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# Comparing climate and cost impacts of reference levels for reducing emissions from deforestation

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**Abstract**
The climate benefit and economic cost of an international mechanism for reducing emissions from deforestation and degradation (REDD) will depend on the design of reference levels for crediting emission reductions. We compare the impacts of six proposed reference level designs on emission reduction levels and on cost per emission reduction using a stylized partial equilibrium model (the open source impacts of REDD incentives spreadsheet; OSIRIS). The model explicitly incorporates national incentives to participate in an international REDD mechanism as well as international leakage of deforestation emissions. Our results show that a REDD mechanism can provide cost-efficient climate change mitigation benefits under a broad range of reference level designs. We find that the most effective reference level designs balance incentives to reduce historically high deforestation emissions with incentives to maintain historically low deforestation emissions. Estimates of emission reductions under REDD depend critically on the degree to which demand for tropical frontier agriculture generates leakage. This underscores the potential importance to REDD of complementary strategies to supply agricultural needs outside of the forest frontier.

**Keywords:** climate change, deforestation, land use, reduced emissions from deforestation and forest degradation (REDD), reference levels

## 1. Introduction

A climate agreement under the United Nations Framework Convention on Climate Change (UNFCCC) is expected to include a mechanism for the reduction of emissions from deforestation and forest degradation, conservation of carbon stocks, afforestation and reforestation, and sustainable management of forests ('REDD'; FCCC 2009a) to address the approximately 17% of recent greenhouse gas emissions from deforestation (IPCC 2007). Parties to the convention and policy-makers developing REDD at national and regional levels will soon need to resolve REDD methodological issues, including reference levels below which countries' emissions from deforestation could be credited as reductions. Parties and non-governmental organizations have proposed dozens of designs for setting national reference levels under a REDD

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mechanism (see Parker *et al* 2009). These reference level designs vary in the incentives they create for countries to reduce or increase deforestation, and thus would likely vary in their impact on overall reductions in emissions from deforestation ('climate-effectiveness'), reductions per dollar spent ('cost-efficiency') and distribution of REDD revenue across countries and regions ('equity'). It is of utmost importance to the UNFCCC negotiation process that REDD stakeholders be able to quantitatively compare impacts across REDD reference level designs, using standardized data and consistent assumptions.

Partial equilibrium economic models, including GTM (Sohngen *et al* 1999), DIMA/G4M (Kindermann *et al* 2006), GCOMAP (Sathaye *et al* 2006), and GLOBIOM (Gusti *et al* 2008), have estimated the impacts of climate policies on carbon fluxes from global forests and agriculture. General equilibrium models that incorporate land use at the global (e.g. Hertel *et al* 2009) or national (e.g. Cattaneo 2001) scale enable examination of a broader suite of policy levers for climate change mitigation and more complex mix of market interactions. Integrated economy climate models have been used to evaluate the potential role of reduced deforestation and other land based activities within a least-cost portfolio of mitigation options (see Rose *et al* 2007 and Fisher *et al* 2007 for a review). And more recently, researchers have examined the impacts of linking REDD credits within a global carbon market (Eliasch 2008, Angers and Sathaye 2008, Bosetti *et al* 2009).

We complement previous analyses by developing a model to explicitly analyze the incentives that countries would face under an international REDD mechanism. These incentives not only depend on carbon price, but also depend on reference levels, which influence countries' decisions whether or not to participate in REDD. Leakage, the displacement of deforestation activities, is endogenous in the model through global demand for the agriculture and timber output of frontier land. This stylized model is parameterized using global data sets on factors relevant to REDD, including forest cover and forest cover change, forest and soil carbon density, and opportunity cost of agriculture and timber[7]. This letter compares the impacts of a simulated REDD mechanism on emissions reductions from deforestation[8] below estimated business-as-usual emissions rates and cost per emissions reduction across REDD reference level designs.

## 2. REDD reference level designs and incentives

Different REDD reference level design proposals will lead to differing incentives for countries to reduce or increase deforestation. In this analysis we consider six national reference level designs[9] (table 1). In the simplest reference level design, a country's reference level is equal to its average national emissions from deforestation over a recent historical reference period, as in one variant of the original 'compensated reduction' proposal (Santilli *et al* 2005). Extending positive incentives only to countries with historically high rates of deforestation risks displacement of deforestation activities, or 'leakage', to countries with historically low deforestation rates, including 'high forest, low deforestation' (HFLD) countries as termed by da Fonseca *et al* (2007). Proposals have attempted to address leakage by extending higher than historical reference levels to countries with historically low deforestation rates (Santilli *et al* 2005, Mollicone *et al* 2007). When the sum of national reference levels is greater than the global business as usual emissions rates, there is the possibility that there could be more credits generated than emissions reduced at the global level, compromising additionality. To maintain additionality, Strassburg *et al* (2009) proposed a 'combined incentives' mechanism which maintains the sum of national references levels equal to the global reference level through a flexible combination of higher reference levels for countries with historically low deforestation rates and lower reference levels for countries with historically high deforestation rates. As an alternative, Cattaneo (2008) proposed withholding some fraction from the price paid for emissions reductions. The funds raised through the withholding would be distributed to forest countries in the form of payments for forest stocks. Historical deforestation rates are unlikely to be a perfect predictor of business as usual emissions and reference levels. Ashton *et al* (2008) proposed that 'forward looking' reference levels be predicted using the annualized fraction of the volume of terrestrial carbon stock estimated to be at risk of emission in the long run, based on biophysical, economic and legal considerations[10]. A cap-and-trade system for REDD (Eliasch 2008) would compensate countries for emissions below their reference level, but would also require capped countries to purchase credits to offset emissions above their reference level.

In this letter we simulate reductions in emissions from deforestation and global cost per net reduction of emissions across these six REDD reference level designs and a counterfactual business as usual scenario derived from 2000 to 2005 rates of forest cover change (FAO 2005). While the crediting period was 2000–2005, historically based reference levels were derived using the 1990–2000 reference period, following Griscom *et al* (2009). The formulae for calculating reference levels under each design are displayed in table 1. Most of these designs require the specification of a design-specific parameter, for instance the weight placed on global average historical rates, or the percentage of flow payment withheld. For each design, a 'best foot forward' design-specific parameter was selected for which the design achieved

[7] This model and data set are publicly available as an open source Excel spreadsheet tool, the open source impacts of REDD incentives spreadsheet (OSIRIS). OSIRIS is available for download as a companion piece to this letter at www.conservation.org/osiris. Stakeholders to REDD negotiations can use OSIRIS to recreate the results of this letter, explore the climate-effectiveness, cost-efficiency and equity implications of key economic parameters and evaluate country-by-country impacts of other published or user-generated REDD reference level designs.

[8] Our model examines the impacts of deforestation, which has been the central focus of REDD discussions to date. We have not modeled degradation, reforestation or sustainable management of forests, which are receiving increasing attention under proposals for a 'REDD plus' system.

[9] Note that we are examining here only those specific features of proposals that relate to the setting of national reference levels, rather than REDD design proposals in their entirety.

[10] Note that a number of defining elements of the Ashton *et al* (2008) proposal have not been modeled here, including the assumption of variable volumes of emissions from deforestation by country into the future under business as usual, the inclusion of forest carbon sequestration, and other non-forest terrestrial carbon emissions and sequestration.

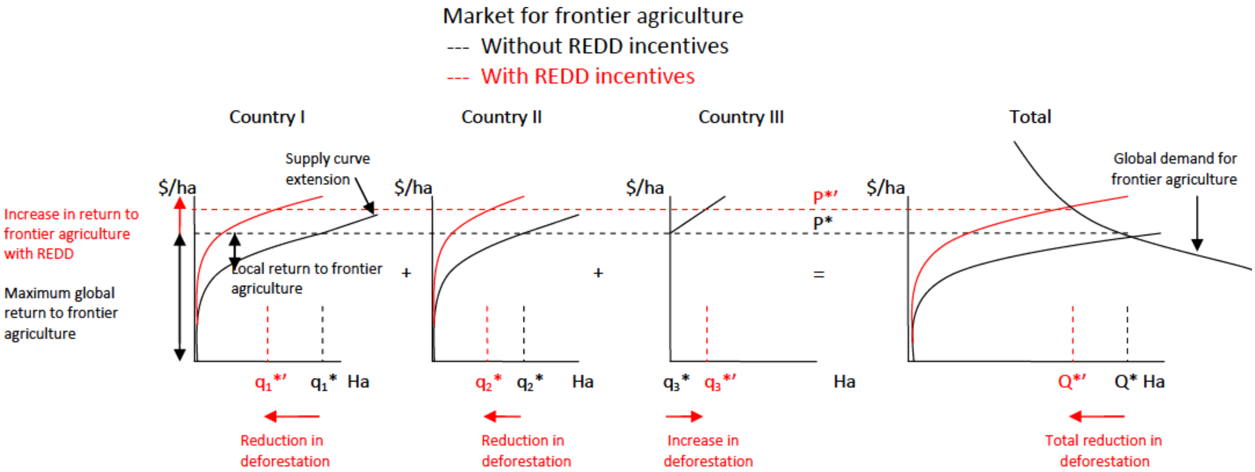


**Figure 1.** Annual market for frontier agriculture, without and with REDD incentives. In this example, REDD incentives for countries I and II shift the supply curves for frontier agriculture inward and upward in these countries. These countries reduce the quantity of frontier agriculture supplied. The slope of the global demand for frontier agriculture determines the extent to which reduced output increases the return to agricultural land output globally, causing country III, which does not receive REDD incentives, to increase frontier agricultural production. Countries' rate of deforestation with REDD are used to calculate emissions from deforestation and REDD financial flows.

**Table 1.** Design-specific reference level formulae. (Note: $B_i$ = reference emission level (baseline) for country $i$ (ton $CO_2$e); $H_i$ = historical emission level (business as usual) for country $i$ (ton $CO_2$e); $E_i$ = emission level for country $i$ (ton $CO_2$e); $\text{REDD}_i$ = REDD payment to country $i$ (\$ $yr^{-1}$); $P$ = carbon price (\$/ton $CO_2e$); $D_i$ = historical deforestation rate for country $i$ (ha $yr^{-1}$); $D$ = cut-off deforestation rate (ha $yr^{-1}$); $\text{CD}_i$ = carbon density for country $i$ (ton C $ha^{-1}$); 3.67 = atomic ratio of carbon dioxide to carbon (ton $CO_2$e/ton C); GAD = global average deforestation rate (ha $yr^{-1}$); $\alpha$ = weight placed on national historical deforestation rate; $\text{REDD\_FLOW}_i$ = flow payment to country $i$ (\$ $yr^{-1}$); $w$ = percentage of flow payment withheld to fund stock payment; STOCK = global stock payment; $\text{REDD\_STOCK}_i$ = stock payment to country $i$ (\$ $yr^{-1}$); $s_i$ = forest carbon stock in country $i$ (ton $CO_2$e); $A_i$ = forest carbon stock at risk of deforestation over the long term in country $i$ (ton $CO_2$e); $T$ = time over which forest carbon stock is at risk (yr).)

| Design option | Formulae for reference levels and REDD payments[a] |
|---|---|
| National historical reference levels (Santilli *et al* 2005) | For all countries, $B_i = H_i$<br>$\text{REDD}_i = \max\{0, (B_i - E_i)P\}$ |
| Higher than historical reference levels for countries with historically low deforestation rates (Santilli *et al* 2005, Mollicone *et al* 2007) | If $D_i > D$, then $B_i = H_i$<br>Otherwise, $B_i = D_i \times \text{CD}_i \times 3.67$<br>$\text{REDD}_i = \max\{0, (B_i - E_i)P\}$ |
| Reference level is weighted average of national and global historical rates (Strassburg *et al* 2009) | For all countries, $B_i = [\alpha D_i + (1-\alpha)\text{GAD}] \times \text{CD}_i \times 3.67$<br>$\text{REDD}_i = \max\{0, (B_i - E_i)P\}$ |
| Percentage of payment for emissions reductions withheld to fund payment for forest stock (Cattaneo 2008) | For all countries, $B_i = H_i$<br>$\text{REDD\_FLOW}_i = \max\{0, (B_i - E_i)Pw\}$<br>$\text{STOCK} = \max\{0, \sum_i (B_i - E_i)P - \sum_i \text{REDD\_FLOW}_i\}$<br>$\text{REDD\_STOCK}_i = \max\{0, (\frac{s_i}{\sum_i s_i}) \times \text{STOCK} - \max\{0, E_i - B_i\}P\}$<br>$\text{REDD}_i = \text{REDD\_FLOW}_i + \text{REDD\_STOCK}_i$ |
| Reference level is annualized fraction of forest carbon at risk of emission (Ashton *et al* 2008) | For all countries, $B_i = A_i/T$<br>$\text{REDD}_i = \max\{0, (B_i - E_i)P\}$ |
| Cap and trade for REDD | For all countries, $B_i = H_i$<br>$\text{REDD}_i = (B_i - E_i)P$ |

[a] These formulae do not include dynamic payment incentive effects. For example, in many designs emissions above reference levels in one year are deducted from creditable emissions reductions in subsequent years.

its maximum climate-effectiveness and cost-efficiency under default parameter conditions.

## 3. Analytical framework

The analytical framework for the open source impacts of REDD incentives spreadsheet (OSIRIS) is a stylized one-period global partial equilibrium market for a single composite commodity, adapted from Murray (2008). The commodity in the OSIRIS model is the output of agriculture, including a one-time timber harvest, produced on one hectare of land cleared from the tropical forest frontier ('frontier agriculture'; figure 1). Expansion of the agricultural frontier is assumed to be wholly responsible for deforestation, and frontier agriculture is assumed to be perfectly substitutable geographically. Demand for frontier agriculture is global, with underlying national demand for agriculture and timber perfectly substitutable between domestic and imported agricultural production. For each of 84 tropical or developing countries thought to be potentially eligible for REDD, we construct a national supply curve for frontier agriculture in the absence of REDD incentives based on spatially explicit estimates of economic returns to agriculture and timber. National supply curves sum horizontally to determine a global supply curve for frontier agriculture. Global supply and demand curves intersect to determine the economic return to frontier agriculture and the quantity of annual deforestation. We assume that the economic return to frontier agriculture determines the national quantities of deforestation instantaneously, as each country simultaneously chooses the quantity of frontier agriculture that maximizes its national surplus from agriculture and REDD carbon payments.

The impact of REDD incentives on deforestation is modeled by shifting national level supply curves for frontier agriculture inward and upward, as the relative return to frontier agriculture is diminished by the opportunity cost of obtaining REDD credits from standing forest. The reduced global supply curve intersects with the global demand curve to predict the global increase in the return to frontier agriculture, and the change in the quantity of frontier agriculture supplied by each country. In countries where REDD provides sufficient incentives to retain standing forest, the estimated quantity of frontier agriculture supplied decreases (figure 1, countries I and II). Conversely, in countries where weak or non-existent REDD incentives are outweighed by increased returns to agriculture, the estimated quantity of deforestation increases as agricultural production expands (figure 1, country III). A country's quantity of deforestation, reference level and estimated average national forest carbon density are used to calculate the country's reductions in emissions from deforestation and REDD revenue.

Real uncertainties exist about the future market price of carbon, transaction and management costs, and especially the elasticity of demand for frontier agriculture. These and other uncertainties are treated transparently in OSIRIS through the use of flexible parameters which can be changed by users. A sensitivity analysis for key parameters follows the results in this letter.

## 4. National supply curves without REDD incentives

National supply curves for frontier agriculture were constructed from national level deforestation data and spatially explicit estimates of agricultural returns and national average estimates of one-time timber harvest returns. In each country $i \in 1{:}84$, there exists $J_i$ hectares of forest land (Schmitt *et al* 2008). For each hectare $j \in 1{:}J_i$ of forest of land in country $i$, a highest-return agricultural activity and productivity level, $a_{ij}$, was determined based on a map of global agro-ecological zones (Fischer *et al* 2000). This highest-return economic activity and productivity level, $a_{ij}$, was converted to a maximum potential gross annual agricultural revenue, $r_{ij}$, using average commodity prices from 1995 to 2005 excluding production costs, following Naidoo and Iwamura (2007) and Strassburg *et al* (2009).

The agricultural land rental price, $p_{ij}$, was estimated to be the net present value of the profit from an annual payment stream of $r_{ij}$, plus the one-time timber extraction value; that is $p_{ij} = (\pi \sum_{n=1}^{N} r_{ij}^{(1-\delta)^n}) + t_i$. Following Stern (2006), we specified a time horizon, $N$, of 30 years, a discount rate, $\delta$, of 0.10, and a uniform profit margin, $\pi$, of 0.15 across all agricultural land. Spatial variation in transport and other costs was not captured in $\pi$. Average national net present value of one-time timber extraction, $t_i$, was a weighted average of timber extraction values by forest type (Sohngen and Tennity 2004) across the country. To form monotonically non-increasing agricultural rent curves across the entire forest estate, hectares of forest were rank-ordered in decreasing potential agricultural land rental price, such that in each country $i$, $p_{ij} \geqslant p_{ij'} \forall j < j'$.

In each country $i$, the without REDD equilibrium quantity of annual deforestation, $q_i^*$, was taken from self-reported historical national levels of deforestation from 2000 to 2005 (FAO 2005)[11]. The distribution of return to agricultural land across deforested hectares was assumed to be identical to the distribution of return to agricultural land across all forest hectares[12], so that the curve of decreasing agricultural rent across deforested hectares was a linear transformation of the curve of decreasing agricultural rent across all forest hectares; i.e. $p_{iq} = p_{ij} \forall q/q_i^* = j/J_i$.

National supply curves for frontier agriculture were constructed by building down from a global clearing price for frontier agriculture using return to agricultural land, rather than building up from the $x$-axis using the cost of agricultural production (figure 1, country I). Changes in national quantities of frontier agriculture supplied are proportional to shifts in the return to frontier agriculture, rather than absolute return. So without loss of generality, we arbitrarily set the without REDD global clearing price of frontier agriculture at equilibrium, $P^*$, to be the global maximum return to frontier agriculture from the data set, $\max\{p_{ij}\}$. Then, in every country $i$, the height of the national supply curve at quantity $q$, $s_{iq}$, was equal to $P_i^* - p_{iq}$, or global maximum return to frontier agriculture minus local return to frontier agriculture.

The final step in constructing national supply curves was to extend the national supply curves to the right, beyond the without REDD equilibrium quantity of annual deforestation, $q_i^*$ (figure 1). Relative slopes of supply curve extensions across countries, $\beta_i$, were produced by running regression lines through each country's curve of agricultural land rental prices across all forest hectares in Excel, fixed to the origin. That is, for each country $i$, $\beta_i$ solved the econometric equation $q_j = \beta_i h_{ij}$ across all $j \in 1{:}J_i$. Thus, supply curve extensions were flatter in countries with more forest and more land with high agricultural rental price, and steeper in countries with less forest and less land with high agricultural rental price. Relative

[11] This is our 'business as usual' reference scenario. We use FAO self-reported rates of forest cover change, which have well-known limitations but are available globally. Highly reliable remotely sensed estimates of deforestation are currently available only regionally. If historically based reference level were to use FAO rates of forest cover change, then over-reporting by countries could lead to artificially inflated reference levels, while under-reporting by countries could lead to insufficient incentives for reduction. For an in depth critique of using FAO Forest Resource Assessment rates for REDD reference levels, see Olander *et al* (2008). Though we have used 2000–2005 emissions rates for business as usual over the time period, OSIRIS can be adapted to use alternative projections of future business as usual deforestation.

[12] This assumption is consistent with an agricultural and timber frontier that is determined by proximity to transportation networks, where the spatial distribution of transportation network expansion is uncorrelated with the spatial distribution of agricultural and timber land rents.

slopes of supply curve extensions were scaled linearly into absolute supply curve extensions using a flexible parameter $n$, such that $\forall\, q > q_i^*$, $s_{iq} = P_i^* + n\beta_i(q - q_i^*)$. The default value of flexible parameter $n$ is 0.10, chosen such that the slope of the global supply curve extensions beyond $Q^*$ is roughly equivalent to the slope of the global supply curves leading up to $Q^*$; i.e. $Q(P^*+\varepsilon) - Q^* \cong Q^* - Q(P^*-\varepsilon)$ for small values of $\varepsilon$.[13]

## 5. Global demand curve

The global demand curve for frontier agriculture determined the extent to which a decrease in the area of frontier agricultural land in one country caused an increase in the prices of the underlying commodities and the corresponding return to frontier agriculture elsewhere. This increased return to frontier agriculture in turn resulted in increased area of frontier agricultural production in other countries. This shifting of deforestation to other locations in response to reductions in deforestation is referred to as international displacement or 'leakage'[14].

We simplified global demand for frontier agriculture using a demand curve for a single aggregate agricultural commodity, rather than treating the elasticity of demand for each agricultural commodity separately. We specified an exponential global demand curve for frontier agriculture, parameterized with an elasticity, $e$, equal to 2.0 (implying that a 2% reduction in quantity results in a 1% increase in price)[15], and calibrated about the point of total reported annual deforestation, $Q^*$ (12.1 million ha $\mathrm{yr}^{-1}$) and estimated global average agricultural return to a hectare of frontier agriculture, $S^*$ (\$506 $\mathrm{ha}^{-1}$); i.e. the demand curve is comprised of all points $(p, q)$ such that $q = Q^*(\frac{S^*}{(p-P^*)+S^*})^e$.

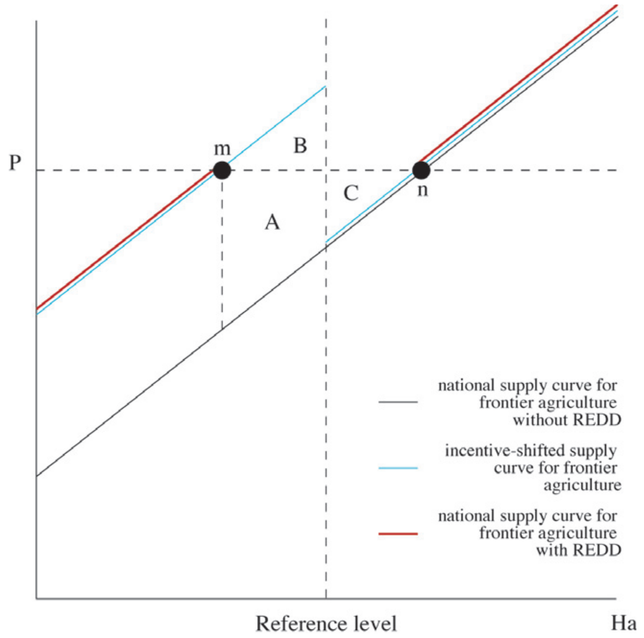


**Figure 2.** National supply curves without and with REDD. National supply curve for frontier agriculture without REDD (black) is shifted upward to the left of the reference level by the magnitude of the per-hectare carbon payment to form the REDD incentive-shifted supply curve for frontier agriculture with REDD (blue). The national supply curve for frontier agriculture with REDD (red) is composed of the points along the incentive-shifted supply curve for which at a given price REDD surplus exceeds agricultural surplus. In the figure, when $A + B = x(A + C)$, the surplus from participating in REDD (A + B) is just enough to offset foregone agricultural surplus (A + C) at the value of $x$, the parameter describing social preference for agricultural surplus to REDD surplus. REDD surplus is potentially large enough to distribute such that all land users are at least as well off with REDD as without REDD. Thus the government is ambivalent about opting in to REDD (point m) and opting out of REDD (point n). When agricultural return is lower than P, national REDD surplus would be more than enough to compensate all land users for lost agricultural surplus, so the government chooses to opt in to REDD. When agricultural return is higher than P, national REDD surplus is insufficient to compensate all land users for lost agricultural surplus, so the government chooses to opt out of REDD. The default value of the social preference for agriculture parameter $x$ in OSIRIS is 1.0.

## 6. National supply curves with REDD incentives

REDD positive incentives increased the monetary value of standing forest relative to the return to agriculture, causing national supply curves for frontier agriculture to shift inward and upward and according to design-specific formulae (table 1). National supply curves with REDD incentives were determined by two steps—first by calculating the change in the per-hectare return to frontier agriculture, and then by choosing the overall national quantity of frontier agriculture supplied that maximizes aggregate national welfare at a given price (figure 2).

First, we calculated the magnitude of the per-hectare marginal incentive. For most designs the per-hectare incentive

[13] This assumption is consistent with a continuous distribution of marginal agricultural and timber rental value across the intrinsic margin (barely profitable land) and extrinsic margin (barely unprofitable land), rather than a discontinuity in the distribution of marginal agricultural and timber rental value at the margin.

[14] For a complete discussion of leakage see Murray (2008) or Wunder (2008).

[15] We are not aware of any direct empirical estimates of the price elasticity of demand for frontier agriculture. Elasticity for frontier agriculture can be decomposed into the product of the elasticity for agriculture and the market share of the frontier sector, as discussed in Angelsen (2007). The empirical evidence of which the authors are aware suggests that agricultural demand is inelastic—the elasticity of demand for food calories cannot be distinguished from perfectly inelastic (Roberts and Schlenker 2009), while the elasticity of demand for agricultural crops in the developing world is between 0.3 and 0.8 (Seale *et al* 2003), meaning that a 0.3–0.8% decrease in quantity generates a 1% increase in price—suggesting a low elasticity of demand for frontier agriculture. On the other hand, frontier agriculture is a small share of the overall agricultural market, with substantial potential for intensification, extensification to degraded lands, increased production efficiency, and commodity substitution. Furthermore there are short term rigidities in trade (Keeney and Hertel 2008), variation in transport costs and components of REDD projects and programs designed to address timber and agricultural leakage, all of which suggest a higher elasticity of demand for frontier agriculture. Empirical estimation of the price elasticity of demand for frontier agriculture is an important area for future research. We calculate leakage as $1 - r_a/r_i$, where $r_a$ is the reduction in deforestation with parameterized elasticity of demand ($e = 2$), and $r_i$ is the reduction in deforestation with hypothetical infinite elasticity of demand ($e = \infty$). For the REDD design in which reference levels are based on national historic emissions rates, which has no feature in place to control international leakage, the demand curve was parameterized such that leakage of 34% was generated (of which 14% was intra-national leakage within reducing countries, which was accounted for in crediting, and 20% was international leakage outside of reducing countries, which was not accounted for in crediting). This parameterization of leakage is comparable to leakage estimates of 34–50% within the developing world generated by a model of the international timber market (Gan and McCarl 2007), though this letter examines a different market and employs different methods.

to reduce deforestation emissions on 1 ha in country $i$, $R_i$, was calculated using the formula $R_i = \mathrm{CD}_i \times 3.67 \times \mathrm{PC} \times \mathrm{PERM} - \mathrm{CM}_i$. Here, the carbon density (tons C $\mathrm{ha}^{-1}$) in country $i$, $\mathrm{CD}_i$ is the average carbon density (Ruesch and Gibbs 2008) over a country's forest land (Schmitt *et al* 2008) plus 0.10 times the average soil carbon density in the top 100 cm of forest soil (GSDTG 2000) across a country's forest land (Schmitt *et al* 2008)[16]. 3.67 is the atomic ratio between carbon dioxide and carbon (ton $CO_2$e/ton C). The market price of a ton of carbon dioxide emission, PC, was set to 2008 US\$5/ton $CO_2$e. A scaling factor applied to a payment for reduced emissions to address non-permanence, PERM, was set 1.00, assuming no permanence reduction[17]. The per-hectare net present cost of management to ensure deforestation is avoided in country $i$, $\mathrm{CM}_i$, was set to \$40 $\mathrm{ha}^{-1}$ for all countries, corresponding to \$3.50 $\mathrm{ha}^{-1}\ \mathrm{yr}^{-1}$, the average cost per hectare of protected area management across developing countries (James *et al* 2001). All costs were deflated to 2000 US\$ using the consumer price index (http://data.bls.gov/cgi-bin/cpicalc.pl) for comparison with opportunity costs. All parameter values are flexible in OSIRIS; a sensitivity analysis follows the results.

Importantly, the national supply curve without REDD (thin black line in figure 2) was shifted upward by the incentive to determine the incentive-shifted supply curve (thin red line in figure 2) only to the left of a crediting reference level, $q_{\mathrm{ref}}$. That is, if $q \leqslant q_{\mathrm{ref}}$, then $S_{iq}^{\mathrm{withoutREDD}} = S_{iq}^{\mathrm{withREDD}} + R_i$; otherwise $S_{iq}^{\mathrm{withoutREDD}} = S_{iq}^{\mathrm{withREDD}}$. At any price, each country chose between the quantity of deforestation on the original supply curve, without REDD, and the quantity of deforestation on the incentive-shifted supply curve. At either quantity, the marginal benefit of supplying frontier agricultural land was equal to the marginal cost. The country chose the quantity of production which provided greatest aggregate national welfare[18]. The set of chosen quantities at every price determined the with REDD supply curve (heavy red line in figure 2). We assumed that all reductions in deforestation had a buyer at a given price[19].

## 7. Caveats

A number of limitations to the analysis should be noted. First and most importantly, OSIRIS is a stylized model designed to simulate the incentives faced by countries under a global REDD mechanism, for the purpose of comparing relative impacts across reference level design options. Absolute estimates of impacts[20] should be considered uncertain, for several reasons: the model relies on global data sources of varying quality, aggregates certain spatially explicit data to the national scale[21], has no prior implementation of a global REDD mechanism against which to test model performance, and is sensitive to parameters such as elasticity of demand for frontier agriculture whose values are uncertain.

Second, following Stern (2006) and others, we based the extent to which countries reduce deforestation on a comparison of benefits from agriculture and benefits from REDD, both at the margin and in aggregate. While this opportunity cost framework offers a starting point for comparing impacts across reference level designs and countries, it oversimplifies reality in two respects. First, countries' decisions to participate in REDD are likely to be more complex than a simple comparison of earnings from agriculture and earnings from REDD. Poverty alleviation, traditional values, political economy, ecological services and biodiversity are likely to factor into countries' land use decisions. Second, some promising methods for reducing emissions from deforestation do not involve directly outcompeting opportunity cost at a site—notably, removal of perverse agricultural subsidies, moratoria on road construction, increased capacity to enforce forestry laws, and improved fire management.

Third, our single-period analysis compared short term but not long term variation in incentives across REDD reference level designs. By using average deforestation rates from 2000 to 2005 as our business-as-usual scenario, we compared impacts if REDD had been in place during this single period in the short term, rather than projecting over many periods into

[16] As with many aspects of the final REDD mechanism, it is not yet clear whether emissions from soil will be creditable. The draft text for a decision on methodological guidance for activities relating to reducing emissions from deforestation and degradation in developing countries (FCCC 2009b) includes text on using the most recently adopted IPCC guidance and guidelines as a basis for estimating anthropogenic forest-related greenhouse gas emissions. The IPCC Good Practice Guidelines (2006) recommend accounting for five carbon pools including soil, and state that conversion of native grassland and forest land to cropland can cause 20–40% of soil carbon to be lost (p 2.28), that roughly half of soil organic carbon is in the upper 30 cm layer (p 4.23), and that the default depth for measurement of soil carbon is 30 cm for Tier 1 and 2 methods though greater depth can be selected and used if data is available (p 2.29). In light of this, our analysis assumes that soil carbon emitted and soil carbon credited would both be 10% of the top 100 cm of soil.

[17] For discussion of insurance, buffers and other permanence reductions, see Dutschke and Angelsen (2008).

[18] We specified a parameter, $x$, such that if REDD surplus from opting in to REDD (A + B in figure 2) was greater than $x$ times the foregone agricultural surplus from opting out of REDD (A + C in figure 2), then a country chose the quantity on the incentive-shifted supply curve (point m in figure 2). Otherwise the country chose the quantity on the without REDD supply curve (point n in figure 2). The default value of $x$ was 1, implying that a country chose to participate in REDD if the REDD surplus outweighed the foregone agricultural surplus. There are two reasons why we may wish to relax this assumption. First, countries may determine that payoff to winners might need to exceed lost surplus to losers by a greater factor than one to justify the opt in decision. Second, countries may have less than perfect targeting of REDD investment to land threatened by deforestation. The sensitivity analysis explores values of $x > 1$.

[19] When all reductions are purchased at a given price, the REDD incentive price, based on the market price of carbon, is the input to the model, and quantity of reductions is an output. However, OSIRIS has the capability to simulate a fund for REDD as well, by specifying a quantity of reductions or size of a fund as an input, with the REDD incentive price as an output.

[20] Compare our estimate of average emissions from deforestation from 2000–2005 across 84 countries considered eligible for REDD, 7.4 billion ton $CO_2$e $\mathrm{yr}^{-1}$, to estimates of 7.6 billion ton $CO_2$e from global land use change and forestry in 2000 (CAIT 2009) 8.5 billion ton $CO_2$e of global emissions from forestry in 2004 (IPCC 2007, figure SPM.3), and 3.2–4.7 billion ton of average annual emissions from deforestation from Africa, Latin America and Southeast Asia projected between 2005 and 2030 (Kindermann *et al* 2008).

[21] One particular caveat relates to the aggregation of carbon density data to the national level. A positive spatial correlation between carbon density and potential agricultural value, if present, would bring agriculture and standing forest into more direct competition over a greater portion of the landscape, but would not clearly bias land use choice in the direction of either agriculture or standing forest. A preliminary investigation of the relationship between carbon density and potential agricultural value at the country level suggests a possible inverted 'U' relationship between the two variables across countries.

the long term future. Similarly, following the standard partial equilibrium model, we assume that countries' adoption of REDD policies, and price feedback to the price of agricultural land take place in a single period, in a perfect-information Nash equilibrium. In reality, some agricultural commodities are not quickly substitutable across countries—it may take several years for information on prices and investment in agricultural production to stabilize to a with REDD equilibrium. Further, heterogeneous capacity between countries means that some countries will require external support or will risk falling behind on adoption of REDD.

Fourth, the model excludes a number of economic sectors important to climate change, land use and markets. The model considers the effects of carbon dioxide emissions but not other greenhouse gas emissions from deforestation, deforestation but not degradation, afforestation, reforestation or sustainable management of forests, and price feedbacks in the agricultural land market but not in the carbon market[22] or in specific agricultural subsectors.

Finally, we recognize that the design of reference emission levels is just one important component of an effective, efficient and equitable REDD mechanism. A REDD mechanism must also treat issues of permanence and liability (Dutschke and Angelsen 2008), monitoring (Olander *et al* 2006), social and political viability, and the rights of indigenous peoples and communities (Seymour 2008).

## 8. Results

All six scenarios in which a REDD mechanism was employed resulted in a significant decrease in emissions from deforestation relative to the business as usual scenario without a REDD mechanism. Under one set of illustrative conditions[23], a REDD mechanism resulted in a 73–84% decrease in emissions from deforestation relative to business as usual (figure 3). The difference between individual REDD reference level designs was relatively small by comparison. The cap and trade system outperformed all other designs in climate-effectiveness and cost-efficiency.

Across all reference level designs, emissions reductions were greater in Asia and Latin America than in Africa, as our data sets indicate that Asia and Latin America contain more land area on which carbon density is high and potential agricultural rent is low. In Africa, emissions reductions in high carbon density forests were offset by increased deforestation and agricultural production in lower carbon density forests in response to increased agricultural rental values.

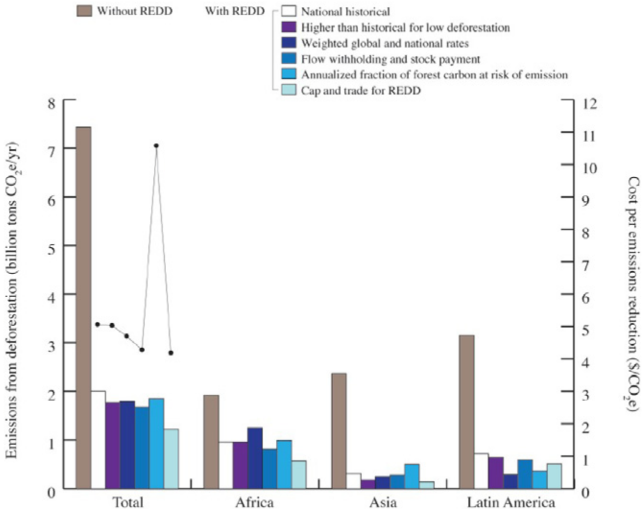


**Figure 3.** Emissions from deforestation under six REDD reference level designs and business-as-usual emissions without REDD, by region. Results are outputs of OSIRIS v2.6 using the following parameter values: carbon price = \$5/ton $CO_2$; permanence reduction scale = 1.00 (no permanence withholding); exponential demand for frontier agriculture with price elasticity = 2.00 (2% decrease in supply leads to 1% increase in price); fraction of soil carbon credited under REDD = 0.10; coefficient on slope of supply curve extensions = 0.10; social preference for agricultural surplus parameter = 1.00; management and transaction cost = 2001 US\$3.50 $ha^{-1}$ $yr^{-1}$; fraction of national average timber rent included = 1.00; reference period = 1990–2000. Furthermore, the following design-specific parameters are assumed: reference level for countries with low deforestation rates = 0.0015; weight on national historic rates = 0.85; flow withholding = 0.15; year by which high deforestation forest carbon at risk of emission is emitted = 2050; year by which low deforestation forest carbon at risk of emission is emitted = 2100.

In countries where weak or non-existent REDD incentives were insufficient to outcompete agriculture, emissions from deforestation increased due to leakage of frontier agriculture from REDD-incentivized countries. This was the case for countries with historically low deforestation rates (deforestation rate below the global average deforestation rate of 0.22% $yr^{-1}$; FAO 2005) in the 'national historical' reference level design. In the absence of incentives to maintain low emissions rates, countries with historically low deforestation rates underwent an increase in emissions from deforestation due to leakage from other countries (figure 4). In contrast, the reference level designs that provided REDD incentives to all countries enabled countries with historically low deforestation rates to maintain low emissions rates, and made the REDD mechanism more climate-effective and cost-efficient overall (figure 4).

Cost-efficiency varied across designs. A cost per emission reduction below market price could occur due to reference levels set low enough that not all reductions that occurred were credited, yet not so low that countries would have chosen to opt out of participation in REDD. A cost per emission reduction above market price could occur for two reasons. Either some

[22] For more on price feedbacks of REDD in the carbon market, see Piris-Cabezas and Keohane (2008); Eliasch (2008).

[23] Results are outputs of OSIRIS v2.6 using the following parameter values: carbon price = \$5/ton $CO_2$; permanence reduction scale = 1.00 (no permanence withholding); exponential demand for frontier agriculture with price elasticity = 2.00 (2% decrease in supply leads to 1% increase in price); fraction of soil carbon credited under REDD = 0.10; coefficient on slope of supply curve extensions = 0.10; social preference for agricultural surplus parameter = 1.00; management and transaction cost = 2001 US\$3.50 $ha^{-1}$ $yr^{-1}$; fraction of national average timber rent included = 1.00; reference period = 1990–2000. Furthermore, the following design-specific parameters are assumed: reference level for countries with low deforestation rates = 0.0015; weight on national historic rates = 0.85; flow withholding = 0.15; year by which high deforestation forest stock is at risk = 2050; year by which low deforestation forest stock is at risk = 2100.

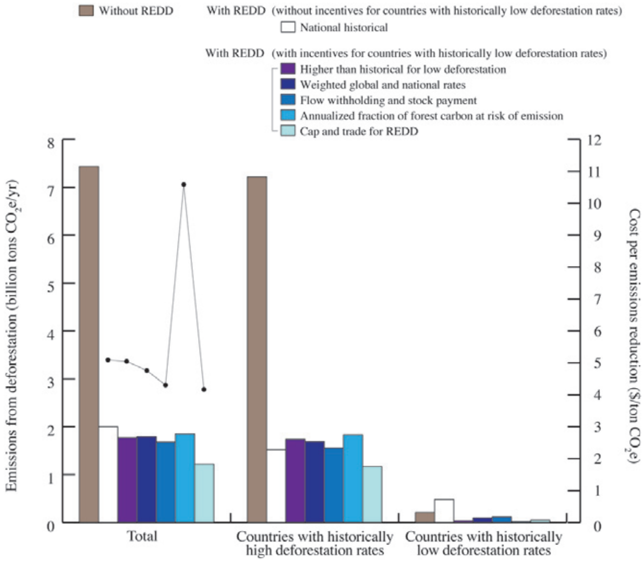


**Figure 4.** Emissions from deforestation under six REDD reference level designs and business-as-usual emissions without REDD, by historical deforestation rate. Results are outputs of OSIRIS v2.6 using the following parameter values: carbon price = \$5/ton $CO_2$; permanence reduction scale = 1.00 (no permanence withholding); exponential demand for frontier agriculture with price elasticity = 2.00 (2% decrease in supply leads to 1% increase in price); fraction of soil carbon credited under REDD = 0.10; coefficient on slope of supply curve extensions = 0.10; social preference for agricultural surplus parameter = 1.00; management and transaction cost = 2001 US\$3.50 $ha^{-1}$ $yr^{-1}$; fraction of national average timber rent included = 1.00; reference period = 1990–2000. Furthermore, the following design-specific parameters are assumed: reference level for countries with low deforestation rates = 0.0015; weight on national historic rates = 0.85; flow withholding = 0.15; year by which high deforestation forest carbon at risk of emission is emitted = 2050; year by which low deforestation forest carbon at risk of emission is emitted = 2100.

reference levels were set too low, in which case leakage of deforestation resulted in more credits purchased than net reductions to the atmosphere, or some reference levels were set too high, in which case some credits purchased emissions reductions which would have occurred anyway[24].

We tested the sensitivity of our results to the value of key parameters (table 2). Of all the parameters examined, REDD climate-effectiveness and cost-efficiency were most sensitive to the elasticity of demand for frontier agriculture, with greater elasticity implying less leakage and greater emissions reductions. When elasticity was at its theoretical maximum ($e$ = inf.), frontier agricultural land taken out of production in one place brought no additional frontier agricultural land into production elsewhere. In this case, leakage was not a consideration, and nearly all emissions from deforestation were avoided. When elasticity was at its theoretical minimum ($e = 0$), every hectare of frontier agricultural land that was taken out of agricultural production in one place was replaced by a hectare of new frontier agricultural production elsewhere. Even in this extreme case, the REDD mechanism still decreased emissions from deforestation, as deforestation activity shifted from high carbon density to low carbon density forests. The true elasticity likely lies between these two hypothetical extremes, though its exact value is uncertain ($e$ = 1.0, 2.0; 3.0). When elasticity was lower and leakage was greater, there was a greater difference in relative emissions reductions between the 'national historical' design and the 'cap and trade' design, representing greater potential gains to features designed to manage leakage.

REDD effectiveness, efficiency and participation were also sensitive to the value of the REDD targeting variable. Increasing the factor by which REDD surplus had to exceed forgone agricultural surplus substantially decreased participation and climate-effectiveness, implying that the precision with which countries can distribute REDD incentives to ensure participation in REDD by land users will play a major role in the effectiveness of REDD. As would be expected, a higher carbon price produced greater emissions reductions. A decrease in the portion of timber revenue included in opportunity cost, or an increase in soil carbon included in REDD credits, increased the value of standing forest relative to opportunity cost, and increased the reductions in emissions under REDD. Neither soil nor timber had a large effect on magnitude of impacts, though the inclusion of these factors would likely have had distributive implications for particular countries. We introduced a national startup cost for REDD, converted to annualized payments, which had to be exceeded by REDD surplus before a country would opt in to REDD participation[25]. This startup cost reduced participation in REDD by smaller countries, and raised the cost per emissions reduction slightly, but had a minor impact on overall emissions reductions, as large countries were not deterred by this cost. Shifting the period from which historic or historically based reference levels were derived from the time preceding the crediting period (1990–2000) to the crediting period itself (2000–2005) increased the effectiveness of these designs but decreased their efficiency, as higher deforestation rates during the later period generated higher reference levels. Reference level designs that balance incentives for historically high and low deforestation countries were more climate-effective than the national historical design across most parameter values, and in most cases were more cost-efficient as well. An elasticity of demand for frontier agriculture much greater or much less than the elasticity for which the design was balanced diminished the effectiveness or efficiency of these designs. The cap and trade design was most climate-effective and cost-efficient under all parameter values.

[24] Short term (2000–2005) reference levels in the 'annualized fraction of forest carbon at risk of emission' design were derived from predicted long term (2010–2100) BAUs. These reference levels matched short term BAU less closely than did reference levels derived from recent historical (1990–2000) average deforestation rates. Thus while other reference level designs appeared to be more cost-efficient in the short term, future work will determine if the 'annualized fraction of forest carbon at risk of emission' design is more cost-efficient in the long term.

[25] That is, in figure 2, a country chooses to opt in to REDD when $A + B > x(A + C) + S$, and chooses to opt out of REDD when $A + B \leqslant x(A + C) + S$, where $S$ represents the annualized value of startup cost, paid over 30 years at 10% rate of interest.

**Table 2.** Sensitivity of climate-effectiveness, cost-efficiency and participation to parameter assumptions.

| Reference level design | | National historical | | | Higher than historical for low deforestation | | | Weighted global and national rates | | | Flow withholding and stock payment | | | Annualized fraction of forest carbon at risk of emission | | | Cap and trade for REDD | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact | Value | Cl-E[a] | C-E[b] | P[c] | Cl-E[a] | C-E[b] | P[c] | Cl-E[a] | C-E[b] | P[c] | Cl-E[a] | C-E[b] | P[c] | Cl-E[a] | C-E[b] | P[c] | Cl-E[a] | C-E[b] | P[c] |
| Carbon price ($/ton $CO_2$) | $2.50 | −42 | $2.53 | 44 | −42 | $2.73 | 58 | −47 | $2.30 | 56 | −53 | $2.11 | 60 | −54 | $6.45 | 51 | −63 | $1.98 | 69 |
| | $5[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | $10 | −87 | $9.84 | 60 | −90 | $9.79 | 71 | −91 | $9.40 | 69 | −93 | $9.24 | 72 | −90 | $19.13 | 70 | −98 | $8.66 | 79 |
| Elasticity | 0 | −8 | $29.64 | 37 | −6 | $42.50 | 53 | −6 | $40.54 | 48 | −8 | $28.30 | 45 | −19 | $36.25 | 39 | −18 | $1.46 | 33 |
| | 1 | −61 | $5.83 | 44 | −61 | $5.78 | 58 | −60 | $5.75 | 53 | −59 | $5.31 | 61 | −64 | $12.17 | 57 | −72 | $4.10 | 73 |
| | 2[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | 3 | −80 | $4.77 | 57 | −82 | $4.80 | 72 | −82 | $4.61 | 69 | −82 | $4.29 | 74 | −79 | $10.25 | 65 | −89 | $4.27 | 80 |
| | Inf. | −96 | $4.36 | 84 | −96 | $4.55 | 84 | −96 | $4.39 | 84 | −91 | $4.32 | 84 | −92 | $9.23 | 84 | −97 | $4.33 | 84 |
| REDD preference/targeting | 1[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | 2 | −36 | $6.20 | 42 | −37 | $6.54 | 58 | −37 | $6.25 | 58 | −37 | $6.07 | 61 | −68 | $11.52 | 56 | −84 | $4.22 | 79 |
| | 3 | −31 | $6.27 | 26 | −32 | $6.69 | 44 | −32 | $6.28 | 44 | −32 | $6.06 | 46 | −59 | $12.57 | 49 | −84 | $4.22 | 79 |
| % soil carbon | 0% | −72 | $5.08 | 52 | −73 | $5.09 | 65 | −73 | $4.81 | 63 | −76 | $4.33 | 70 | −73 | $10.87 | 63 | −82 | $4.20 | 77 |
| | 10%[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | 25[d] | −75 | $5.07 | 57 | −78 | $5.11 | 72 | −77 | $4.78 | 67 | −80 | $4.41 | 71 | −78 | $10.33 | 65 | −87 | $4.25 | 79 |
| Timber revenue | 0% | −75 | $5.06 | 58 | −77 | $5.07 | 73 | −78 | $4.78 | 70 | −79 | $4.41 | 71 | −77 | $10.60 | 66 | −87 | $4.25 | 82 |
| | 50% | −74 | $5.11 | 55 | −76 | $5.11 | 71 | −76 | $4.75 | 68 | −79 | $4.35 | 73 | −76 | $10.65 | 64 | −86 | $4.24 | 82 |
| | 100%[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| Start up cost (million USD) | $0[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | $50 M | −73 | $5.11 | 49 | −74 | $5.15 | 57 | −73 | $4.86 | 53 | −77 | $4.49 | 58 | −74 | $10.80 | 56 | −84 | $4.29 | 79 |
| | $100 M | −72 | $5.18 | 45 | −74 | $5.17 | 53 | −73 | $4.91 | 52 | −76 | $4.56 | 55 | −74 | $10.83 | 55 | −84 | $4.35 | 79 |
| Reference period | ‘90–‘00[d] | −73 | $5.11 | 55 | −76 | $5.07 | 68 | −76 | $4.79 | 66 | −77 | $4.38 | 71 | −75 | $10.67 | 64 | −84 | $4.22 | 79 |
| | ‘00–‘05 | −76 | $5.78 | 58 | −78 | $5.70 | 74 | −79 | $5.39 | 71 | −80 | $5.04 | 78 | −75 | $10.67 | 64 | −84 | $5.00 | 79 |

[a] Cl-E: climate-effectiveness—reduction in emissions from deforestation below business as usual (%).

[b] C-E: cost-efficiency—total cost per net reduction in emissions from deforestation ($/ton $CO_2$e).

[c] P: participation in REDD reductions—number of countries ($n = 84$) reducing or maintaining emissions from deforestation.

[d] Default parameter value. Unless otherwise indicated, the following parameter values were used in OSIRIS v2.6: carbon price = $5/ton $CO_2$; permanence reduction scale = 1.00 (no permanence withholding); exponential demand for frontier agriculture with price elasticity = 2.00 (2% decrease in supply leads to 1% increase in price); fraction of soil carbon credited under REDD = 0.10; coefficient on slope of supply curve extensions = 0.10; social preference for agricultural surplus parameter = 1.00; management and transaction cost = 2001 US$3.50 $ha^{-1}$ $yr^{-1}$; fraction of national average timber rent included = 1.00; reference period = 1990–2000. Furthermore, the following design-specific parameters are assumed: reference level for countries with low deforestation rates = 0.0015; weight on national historic rates = 0.85; flow withholding = 0.15; year by which high deforestation forest carbon at risk of emission is emitted = 2050; year by which low deforestation forest carbon at risk of emission is emitted = 2100.

## 9. Discussion

A number of conclusions can be drawn across REDD design options, despite uncertainty about the absolute magnitude of emissions reductions under REDD. First, all REDD reference levels modeled yielded substantial emissions reductions relative to business as usual. The difference in emissions among particular reference level designs was minor relative to the substantial difference in emissions with and without REDD. This suggests that the implementation of a REDD mechanism can contribute significantly to mitigating climate change under a broad range of reference level designs.

Second, the REDD mechanism can be made most climate-effective and cost-efficient by balancing incentives for reduction of deforestation in countries where deforestation has historically been high with incentives for prevention of deforestation in countries where deforestation has historically been low. The optimal balance between incentives for reduction and prevention will depend on leakage and the demand for frontier agriculture. Less leakage requires a greater weight on incentives for reduction, while more leakage requires a greater weight on incentives for prevention. REDD design will benefit from empirical research into the elasticity of demand for frontier agriculture, and the exploration of deforestation–reduction strategies with low associated leakage. Excluding any countries from REDD incentives entirely could result in leakage of deforestation emissions to those countries. For example, setting reference levels using unadjusted historical deforestation rates could increase deforestation in countries with historically low deforestation rates. To avoid this loss in climate-effectiveness and cost-efficiency, the REDD system should encourage broad participation through positive incentives for all countries, including those which have in the past had low rates of deforestation.

Third, the climate-effectiveness and cost-efficiency of REDD is dependent upon the elasticity of demand for frontier agriculture. This elasticity can be influenced; the more agricultural demand can be met outside of the forest frontier, the greater elasticity will be for frontier agriculture, the less leakage will occur, and the more effective and efficient REDD is likely to be. A REDD mechanism can likely achieve greater emissions reductions when complemented with policies and measures to intensify agriculture off the forest frontier, expand agriculture on degraded lands and shift agricultural consumption toward less land- and carbon-intensive products.

A key next step for REDD incentives research is to work with parties to the UNFCCC to compare impacts of additional reference level designs which parties consider to be likely or politically feasible. This research can also inform the design of reference levels for other multilateral REDD structures, including those developed for interim finance for REDD, or developed under US federal climate policies. Analysis can also be extended to designs which combine component features of proposals. Research can compare the equity and co-benefits dimensions of REDD reference level designs, and can compare long term impacts by integrating OSIRIS with a dynamic projection of land use change (e.g. Kindermann *et al* 2006). OSIRIS can be extended to include reforestation, and can be integrated with more detailed national level data sets to analyze sub-national land use implications of national REDD designs. Finally, the accuracy of OSIRIS can be continually improved by integrating more accurate and finer scale data as these become available.

## 10. Conclusion

The results of this analysis support a growing consensus that a well-designed REDD mechanism can be an effective component of an overall agreement to avoid dangerous climate change (Pacala and Socolow 2004, Stern 2006, Eliasch 2008), under a broad range of reference level designs. Quantitative economic models such as OSIRIS can help climate negotiators design reference levels for a REDD mechanism that is effective, efficient and equitable.

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