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On international equity in reducing emissions from deforestation

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ABSTRACT

Reducing emissions from deforestation and forest degradation (REDD) can be an effective and efficient means of mitigating climate change. However, the perceived equity in the distribution of financial incentives for REDD could also emerge as a critical issue in international negotiations. The design of reference levels, which provide the benchmark for crediting emissions reductions, affects the economic incentives for national participation in a REDD mechanism and thus the overall willingness to reach an agreement on REDD. This paper compares the equity impacts of five proposed reference level designs using a partial-equilibrium model. Tradeoffs among equity, environmental effectiveness and cost-efficiency indicate the proposals trigger similar aggregate emissions reductions but lead to different outcomes in efficiency and alternative measures of equity. If equity across countries is measured as the financial incentive provided relative to a country's forest carbon stock, then a REDD mechanism compensating a uniform share of at-risk carbon stocks is the most equitable. On the other hand, if equity is evaluated as the financial incentive relative to the opportunity costs of participating in REDD, then the most equitable approach would be compensating emissions reductions but withholding a part of the payments to compensate for carbon stocks, which also encourages broader country participation under our model.

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1. Introduction

There is growing consensus among researchers and policymakers that avoiding dangerous climate change requires large-scale effective action on reducing emissions from deforestation and forest degradation (REDD) and on increasing carbon sequestration in land-based systems (Eliasch, 2008).[1] Including a REDD mechanism in a global climate agreement presents an opportunity to achieve stronger global emission-reduction targets more quickly and cheaply, while providing countries that preserve their forests with a valuable economic development opportunity (Stern, 2007; Eliasch, 2008). In this context, a central issue for REDD negotiations is how to determine the reference level relative to which emissions

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[1] Although we refer to REDD throughout the paper, the analysis presented here focuses on reducing emissions from deforestation. Degradation is not factored into the quantitative analysis due to data limitations, but we qualitatively assess the implications for the results of including degradation in the policy mechanism. Policies to increase sequestration are not addressed in this analysis.

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reductions from participating countries would be measured to determine compensation. Reference levels of emissions will be a key element in determining a REDD mechanism's overall reductions in emissions from deforestation ("effectiveness"), reductions per dollar spent ("cost-efficiency"), and distribution of REDD revenue across countries and regions ("equity") (Stern, 2007; Angelsen, 2008). While recent research has analyzed aspects of effectiveness and efficiency of different reference level designs (Busch et al., 2009a,b; Griscom et al., 2009a), the international equity dimension of REDD has not been precisely defined, and remains to be analyzed in depth.

This paper clarifies possible interpretations of equity surrounding REDD in the international policy arena, and then uses a partial-equilibrium model (the Open Source Impacts of REDD Incentives Spreadsheet; OSIRIS) to examine how different design options to reduce deforestation compare in terms of equity measures. The results are discussed and interpreted, and tradeoffs between equity, emissions reductions, and cost per unit of reduction are analyzed. We restrict our analysis to South-South equity concerns, examining the distribution of financial incentives among tropical forest countries as opposed to broader issues of burden-sharing or inter-generational equity in climate change policy, as these have been extensively addressed elsewhere (e.g., Ridgley, 1996; Rose et al., 1998; Azar, 1999; Metz, 2000; Carraro, 2000; Ringius et al., 2002; Kavuncu and Knabb, 2005; Stern, 2007; Leach, 2009). The North-South issue of the extent to which developed and developing countries, respectively, would capture the consumer and producer surplus from trade in REDD credits is a particularly important equity consideration. Here we focus on the equally critical, inadequately considered South-South equity concerns, which will affect participation by developing forest nations in a REDD program and the feasibility of achieving an international agreement.

The analysis presented here does not take into consideration the degradation component of REDD. In countries dominated by landscapes where degradation increases the likelihood of subsequent deforestation, as reviewed by Griscom et al. (2009b), a substantial proportion of degradation emissions may be attributed to deforestation at a later time period if emissions factors are used that ignore degradation. In such countries, not accounting for forest degradation leads to errors in precisely quantifying emissions per time period, which are imperfectly resolved through later attribution to full deforestation. These errors will tend to cancel out over longer time periods as deforestation occurs. However, reference levels for countries that experience degradation without deforestation could differ considerably from their characterization in models not accounting for degradation. In this case the error would persist, likely increase over time and remain unresolved. This potential error in accounting for degradation can be addressed by the development of more accurate emissions inventories, which would enable appropriately nuanced policies and incentives.

2. Design options for an international policy mechanism to reduce emissions from deforestation

The main objective of REDD is to substantially reduce emissions from deforestation. Since funds for climate change mitigation are limited, significant reductions require a cost-efficient approach. In this context, REDD is not envisioned as an income redistribution program, so therefore equity is not the primary objective of the REDD design. However, since the design of REDD will likely be determined through a negotiated process and participation in the system will be voluntary, a challenge for international negotiations is to design a system of positive incentives that encourages widespread agreement and participation. A central element of this process will be reaching agreement on the approach to setting a country's reference level of emissions. These reference levels are benchmarks against which countries' actual emissions from deforestation would be monitored and verified for the purpose of compensation. Any country whose actual level of emissions from deforestation is less than its agreed-upon reference level would be eligible to credit this difference as an emissions reduction achievement. Following Angelsen (2008), these benchmarks *may or may not* be entirely distinct from historical emissions, and may be entirely distinct from the unobservable business-as-usual baseline that would occur without REDD. Proposed methods for establishing such reference levels have different implications for the amounts of credits generated through REDD activities and the resulting distribution of incentives for countries to participate in a REDD program.

One of the earliest proposals for a reference level design was to set a country's reference level equal to its average national rate of emissions from deforestation over a recent historical period, as in one variant of the original compensated reduction design proposal (Santilli et al., 2005). However, when positive incentives are extended only to countries with historically high rates of deforestation, there could be exacerbated threat of displacement, or "leakage," of deforestation activities 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 this potential for leakage by extending higher than historical reference levels to countries with historically low deforestation rates (Santilli et al., 2005; Mollicone et al., 2007). Countries with high past rates of deforestation would be rewarded for reducing these emissions under a crediting reference level set relative to historical deforestation rates. In contrast, under these proposals, countries with low rates of past deforestation would gain credits for avoiding emissions growth relative to reference levels that are elevated based on assumptions of increased future rates of deforestation.

As the objective of REDD is to significantly reduce global emissions from deforestation from current levels, one policy design approach seeks to ensure that only reductions below current aggregate levels are credited for the global forest sector by allocating the historical global baseline across countries. This condition means that any country-level reference level that is set above a country's historical emissions, to allow for future potential emissions increases for example, would need to be counterbalanced with reference levels set below historical emissions in other countries. Strassburg et al. (2009) have proposed a combined incentive 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. If the reference level for a country is set above its historical emissions, the country may increase emissions while still receiving incentives, whereas if it is set below a country's historical emissions, the country must achieve a range of emissions reductions relative to past trends before any reductions are compensated.

The design of reference levels could also attempt to reflect future deforestation projections. Ashton et al. (2008) have proposed a ''forward looking'' reference level that uses the fraction of the terrestrial carbon stock estimated to be ''at risk'' in the period over which the reference level is to be used. This ''at risk'' portion is estimated based on future biophysical, economic and legal considerations.

Since countries' participation in REDD will be voluntary, the design of the incentives should take into consideration both how to encourage broad participation and efficiently achieve emissions reduction goals.[2] Using only the reference level as a parameter, it could be difficult to both reach efficiently an environmental target among participating countries and maximize country participation (so as to avoid overall loss in efficiency due to leakage). Following Tinbergen (1952), two separate policy instruments are necessary to pursue two separate objectives. The ''flow-withholding and stock payment'' approach (Cattaneo, 2008, 2010) uses reference levels based on historical emissions, but relies on a second instrument as well: a stabilization fund which provides payments for stocks but is not associated with credits. In this proposal a fraction of the price paid for reductions is withheld to raise funds to be distributed to forest countries in the form of payments for forest stocks. However, if a country exceeds historical emissions its stock payments would be reduced by the cost of offsetting the increase in its emissions elsewhere. Therefore, there is a base payment to a country that is related to the country's forest carbon stocks, but this base payment is diminished proportionally to the emissions.[3]

Summarizing, alternative proposals call for setting reference levels and establishing positive incentives according to either: (i) historical emissions, (ii) historical emissions with an adjustment factor, (iii) forward-looking projections possibly averaged over time, or (iv) historical emissions with a share of funds withheld to stabilize stocks.

3. Notions of equity and measuring inequality

The perception of equity is a key element determining stakeholders' acceptance of the outcome of a negotiation. The equity aspects of a given negotiation or transaction may be usefully distinguished among concerns for ''distributive justice governing outcomes'', and ''procedural equity governing the conduct of the process to come to an agreement'' (Lind and Tyler, 1988). Here we focus on distributive justice of outcomes, as discussed extensively in both philosophy and economics (Vickrey, 1945; Harsanyi, 1953; Harsanyi, 1955; Rawls, 1971; Nozick, 1973; Varian, 1975; Arrow, 1985).

We follow the definition of distributive justice of outcomes in negotiations used by Zartman et al. (1996). Specifically, we consider the notion of proportional justice, in which outcomes are allocated in proportion to some criterion – generally either *merit*, according to which he who contributes most gets most, or by *need*, in which he who has least gets most.

The notion of equity of a REDD mechanism is closely related to the concept of distributive justice. For a policy mechanism providing a given amount of positive incentives to be distributed across countries, what does it mean to have an equitable distribution? Zartman et al. call this the referent question: equality or inequality of *what* and *why*? With respect to distributing incentives to reduce emissions from deforestation, the referent question can be answered in more than one way. Here we consider two possible measures of equity that are relevant for the REDD mechanisms:

Equity Measure 1: equity relative to endowment of carbon – this can be interpreted as compensation commensurate with carbon stock, and is measured in (REDD incentives in $)/(total tons of carbon in standing forest).[4] This measure captures the concern that over time, without a priori information, any hectare of forest could potentially be deforested and its carbon emitted into the atmosphere. Therefore, in terms of environmental impact all carbon stored in forests could be viewed as having the same standing according to this measure of equity. Also, the measure captures the sense that any country that has retained its forest carbon in the past, perhaps as a ''good'' or ''early actor'', deserves the same per unit compensation as countries that have deforested historically. Along similar lines one could also envision equity based on endowment of forest area.

Equity Measure 2: equity relative to total opportunity costs – countries reducing emissions from deforestation may have very different opportunity costs, and the provision of compensation commensurate with the opportunity costs of REDD could be a key equity concern. The extent to which compensation is commensurate with opportunity costs is measured in (REDD incentives in $)/(opportunity cost of REDD in $). This measure reflects the extent to which countries receive equivalent returns or profit margins given the costs borne to achieve REDD. To the extent opportunity costs appropriately reflect what countries are giving up to achieve REDD, equality along opportunity costs could be viewed as ''equal compensation for equal effort.'' This can also be seen as ensuring some countries do not gain

[2] If REDD were not voluntary, then a cap-and-trade system would be a straightforward approach. The aggregate environmental objective would be fixed and the allocation of environmental permits (equivalent to setting the baseline) would simply be a rent distribution issue with no environmental effect.

[3] The flow withholding and stock payment can also be interpreted as adjusting reference levels above historical emissions for all countries, and paying for this increase in reference levels through a lower carbon price to compensate reducing or not increasing emissions relative to these levels.

[4] The equity measure is based on the incentives offered. If the country accepts to participate in REDD then the incentives will equal the revenue from REDD. This distinction between incentives offered by a REDD program and revenue generated is maintained throughout the paper.

disproportionate windfall profits from the design of REDD. One could similarly examine equity based on other indicators of national investment or effort to achieve REDD.

These two measures are meant to highlight how equity can mean different things to different people, and how REDD proposals could be perceived as equitable or not depending on the notion of equity employed. Clearly one could envision other measures of equity as well, such as the distribution of funds relative to the development needs of the areas being protected from deforestation. Here we limit the analysis to just the two measures introduced above and test how different proposals for distribution of REDD incentives perform according to these equity criteria. These two specific equity measures were chosen because they relate directly to how the different proposed reference level design options function in treating carbon stocks and in mitigating drivers of deforestation by outcompeting the opportunity costs of REDD. Other equity measures could be tested with the proposed approach, but would likely not exhibit much variation among the policy design proposals presented here.[5] We consider equity relative to the financial incentives offered to all countries, irrespective of whether or not the model predicts these incentives will be large enough relative to opportunity costs to induce acceptance of the offer, as described below.

Next we need to define the measurement of the degree of equality or inequality. Multiple indicators of inequality exist in the economics literature. Probably the most well known is the Gini coefficient (G), developed by Gini (1912) as a summary measure of income inequality in society. It is usually associated with the plot of wealth concentration introduced a few years earlier by Max Lorenz (1905). The Gini coefficient has, as we shall see, an intuitive interpretation that makes it appealing to use in applied analyses.

As an example, if one considers equity based on endowment of carbon stock, the Lorenz curve can be used to map the cumulative share of REDD funds offered to tropical countries on the vertical axis against the distribution of the forest carbon present in countries on the horizontal axis (Fig. 1). The area (A) between the Lorenz curve and the equality diagonal is a measure of inequality. The greater the distance of the Lorenz curve from the diagonal line, the greater the inequality.

In the hypothetical example in Fig. 1, countries representing 60% of the forest carbon stock would be eligible to receive around 20% of total available REDD funds, indicating a disproportionate level of financial incentives relative to forest carbon stock. If each country were offered the same level of compensation per ton of forest carbon stock, the distribution of this potential income would be illustrated by the diagonal line in the graph – the line of total equality. The Gini coefficient is calculated as the area *A* divided by the sum of areas *A* and *B*. If potential REDD revenues are distributed completely equally such that the Lorenz curve and the line of total equality are merged, then the Gini coefficient is zero. If an individual country stands to receive all the REDD revenue, the Lorenz curve would pass through the points (0,0), (100,0) and (100,100), and the areas *A* and *A* + *B* would be identical (area of *B* = 0), leading to a Gini value of one.

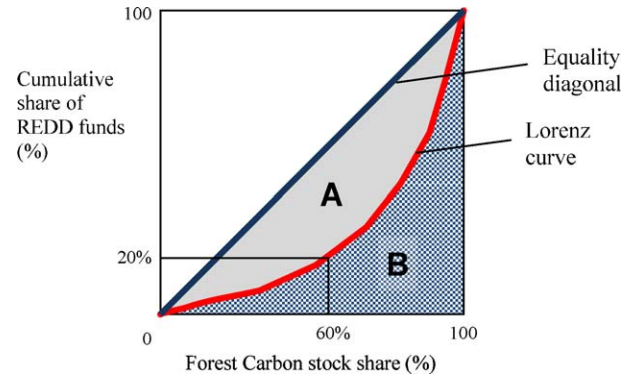

Fig. 1 – A hypothetical Lorenz curve of REDD funds distribution relative to carbon stock: the further the curve is from the equality diagonal the greater the inequality in the distribution of funds.

4. Analytical and empirical framework

We extend previous analyses based on the OSIRIS model (Busch et al., 2009a,b) to quantitatively compare the equity of distribution of REDD financial transfers for emissions reductions for five national-scale REDD reference level options, described below. OSIRIS is a single-period partial equilibrium model for a single commodity – the composite output of agriculture, including a one-time timber harvest, produced on one hectare of land cleared from the tropical forest frontier. Countries participate voluntarily in REDD, choosing to 'opt in' only if the national economic surplus from forest carbon exceeds the foregone national economic surplus from agriculture and one-time timber harvest. Otherwise countries choose to 'opt out.' A higher national reference level provides a country with greater financial incentive to opt in to REDD. After opting in to or out of REDD, countries choose a level of deforestation that maximizes aggregate national economic surplus from forests and agriculture based on REDD reference level design-specific incentives. Leakage of deforestation occurs endogenously in the model through a demand curve for tropical agriculture. A reduction of deforestation in one country leads to a higher price for frontier agriculture and increased pressure to deforest in other countries (see Busch et al. (2009a,b) for mathematical details and a graphical representation and Murray (2008) for the conceptual underpinning of the OSIRIS model).

For each of 84 tropical or developing countries considered to be potentially eligible for REDD, national supply curves for frontier agriculture were constructed from national-level deforestation data, spatially explicit estimates of agricultural returns, and national average estimates of one-time timber harvest returns. For each country the hectares of forest land were taken from Schmitt et al. (2008). For each hectare of forest of land a highest-return agricultural activity and productivity level, was determined based on a map of global agro-ecological zones (Fischer et al., 2000) and was converted

[5] For policy designs that are different from those analyzed in this paper, it may be that other equity metrics from those considered here could lead to a different set of tradeoffs with effectiveness and cost-efficiency.

to a maximum potential gross annual agricultural revenue 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 was estimated to be the net present value of the profit from an annual payment stream of agricultural revenue plus the one-time timber extraction value. Following Stern (2007), we specified a time horizon of 30 years, a discount rate of 0.10, and a uniform profit margin of 0.15 across all agricultural land. Spatial variation in transport and other costs was not captured in our opportunity cost estimates, although national data were calibrated to be consistent with historical deforestation rates. Average national net present value of one-time timber extraction 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.

In each country the without-REDD equilibrium quantity of annual deforestation was taken from self-reported historical national levels of deforestation from 2000 to 2005 (FAO, 2005). We specified an exponential global demand curve for frontier agriculture, parameterized with an elasticity equal to 2.0 (implying that a 2% reduction in quantity results in a 1% increase in price), and calibrated about the point of total reported annual deforestation (12.1 million ha/year) and estimated global average agricultural return to a hectare of frontier agriculture. Each country's supply curve for frontier agriculture is based on estimated potential land rental prices across that country's forests and scaled to match observed deforestation rates at the global average agricultural return. Reference levels based on historical emissions use data from 1990 to 2000 (reference period), and are applied to a 2000 to 2005 implementation and crediting period, for which the actual deforestation in the data for those years is taken to be the business-as-usual without REDD.

The carbon density (tons C/ha) in country is the average carbon density (Ruesch and Gibbs, 2008) over a country's forest land (Schmitt et al., 2008) plus a portion (0.10) of 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). For illustration, the market price of a ton of carbon dioxide emission was set to 2008 US$5/ton CO_2e. A scaling factor applied to a payment for reduced emissions to address non-permanence was set 1.00, assuming no permanence reduction.[6] The per hectare net present cost of management to ensure deforestation is avoided in was set to $40/ha for all countries, corresponding to $3.50/ha/year, the average cost per hectare of protected area management across developing countries (James et al., 2001).[7]

Uncertainties exist concerning a number of model parameters. We tested the sensitivity of our results to the value of key parameters such as uncertainty in (i) the carbon price paid for reductions in emissions, (ii) the average carbon density, (iii) start-up costs, (iv) the extent to which timber rents have to be forgone when participating in REDD, (v) reference periods to be chosen, and (vi) in the elasticity of demand for frontier agriculture. Results from this sensitivity analysis are presented in the supplemental online material. For further insight these and other uncertainties are treated transparently in OSIRIS through the use of flexible parameters which can be changed by users.

The results are presented for five proposed reference level designs under one set of illustrative conditions[8]:

- "National historical" – reference levels equal to a country's national historical rate (Santilli et al., 2005).
- "Higher than historical for low deforestation" – reference levels equal to national historical rates for countries with historically high deforestation; reference levels higher than national historical rates for countries with historically low deforestation rates (da Fonseca et al., 2007; Mollicone et al., 2007). It is assumed here that the reference rate for countries with low deforestation rates is set at 0.15%, which is higher than their historical rate and creates incentives for them to participate.
- "Weighted average of national and global" – reference levels are a weighted average of national and global historical rates (Strassburg et al., 2009). The results presented are based on reference levels by country obtained weighing at 85% the national historical emissions rate and at 15% the global average emission rate. Countries with a historical emissions rate lower than the global average will have a reference level that is higher than their historical emissions, and vice versa for countries with historical emissions rates higher than the global average.
- "Flow withholding and stock payment" – a percentage of payment for emissions reductions relative to historical is withheld to fund payments for forest stock (Cattaneo, 2008, 2010). The withholding level is assumed here to equal 20% of the price paid for emissions reductions. The funds generated by the 20% withholding will be redistributed proportionately

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

[7] Although data are not available by country, in reality the management costs are likely to vary depending on deforestation pressure. The results presented in the present analysis should not be affected, however, given that management costs are proportionately very small relative to opportunity costs.

[8] Results reported here 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 with price elasticity = 2.00 (elasticity neither perfectly elastic nor perfectly inelastic); fraction of soil carbon eligible for REDD = 0.1; coefficient on slope of supply curve extensions = 0.10; Social preference for agricultural surpluses parameter = 1.00; management and transaction cost = 2001 US$4.20/ha/year; fraction of national average timber rent included = 1.00. 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 = 0.20; year by which high-deforestation forest stock is at risk = 2050; year by which low-deforestation forest stock is at risk = 2100.

to stock, subject to performance relative to the historical emissions rate.

- "Uniform fraction of at-risk stock" – reference levels are based on the fraction of national forest stock assumed to be at risk of deforestation under business as usual (Ashton et al., 2008).[9] In reality, at-risk stock varies by country, and over time. In the current absence of detailed projections by country over time, for this analysis, country-specific long run projections of deforestation (TCG, 2009) are averaged to give a uniform reference level per annum for that country. For currently high deforestation rate countries (>0.58% year^{-1}), it is assumed that "at risk" stock will be depleted by 2050 (so the long run "at risk" stock is averaged over 40 years to give a per annum reference level). For currently low deforestation rate countries (<0.58% year^{-1}), it is assumed that "at risk" stock will be depleted by 2100 (so the long run "at risk" stock is averaged over 90 years to give a per annum reference level).[10] The at-risk carbon stock estimates capture the long-term deforestation process on a country-by-country basis, while the two time horizons characterize the influence of current deforestation on the dynamics of deforestation in the short to medium term, as OSIRIS is a single period model using levels of deforestation from 2000 to 2005.

The formulae for calculating reference levels under each design option are presented in Busch et al. (2009a,b). Most of these design options require the specification of a design-specific parameter, e.g. the weight placed on global average historical rates, or the percentage of flow payment withheld (listed above in the bullet points). For each design, a "best foot forward" design-specific parameter was selected for which the design achieved its maximum effectiveness and efficiency.

5. Results

Fig. 2 shows how the financial incentives are distributed by alternative REDD reference level mechanisms. The curves display the cumulative share of REDD funds offered to all potential REDD countries on the vertical axis against the distribution of countries' forest carbon stocks (or opportunity costs) on the horizontal axis (Fig. 2). As mentioned above, the closer a Lorenz curve is to the diagonal, the more evenly financial incentives are distributed relative to the variable under consideration as defining equity. The Gini coefficient summarizes this degree of inequality according to the area between the Lorenz curve and the equality diagonal, and varies between zero (perfect equality) and one (maximum inequality). The text along the left side of Fig. 2 indicates the share of total incentives offered to countries in the quartile of the equity variable (either global carbon stock or total opportunity costs) that is offered the lowest payments.

Which designs perform most equitably relative to *Equity Measure 1*, equity relative to carbon endowment? For comparative purposes, we designate the historical national emissions design as the base scenario. Under this design, countries accounting for 25% of forest carbon stock are eligible to receive only 3% of potential REDD funds. This occurs because some countries with large forest stocks have very low emissions and, under this base scenario, would receive very little or no compensation if they participated in the global REDD mechanism. This type of uneven distribution has already emerged as an important point of debate in global climate negotiations. Relative to the national historical emissions scenario, two proposals, "Higher than historical for low deforestation" and "Weighted average of national and global", double the financial incentives to the countries with the bottom quartile of the global carbon stock in terms of payments. Under the "flow withholding and stock payment" and the "uniform fraction of at-risk stock", the financial incentives to this subset of countries increase even more, reaching three times those based exclusively on national historical emissions.

One may also ask whether the financial incentives countries would potentially receive are proportional to their opportunity costs of participating in REDD (*Equity Measure 2*). If not, then some countries may gain a large profit from participating whereas others may barely cover their opportunity costs and receive no added surplus. If a mechanism introduces a large enough disparity in incentives relative to opportunity costs, then some countries that otherwise would join a REDD system would receive financial incentives that do not outweigh opportunity costs, and consequently elect not to participate in REDD. At the same time, other countries may receive far more than needed to induce their participation at early stages of a REDD mechanism. The "uniform fraction of at-risk stock" mechanism, while the most equitable in providing incentives relative to carbon stock, provides the least financial incentives (6% of funds) to the countries with the quartile of the global opportunity costs that is offered the lowest compensation. The other proposed designs are more equitable in terms of distributing incentives proportionately to opportunity costs, starting with the "national historical" offering 13% of funds to this subset of countries, and ending with the "flow withholding and stock payment" offering 17% of funds (perfect equity being 25%).

In sum, the analyses reveal that the mechanism based on the "uniform fraction of at-risk stock" design is the most equitable of the reference level proposals examined here, as measured by financial incentives payments relative to carbon stock, with a Gini coefficient (G) of 0.28. On the other hand, the "flow withholding and stock payment"' design is the most equitable in terms of distributing funds according to opportunity costs faced by countries (G = 0.20) (Fig. 2). In the first case, this is because, in this analysis, the reference emission levels which reward as a proportion of at-risk stock, obtained using the 3-filter method (Ashton et al., 2008), are more closely

[9] This approach should not, therefore, be interpreted to mean that the reference levels are assigned based on stocks, as they are assigned based on projected deforestation. These projections take into account a range of legal, biophysical and economic factors. Further, a number of defining elements of the Ashton et al. (2008) proposal have not been modeled here.

[10] The threshold value of 0.58% year^{-1} is the global average deforestation rate for the period 2000–2005 (FAO, 2005).

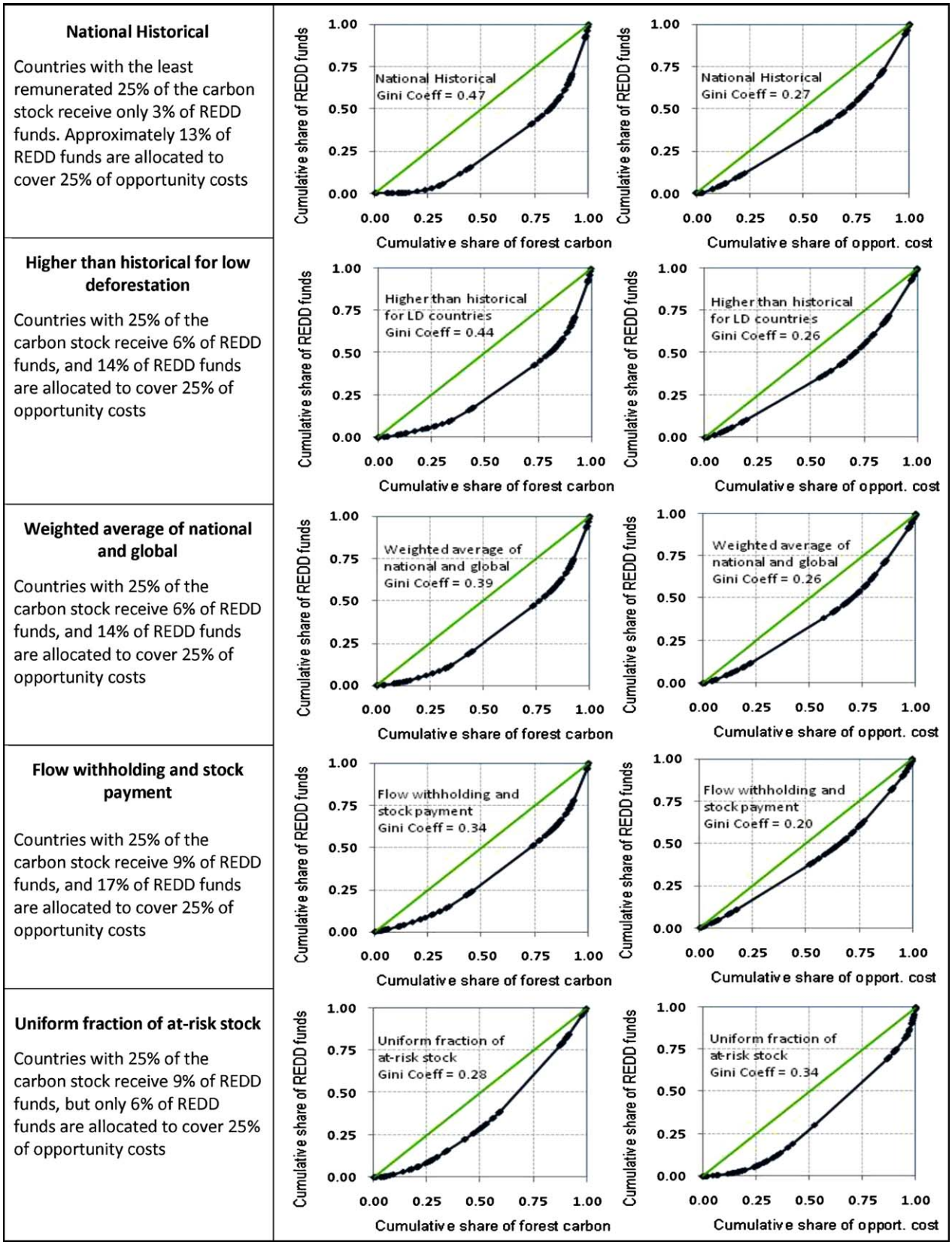

Fig. 2 – Lorenz curves for five proposed mechanisms of distributing REDD incentives relative to measures of: (a) equity based on endowment of carbon, and (b) equity based on return relative to the opportunity cost. ***The closer the curve is to the diagonal, the lower the inequality.***

Table 1 – Gini coefficients for REDD proposals according to different notions of equity (the lower the coefficient, the more equitable the outcome), with estimated emissions reductions and REDD payments per unit of emission reduction.

REDD incentive mechanism	Inequality relative to carbon stock	Inequality relative to opportunity cost	Number of countries opting into REDD (out of 84)	Total reduction in deforestation emissions	Cost-efficiency
	Gini coefficient	Gini coefficient		%	$/t$CO_2$e
National historical	0.47	0.27	55	−73%	5.10
Higher than historical for low deforestation	0.44	0.26	68	−76%	5.06
Weighted average of national and global	0.42	0.26	66	−76%	4.78
Flow withholding and stock payment	0.34	0.20	77	−75%	4.31
Uniform fraction of at-risk stock	0.28	0.34	64	−75%	10.65

correlated to carbon stocks than the 1990–2000 historical emissions which we use to determine the other reference levels.[11] This occurs partly because countries with large forest carbon stocks exhibit a long-term viability in agriculture that puts those stocks at risk between now and 2050 or 2100. Further reinforcing this correlation is the fact that overall carbon stocks do represent an upper bound for at-risk stocks, particularly in countries with low stocks of forests, which is a constraint that reference levels based on historical emissions rates do not account for.

Understanding why the ''flow-withholding and stock payment'' design emerges as the most equitable relative to opportunity costs depends on the fact that the opportunity costs of participation are endogenous to the design mechanisms. In contrast to a country's existing forest carbon stock, the opportunity costs of participating in REDD depend on the REDD reference level design. Different proposed mechanisms lead to different predicted levels of participation, yielding a different equilibrium price for tropical forest frontier agricultural land, which in turn affects opportunity costs (a ''price'' effect). Typically designs that lead to broader participation will have a higher equilibrium frontier land price, which entails higher opportunity costs of participating in REDD. The ''flow-withholding and stock payment'' has an additional element relative to the other mechanisms–it affects the level of incentive payment per unit of emission reduction through the withholding. This has the effect of reducing the shift in the supply of land introduced by the mechanism, and therefore leading to lower opportunity costs. This differentiated impact by country explains why the ''flow-withholding and stock payment'' provides a set of incentives that is more aligned with opportunity costs when compared to other proposed designs.[12]

5.1. *What tradeoffs do equity considerations involve?*

Each proposed mechanisms distributes payments among countries in a manner that is comparable with the other proposals on equity grounds in terms of at least one, if not both, of the two equity measures considered. It is therefore useful to examine other tradeoffs by comparing how proposals perform in terms of environmental effectiveness and economic efficiency alongside equity considerations. Under one set of illustrative conditions, the REDD mechanisms considered here result in a 73–76% decrease in emissions from deforestation relative to business as usual (Table 1).

The mechanisms vary considerably in cost-efficiency expressed as amount paid per ton of net global emission reduction from REDD. At a price of $5/ton CO_2e, the unit cost for reductions ranges from $4.4/ton CO_2e to more than $10/ton CO_2e. Therefore, some mechanisms have an efficiency that is greater than 100% because the actual programmatic unit cost is less than the explicit market price of carbon. This could occur if reference levels are set low enough so that the full amount of reductions that is achieved is not credited, yet still high enough to encourage country participation in REDD. An efficiency measure lower than 100% could occur for two reasons. If some reference levels were not set high enough to encourage full participation in REDD, leakage of deforestation would reduce the net reductions achieved globally. Alternatively, if some reference levels were set too high,

[11] Total forest carbon stock has a correlation of $r = 0.98$ with preliminary estimates of at-risk forest carbon stock used for this analysis produced by applying three filters of biophysical suitability, economic pressure and effective legal protection (TCG, 2009). Financial incentives under other proposals are also highly correlated with carbon stocks but to a lesser degree with correlation ranging from $r = 0.87$ for a national historical emissions reference level to $r = 0.92$ for the flow-withholding and stock payment. The correlation between reference levels and carbon stocks is in part driven by the large stocks in Brazil, which are associated with high reference levels under all proposals. Recalculating the correlation excluding Brazil from the sample one obtains a correlation $r = 0.84$ for at-risk forest carbon, with the other proposals ranging from $r = 0.64$ for a national historical emissions reference level to $r = 0.74$ for the flow-withholding and stock payment. The relative magnitude, across proposals, of the correlation between carbon stocks and reference levels does not change when changing the number of countries included in the sample to calculate the correlation.

[12] For reference level designs that are based on historical emissions with an adjustment, the ''price effect'' alone does not alter distributional equity by much because opportunity costs for all countries increase or decrease proportionately when the equilibrium price for frontier agricultural land rises or falls. This is the reason that for two proposals the Gini coefficient for equity relative to opportunity costs is very close to the historical emissions reference level case. The supplemental online material (SOM 1) includes a sensitivity analysis and analyzes in greater depth the underlying causes for the differences in distributional equity between the proposed mechanisms.

some credits would be issued without any associated reductions in emissions.

The disparity in cost-efficiency results in considerable variation in the annual cost of a ''full'' REDD mechanism with all tropical countries eligible to participate – from $26 billion per year for the most efficient to $60 billion per year for the least efficient. The ''flow-withholding and stock payment'' preserves economic efficiency, while also being relatively equitable compared to other design options in terms of distributing payments in proportion to carbon endowment and to opportunity costs. This approach demonstrates that equity on these grounds may be achieved in a manner compatible with reducing costs.[13]

Table 1 also reports the estimated number of countries opting to participate in REDD under each mechanism. For participating countries the financial return to increasing deforestation is lower than the one they would obtain by opting in to REDD. Instead of equity relative to carbon endowment, equity relative to opportunity costs is most aligned with greater levels of country participation across the mechanisms considered. The rationale for this result is quite simple: participation in REDD, as modeled here, is based on the expectation that REDD payments will meet or exceed opportunity costs. Accordingly, for a given carbon price or total level of financing, the more equitably profits are distributed relative to opportunity costs, the broader the participation because fewer countries will be left with costs exceeding benefits of participation.

A dual-instrument approach which uses a portion of the carbon price (or other sources of revenue) to fund stabilization of stocks could help achieve the dual goals of both cost-efficiency and broad participation needed for environmental effectiveness. However, for stock stabilization incentives to be an effective and cost-efficient complement to incentives for emissions reductions, the incentive mechanism would have to be carefully designed following specific criteria so that (i) direct incentives to reduce emissions are not watered down by diverting too many funds towards stock stabilization, (ii) finance for stock stabilization is adequate and (iii) stock payments are structured as conditional on emission reductions relative to the reference level rather than in proportion to standing stocks. The ''flow-withholding and stock payment'' mechanism analyzed in this paper fulfills these three criteria.

As mentioned earlier, our analysis has not taken into consideration the degradation component of REDD. Including degradation in the reference level may complement some of the adjustments being proposed to compensate countries with low deforestation rates because countries could receive compensation for reducing degradation even if no deforestation is occurring. Potential mechanisms to adjust countries' reference level based on emissions from degradation could put in place incentives for more sustainable timber use, assuming a system of monitoring, reporting and verification for degradation is put in place. This could be analyzed in OSIRIS by lowering the share of timber rents that have to be forgone to participate in REDD. The sensitivity analysis presented in the supplemental online material indicates that lowering the forgone timber rent through more sustainable forest management would increase country participation.

Further results from the sensitivity analysis confirm in qualitative terms the results presented in the paper, indicating that performance, in relative terms, concerning equity, cost-efficiency, and effectiveness is robust to parameter uncertainty. Sensitivity results indicate that as the carbon price decreases the different policy proposals vary more widely in terms of the estimated impacts on emissions reductions since it becomes more important to target payments efficiently to achieve the environmental outcome. We also find that different estimates of carbon densities can have a considerable impact on country participation. As the start-up cost increases, smaller countries are less likely to participate in REDD, but the relative ranking of the proposed mechanisms is not affected. A lower share of timber rents forgone to achieve REDD leads to broader participation and a slightly higher cost per unit of emissions reductions. Comparative results are similar under different reference periods, whereas the elasticity of demand (which determines the potential for leakage) changes the relative ranking of the different proposed mechanisms in terms of total reductions of deforestation emissions. More details are available in the supplemental online material.

6. Conclusion

Since financial resources for climate change mitigation will be limited, achieving ambitious environmental goals will depend on policies that can distribute funding across mitigation options so as to obtain the greatest possible reductions in emissions. This requires policy designs that are environmentally effective and cost-efficient as well as equitable. For mitigation options that are voluntary, such as reducing emissions from deforestation and forest degradation (REDD), it is crucial for incentives to be distributed sufficiently broadly so as to expand the number of countries that decide to participate, since broader participation tends to increase the overall effectiveness and efficiency of this voluntary mitigation option. Furthermore, perceptions of equity among countries potentially participating in REDD could determine the successful negotiation of an agreement on an international REDD mechanism.

Our analysis used a static partial equilibrium model to compare the distribution of financial incentives under five alternative REDD mechanism designs along two possible measures of equity. Results indicate similar emissions reduction potential across mechanisms but reveal marked

[13] The correlation between efficiency and equity relative to opportunity costs does not imply that the two measures are conceptually similar. The reason for the correlation is that the underlying data collected for the model indicate that more deforestation is currently occurring in countries where there is higher agricultural potential, i.e. higher opportunity costs. This generates a link between efficiency and equity: if all countries receive REDD incentives proportionately to their opportunity costs then there will be less leakage compared to a case where some range of opportunity costs are not minimally compensated. Lower leakage could enhance efficiency, but efficiency will also depend on the payment level for reductions relative to the reference level, and on the overall global reference emissions level of a given mechanism design.

differences in terms of cost-efficiency and the different equity measures. The relative equity of the mechanisms varies with the measure considered. There are also important tradeoffs between cost-efficiency and equity when equity is considered in terms of whether the distribution of financial incentives is commensurate with tons of standing forest carbon. The reason for this tradeoff is that the overall cost will be higher if, for a given level of payment per ton of emissions reduction, the reference level is more correlated with carbon stocks than with emissions. On the other hand, if one considers equity as "equal payment for equal effort," using the opportunity cost of reducing emissions as a proxy for effort, then some REDD mechanism designs encourage broad participation in a manner that is both efficient and equitable. Thus, in addition to improving the cost-efficiency of REDD, a more equitable REDD mechanism design according to this criteria could also make an international agreement easier to achieve and reduce potential leakage of deforestation by encouraging greater country participation.

Our analysis indicates that, among the mechanism design options compared here, withholding a portion of the carbon price to fund stock stabilization is the approach with the highest overall performance across the metrics considered. Withholding a portion of the carbon price to fund stock stabilization appears equitable relative to both carbon stocks and opportunity cost, and also achieves the dual goals of cost-efficiency and broad participation for environmental effectiveness. Future work in this area could usefully extend the analysis to consider additional measures of equity, longer-term dynamics of REDD, including how countries' opportunity costs may change with time, and how REDD incentives might be adjusted as countries successfully reduce emissions from deforestation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2010.08.009.

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