceptions of fairness.

Applying PES as a compliance subsidy, as suggested above, could reduce excessive welfare losses for compliant land users, but fail to be inclusive of good past forest stewards. Yet, designing an effective Brazilian REDD strategy will also require provisions for leakage into still relatively well-preserved indigenous lands and extractive reserves. Dwellers in these public land categories may not qualify for compensation based on their historical deforestation record. Our assessment of enforcement costs, nevertheless, suggests that actively involving local people in the protection and management of protected areas may justify conditional payments also on the grounds of conservation efficiency.

7 Conclusions

Quantitative research on the potential costs and welfare implications of REDD has so far focused primarily on incentive-based on-the-ground implementation tools, such as PES. Yet, many REDD candidate countries, most notably Brazil, will have to also rely heavily on C&C based disincentives, including because the bulk of historical deforestation was illegal but tolerated, and often a result of land grabbing. In this paper, we presented a simple conceptual framework for the spatial analysis of the costs and welfare implications of C&C based REDD, and applied it to the Brazilian Amazon.

Our findings suggest that C&C measures in isolation constitute the most cost-effective REDD instrument, from an environmental regulator's point of view. We estimate that an enforcement strategy to achieve the 80% reduction in forest loss stipulated by the Brazilian REDD strategy could cost regulators approximately R$392 million in concurrent annual operational expenses for field presence and administrative follow-up. This cost estimate represents little more than half of the maximum potential fine revenue that could result from this scenario, provided these fines can be collected. Realizing this potential fine revenue, however, requires significant improvements in administrative efficiency and more effective legal mechanisms for coercive action (Brito and Barreto 2006). Moreover, both enforcement costs and fine revenues are sensitive to the degree of tenure regularization: improvements in the delimitation of land claims could potentially boost overall cost-effectiveness by up to 14%.

The cost-effectiveness of C&C enforcement, nonetheless, differs in space. We find that potential fine revenues exceed enforcement costs only in 16% of the study region. At disaggregated spatial scales, enforcement costs tend to be higher than fines wherever deforestation patches are small and scattered, which applies, in particular, to states with comparatively low population densities like Amazonas, Acre and Amapá. Given that the current institutional set up requires states to complement federal environmental law enforcement, an optimal distribution of fine revenues probably involves disproportionally high transfers to states with low deforestation pressure.

A purely C&C based Brazilian REDD strategy to achieve an 80% reduction in forest loss would cost land users over R$2.5 billion annually in foregone opportunity costs and paid fines. This represents more than two thirds of the growth in annual agricultural value added of the Amazon states. Though the lion's share of economic loss would accrue to large-scale producers, losses to smallholders, especially in agricultural reform settlements, could be substantial. Not surprisingly, a "desire of the public not to enforce the law" has been identified in the early enforcement literature as a key obstacle to optimal enforcement (Stigler 1970, p. 534). Indeed, outright enforcement of the 80% REDD target could have severe consequences for the development of regions and sectors that currently depend heavily on a continuous expansion of the agricultural frontier. PES incentives, in turn, could significantly reduce the net economic losses for land users, but would increase budget outlays vis-à-vis a C&C dominated strategy.

Further implications arise for the design of the national PES program currently underway in Brazil. Even if an international REDD mechanism provided ample resources for direct conservation payments may remain partially ineffective unless PES contract enforcement was substantially improved vis-à-vis the status quo of C&C enforcement. The reason is that the loss of payments as a sanction of non-compliance becomes uncertain under imperfect enforcement. PES recipients facing a low enforcement probability may thus prefer to continue forest conversion and receive PES as an additional rent. Small to medium-scale offenders in remote locations would appear particularly prone to cause this form of loss in cost-effectiveness, which is specific to incentive-based conservation approaches and potentially significant in the context of REDD.

The prospect of REDD also raises equity issues in a country, where unequal access to land is only gradually being tackled by an agricultural land reform and the designation of public land as indigenous territories or extractive reserves for traditional populations. Combining existing C&C sticks with PES carrots could increase the political scope for REDD as it could straighten out otherwise widely unacceptable and unequally distributed welfare gains or losses of applying any of the two instruments individually. While forest populations without deforestation record would miss out on PES if payments where distributed according to a historical reference scenario, leakage provision represents a key argument to compensate indigenous and traditional populations for co-management efforts.

Institutional barriers to combining C&C with PES on larger scales, however, persist in the form of unclear or poorly delimited tenure conditions on the majority of threatened forest land (Börner et al. 2010). Payment schemes may therefore initially remain confined to relatively well-defined tenure categories, such as agricultural reform settlements (Ezzine-de-Blas et al. 2011). Moreover, pre-existing regulatory policies render deforestation illegal in large parts of the Amazon, where conditional compensations could possibly be applied only to subsidize compliance costs.

Hence, an optimal REDD policy mix for the Brazilian Amazon requires balancing at least two performance measures, cost-effectiveness and distributional equity. Stick policies require lower budget outlays and are thus more cost-effective than compensatory carrots, yet none of the two policy instruments alone addresses distributional equity. Only a combination of sticks and carrots, though not necessarily welfare neutral at the local level, could possibly be perceived as a politically viable REDD approach by a majority of stakeholders. Accelerating the process of land tenure delimitation and regularization as well as removing administrative obstacles to effective enforcement in order to make conditional compensations work at larger scales thus represent prime REDDiness conditions.

Alternative forms to compensate land users for higher enforcement levels, such as subsidized credit lines, certification, as well as technology development and dissemination are often proposed as means to promote sustainable development and thus reduce deforestation through enablement. These may still play a role, but can backfire by inducing further forest loss unless they are conditional on avoided deforestation (Angelsen and Kaimowitz 2001). Most PES alternative are therefore equally demanding in terms of tenure clarity and enforcement, but also face additional obstacles, such as adoption barriers (technological alternatives), demand constraints (certification), or limited leverage in case of non-compliance (credit). While sustainable development in the Amazon may require a much broader set of policy tools, complementing C&C sticks with REDD funded PES carrots could provide the necessary underlying incentive structure.

8 Discussion

A number of caveats to our enforcement model and its underlying assumptions merit further discussion. First, our assumed linear relationship between fines and enforcement probabilities may produce misleading results, especially for very high fine levels (Section 2; Robinson et al. 2010). We experiment with very high fine levels only in the sensitivity analyses (e.g., in Figure 3), so seemingly our key findings with regard to enforcement effectiveness would be robust if this assumption was relaxed.

Second, the nature of the enforcement-compliance game may change over multi-period iterations (Heyes 2000). Compliance is the time-bound result of interactions and learning between land users and environmental authorities. For example, recent inspections may have higher deterring effects than time-distant ones. We abstract from this by assuming a quasi-equilibrium state, in which enforcement-compliance learning rounds would already have taken place, so that the frequency of enforcement visits can be directly translated into enforcement probability as perceived by land users. Building up effective enforcement could take several years, and require more investments than the ones considered here, e.g. in building an effective local and national level institutional infrastructure for C&C enforcement. Hence, we here somewhat underestimate total C&C investment needs.

Over multiple interaction periods, in addition, land users could learn about the regulators revealed priorities for preferably inspecting large and non-remote deforestation polygons. In response, agents could incrementally target smaller-sized and remote areas, to lower detection probabilities. IBAMA has seen incipient evidence that this may already be happening (pers.

comm. Nov. 2010). Counter-acting this adaptive behaviour of offenders, the authorities would need to inspect more areas, which would add costs and reduce C&C effectiveness.

Fourth, our approach also assumes that compliance is a binary ‘yes or no’ decision at the 20x20 km grid-cell level (see equation 1), whereas compliance decisions are continuous in reality. Our model may consequently underestimate non-compliance or overestimate non-compliance especially where opportunity costs within grid cells are highly heterogeneous. While increasing the model’s resolution could alleviate the problem, only a full specification of land users’ net profits in each grid cell would eliminate it.

Fifth, in the absence of adequate empirical observations our analysis ignores that deforestation in the Brazilian Amazon is the outcome of a pre-existing C&C disincentive. Though allegedly small due to chronically ineffective enforcement, a pre-existing disincentive would reduce returns to forest conversion compared to our estimates of opportunity costs. Our approach may thus slightly underestimate the cost-effectiveness of additional C&C action.

Finally, it is worth restating that fines are used in our model merely as a currency for the size of the penalty required to induce compliance. However, fines are effective deterrents only when offenders can successfully be pursued to pay them. In the Brazilian Amazon, enforcement agents thus increasingly resort to in-situ confiscation of produce and equipment whenever illegality is obvious. But, confiscation and any other field-based legal follow-up results in additional enforcement costs. A key implication here is that actual fine revenues of improved enforcement in the region may be much lower than our estimate of maximum potential fine revenue. While lower fine revenues would not invalidate our findings regarding operational C&C costs, welfare impacts, and integration with PES, regulatory enforcement may ultimately represent a significant cost factor in the national budget.

References

Andersen LE, Granger CWJ, Reis EJ, Weinhold D, Wunder S. 2002. The dynamics of deforestation and economic growth in the Brazilian Amazon. Cambridge University Press, Cambridge, UK.

Angelsen A, Brockhaus M, Kanninen M, Sills E, Sunderlin WD, Wertz-Kanounnikoff S. 2009. Realising REDD+: National strategy and policy options. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Angelsen A, Kaimowitz D. 2001. Agricultural technologies and tropical deforestation. CIFOR, CABI Publishing New York, Oxon.

Armas A, Börner J, Tito MR, Cubas LD, Coral ST, Wunder S, Reymond L, Nascimento N. 2009. Pagos por Servicios Ambientales para la conservación de bosques en la amazonía peruana: Un análisis de viabilidad. SERNANP, Lima, Perú.

Becker G. 1968. Crime and punishment: an economic approach. *Journal of Political Economy* 76: 169-217.

Blom B, Sunderland T, Murdiyarso D. 2010. Getting REDD to work locally: lessons learned from integrated conservation and development projects. *Environmental Science and Policy* 13: 164-172.

Bond I, Grieg-Gran M, Wertz-Kanounnikoff S, Hazlewood P, Wunder S, Angelsen A. 2009. Incentives to sustain forest ecosystem services: a review and lessons for REDD. International Institute for Environment and Development, London, with CIFOR, Bogor, Indonesia, and World Resources Institute, Washington DC, USA.

Börner J, Wunder S, Wertz-Kanounnikoff S, Tito MR, Pereira L, Nascimento N. 2010. Direct conservation payments in the Brazilian Amazon: scope and equity implications. *Ecological Economics* 69: 1272-1282.

Brito B, Barreto P. 2006. A eficácia da aplicação da lei de crimes ambientais pelo Ibama para proteção de florestas no Pará. *Revista de Direito Ambiental* 43: 35-65.

Cenamo MC, Pavan MN, Campos MT, Barros AC, Carvalho F. 2009. Casebook of REDD projects in Latin America. TNC and IDESAM, Manaus, Brazil.

Cerbu, G. A., Swallow, B. M., and Thompson, D. Y. 2011. Locating REDD: A global survey and analysis of REDD readiness and demonstration activities. *Environmental Science & Policy* 14, 168-180.

Ezzine-de-Blas D, Börner J, Violato-Espada A-L, Nascimento N, Piketty M-G. 2011. Forest loss and management in land reform settlements: Implications for REDD governance in the Brazilian Amazon. *Environmental Science & Policy* 14: 188-200.

Ferraro PJ, Kiss A. 2002. Direct payments to conserve biodiversity. *Science* 298: 1718-1719.

Geist HJ, Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52: 143-150.

Grieg-Gran M. 2006. The cost of avoiding deforestation. Report prepared for the Stern Review of the Economics of Climate Change. International Institute for Environment and Development (IIED), London.

Hansen MC, Stehman SV, Potapov PV, Loveland TR, Townshend JRG, DeFries RS, Pittman KW, Arunarwati B, Stolle F, Steininger MK, Carroll M, DiMiceli C. 2008. Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. *Proceedings of the National Academy of Sciences* 105: 9439-9444.

Heyes A. 2000. Implementing Environmental Regulation: Enforcement and Compliance. *Journal of Regulatory Economics* 17: 107-129.

Kaimowitz D. 2002. Amazon deforestation revisited. *Latin American Research Review* 37: 221-235.

May PH and Millikan B. 2010. The context of REDD+ in Brazil: drivers, agents, and institutions. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Micol L, Guimarães S, Mônico I, Santos Rd. 2008. Transparência florestal Mato Grosso: Análise do desmatamento e da gestao florestal. Instituto Centro de Vida, p 22.

MMA. 2009. The Brazilian REDD Strategy: How the country has achieved major deforestation reduction in the Amazon. Ministerio do Meio Ambiente

Muñoz-Piña C, Guevara A, Torres JM, Braña J. 2008. Paying for the hydrological services of Mexico's forests: analysis, negotiations and results. *Ecological Economics* 65: 725-736.

Nepstad D, Soares-Filho BS, Merry F, Lima A, Moutinho P, Carter J, Bowman M, Cattaneo A, Rodrigues H, Schwartzman S, McGrath DG, Stickler CM, Lubowski R, Piris-Cabezas P, Rivero S, Alencar A, Almeida O, Stella O. 2009. The End of Deforestation in the Brazilian Amazon. *Science* 326: 1350-1351.

Robinson EJZ, Kumar AM, Albers HJ. 2010. Protecting developing countries' forests: enforcement in theory and practice. *Journal of Natural Resources Policy Research* 2: 25-38.

Seroa da Motta R, Ruitenbeek J. and Huber R. 1996. Uso de instrumentos econômicos na gestão amiental da América Latina e Caribe: lições e recomendações. IPEA, Rio de Janeiro.

Soares-Filho BS, Nepstad DC, Curran LM, Cerqueira GC, Garcia RA, Ramos CA, Voll E, McDonald A, Lefebvre P, Schlesinger P. 2006. Modelling conservation in the Amazon basin. *Nature* 440: 520-523.

Stigler GJ. 1970. The optimum enforcement of laws. *The Journal of Political Economy* 78: 526-536.

Wunder S. 2007. The efficiency of payments for environmental services in tropical conservation. *Conservation Biology* 21: 48-58.

Wunder S, Engel S, Pagiola S. 2008. Taking stock: a comparative analysis of payments for environmental services programs in developed and developing countries. *Ecological Economics* 65: 834-852.

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