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Readiness and Avoided deforestation policies: on the use of the REDD fund

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The first phase of the REDD+ mechanism consists of helping countries to improve their capacity to carry out national forest inventories, notably to assess land-use changes and forest carbon stocks and fluxes. However, there might be some links between the funding of this first phase and the quantity of avoided deforestation that will happen during the following phases of REDD+. This paper precisely investigates those links, using a simple two-step, two-players, subsidiary-based REDD+ mechanism.

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1 Introduction

It is now broadly accepted that the protection of tropical forests represents a priority due to the many economic, social and environmental services they provide. With the emergence of several initiatives aiming at fighting climate change, notably through carbon economics, the possibility to limit greenhouse gases (GHG) emissions arising from deforestation constitutes another strong argument for preserving tropical forests. Indeed, deforestation and forest degradation occurring in tropical forests lead to gross emissions of GHG estimated between 5.5 (Werf, 2009) to 10.8 (Pan et al., 2011) billion tons of CO_2 per year.

In spite of the major contribution of forests in global GHG emissions, this sector remained a neglected topic in the international negotiations on climate change until the 11th Conference Of Parties (COP of Montreal, 2005). During this COP, Costa Rica and Papua New Guinea suggested creating a system that would provide incentives for reducing deforestation by assigning a value to the carbon stored in forests (Climate Economics in Progress, 2011). With the creation of this mechanism aiming at Reducing Emissions from Deforestation and forest Degradation (REDD), tropical forests came in the spotlight of international negotiations.

In 2009, REDD became REDD+ to include the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. The now called REDD+ mechanism has been divided in three steps: (1) a preliminary Readiness phase followed by (2) a phase of Implementation of national policies and measures, and then by (3) the financial Compensation of result-based actions. The most advanced phase in terms of design and financing is the on-going Readiness phase. As of January 2015, 58 countries are receiving support from the United Nations Collaborative Programme on REDD (UN REDD) and 47 countries have committed to participating in the Readiness fund of the Forest Carbon Partnership Facility (FCPF) of the World Bank.

The aim of this paper is to understand how the first phase of readiness may be related to the second and third phases of implementation and compensation. Indeed, in a world where financial resources are crucially constrained, the spendings of the Readiness phase may limit the budget for the next phases of REDD+. Moreover, the degree of measurement precision chosen is likely to have an impact on the willingness to pay for carbon credits from avoided deforestation. In order to give a better understanding of those effects, we build a very simple, two-step two-player model, in which the North and South agree upon a level of forest carbon measurement and a level of avoided deforestation. We show that, in a world with tight budget constraint, and depending on the North and South risk aversion, the REDD+ budget will trade off between the measurement precision and the level of expected avoided deforestation. Although focusing on REDD, the analysis given in this paper is also applicable to any payment for environmental services in which MRV (Monitoring, Reporting and Verification) is of important matter. In a broader dimension, our results bring useful information to cases in which measurement errors are detrimental to both agents of a particular transaction, who have to invest in measurement investment in the context of limited fundings.

In section 2, we introduce the issue of the lack of precision in forestry emissions measurement and explain what is at stake with the Readiness phase. Section 3 highlights the potential lack of financial means for the different phases of the REDD+, leading to a discussion in section 4 on the way the REDD fund should be shared between the Readiness phases and the next ones. We develop a two-player model to illustrate this issue. We then discuss the main results of this model.

2 Precision and Readiness

One of the reasons for the late inclusion of the forestry sector in carbon economics is the complexity for measuring, monitoring and verifying forestry carbon fluxes. In addition to the leakage (Atmadja and Verchot, 2011) and the permanence issues, specific measurement problems appear when tackling forestry carbon.

Four main dimensions have to be considered when measuring emissions reduction from the forestry sector: (1) an assessment of the change in forest area, which requires a specific monitoring, hardly feasible without having recourse to remote sensing; (2) an estimation of the per-hectare carbon stock, which involves field inventories; (3) the deduction of the carbon fluxes between the land and the atmosphere; (4) the construction of a baseline of forest cover change. Each step entails a high level of uncertainty and it is thus particularly challenging to calculate the emissions of carbon within the boundaries of a forest with a satisfactory level of precision. Pelletier et al. (2010) identified that the key sources of uncertainty in the quantification of emissions from deforestation for Panama were the forest carbon stocks and the quality of land-cover maps, a result which might probably be applied to other countries involved in REDD+. Barbier (2012) and Barbier and Tesfaw (2012) underline the importance of transaction costs of the REDD+ mechanism, that are related to monitoring and verifying changes in deforestation rates in developing countries. Those costs are likely to significantly increase the total cost of REDD implementation.

Indeed, most developing countries have a weak capacity to assess the changes in their forestry cover, as well as forest carbon stocks, leading to uncertainties in the emission factors. Regarding the forest cover, the development of remote sensing technologies in the early 21st century significantly improved the precision of forest cover monitoring. Indeed, several studies based on remote sensing revealed that the deforestation rates compiled by the Food and Agriculture Organization of the United Nations (FAO) from national surveys and published in their Forest Resource Assessment (FRA) were often overestimated (Achard et al. 2002; DeFries et al. 2002; Hansen et al. 2010). Achard et al. (2002) for example found that the global net rate of deforestation in the humid tropics over the period 1990-1997 was 23% lower when using remote sensing data instead of national surveys.

Assessing forest carbon stocks is more challenging since this stock varies from a forest to the other, depending on species, climate, latitude, density or management. Default values of carbon stocks are provided by the guidelines of the Intergovernmental Panel on Climate Change (IPCC) or by the FAO but they contain a significant error. Waggoner (2009) shows that discrepancies in forest carbon inventories range up to multi-billion ton-differences. The only way to obtain precise data is to proceed to numerous local inventories, which is time-consuming and costly. A new approach using airborne Lidar sensors is being tried out at the project or regional scale (see for instance (Asner et al., 2010)), showing promising results but whose cost is still prohibitive.

It should be noticed that, even after having assessed forest area and the forest carbon stocks, an additional uncertainty arises from step 3 as most estimates neglect tracking the carbon after deforestation, whereas the fate of land -regrowth or conversion to pasture or cropland- and the fate of wood -abandoned, burnt or transformed into wood products - clearly impact carbon emissions (Simonet, 2011).

Finally, a last but main source of uncertainty regarding the estimation of national emissions reduction stems from the construction of the national empirical business-as-usual scenario of forest cover change, or baseline. Indeed, as highlighted by Sloan and Pelletier (2012), "defining a credible and accurate baseline is both critical and challenging", which could result in significant errors when estimating the performance of countries.

Achieving a correct level of precision requires having recourse to expensive remote sensing tools and ground inventories, something that most developing countries are currently not able to do. The United Nations Framework Convention on Climate Change (UNFCCC) assessed that the majority of developing countries (referred to as non-annex I countries) have limited capacity in providing complete and precise estimates of their forestry emissions (UNFCCC 2009). However, to be efficient, the REDD+ mechanism should be based on precise data on the amount of avoided deforestation and the related avoided emissions. Without precise measurements of emission reductions, the environmental integrity of the system could be threatened and a potential "hot air" could be introduced in the climate regime (Angelsen 2008, Karsenty 2008). Grassi et al.(2008) study the way the conservativeness principle could be applied to reduce the uncertainty in forestry emission data, arguing that high uncertainties could undermine the credibility of REDD+ as a mitigation option.

The Readiness phase was thus designed to "assist developing countries to determine a national reference scenario of deforestation, develop a monitoring system for REDD+, and adopt a national strategy for reducing deforestation and forest degradation."(Davis et al. 2008). This preliminary step is necessary to ensure that the emission reductions claimed by developing countries under REDD+ are actual. Pelletier et al. (2011) highlights the importance of current efforts to establish forest monitoring systems and enhance capabilities for REDD+ in developing countries, "to avoid that real emissions reductions in developing countries be obscured by their associated uncertainties". Plugge and Kohl (2012) also consider that "MRV systems for REDD+ should clearly define how uncertainties are to be included in national accounting rules" because of the effect on the benefits achievable by countries involved in REDD+. However, improving countries capacity to provide precise estimates of their forestry emissions has a significant cost, and the money available for REDD+ is limited.

3 Cost of REDD+ and available funds

An issue which remains unresolved after the 20th Conference of Parties in Lima (December 2014) is the financial modalities of REDD+. Although the first and the second steps of REDD+ should be financed by funds, two main options are currently considered for the third one: a fund-based mechanism and a market-based mechanism. In this paper, we consider the case where a fund-based implementation is chosen. Significant amount of money will be needed for REDD+, in contrast with the money currently available.

The amount of money required for the implementation phases of REDD+ has been estimated by several authors. Stern (2007) estimated that between USD 3 and 11 billion would be needed to halve emissions from deforestation depending on the valuation of any timber and on land use opportunity cost. Other estimates are much higher, like Kindermann et al. (2008) who estimated the cost of reducing deforestation by 50 percent to be between 17.2 and 28 billion dollars. Finally, the United Nations Environment Programme Finance Initiative (UNEP FI) estimates that USD 17-40 billion per year is required to halve emissions from the forest sector by 2030 (UNEP 2011).

The large variety of REDD+ costs estimated is a good illustration of the uncertainty related to transaction costs, among which MRV costs are one of the most important components.

To date, several public and private funds have been raised by developed countries to finance REDD+. According to Canby et al. (2014), over USD 7.3 billion has been pledged for REDD+ Readiness by 2015, mainly by the public sector (93.6%) . Brazil is the main recipient of REDD+ funds thanks to the Amazon Fund, whose contributions from Norway, KfW and the Brazilian oil company Petrobras reached USD 775 billion at the end of 2013. Although bilateral donors and private foundations dominate REDD+ finance, the role of multilateral institutions such as the Word bank and UN-REDD increased since 2011 (Canby et al. 2014).

Contrary to REDD+ Readiness, it is not clear how the second and third phases of REDD+ will be financed. The financial crisis that affects developed countries increases the uncertainty on available funds for REDD+. As of January of 2015, the World Bank has pledged USD 390 million for the compensation phase of REDD+ through its FCPF Carbon Fund. However, this represents a small budget compared to UNEP forecast of between USD 18 and 40 billion per year needed. The Green Climate Fund could participate in reaching such a sum and its key role for REDD+ was highlighted during COP 19 in Warsaw. However, the objective of USD 100 billion by 2030 might be difficult to achieve (only USD10.19 billion pledged as of December 2014) and REDD+ would not constitute the only beneficiary of this fund.

4 Sharing the REDD+ fund between the Readiness phase and the next ones

There is no simple answer to what should be the optimal precision for REDD+. The mechanism could not start before the participants have the capacity to measure the avoided deforestation with enough precision not to threaten the environmental integrity of the system. Measuring avoided deforestation therefore encompasses three combined elements in the context of this paper: (1) assessing the carbon stock in standing forests; (2) evaluating the net rate of deforestation; (3) setting a trustful deforestation baseline or Business-As-Usual scenario. An important error could harm both developed and developing countries. Indeed, developed countries may not be willing to pay for emissions reduction that are likely to be overestimated. Conversely, developing countries are likely to display less effort for avoided deforestation if emission reductions tend to be underestimated.

However, requiring a high level of precision might exclude some countries with low MRV capacity but high potential for reducing forestry emissions. If a lot is invested to allow all countries to achieve the sufficient level of precision, the money engaged in Readiness will not be used for the compensation phase. Consequently, spending too much money in improving countries' capacity might prevent from financing the avoided deforestation to come, thus potentially reducing avoided deforestation.

As seen in section 2, several papers tackle precision issues. Research has also been led on the financing of REDD+, either assessing the funds available (Creed and Nakhooda, 2011; Canby et al. 2014) or discussing the right financing system for REDD+ (Karousakis and Corfee-Morlot 2007, Leplay et al. 2011, Neeff and Ascui 2011). However, the issue of the right distribution of the limited REDD+ fund between the Readiness phase and the implementation and compensation ones has not been tackled so far.

This paper analyzes the way the Readiness phase could impact the future avoided deforestation. We develop a model which represents the competition between investing in diminishing measurement errors and paying for actual avoided deforestation in a subsidiary-based REDD+ mechanism.

We consider a two-player (North N and South S) and two-period game. In the first period, i.e the readiness phase, the North pays the South for accounting its forests, with a chosen precision P. In the second period, the implementation phase, the North pays the South for measured avoided deforestation A. The REDD+ program is financed by a fund B, and both periods are subject to related budget constraints. Without loss of generality, we assume that what is spent in the first period can no longer be spent afterwards: $B = B_1 + B_2$. [1] Note however that the analysis given below remains valid for a less tight budget constraint, i.e when the first-period budget impacts negatively the available fund in the second period: $\frac{\partial B_2}{\partial B_1} < 0$. Precision P is positively and directly depends on the budget share spent in the first period: $P = P(B_1)$, with $P_{B_1} = \frac{\partial P}{\partial B_1} > 0$ and $P_{B_1 B_1} = \frac{\partial^2 P}{\partial B_1^2} < 0$. [2]

Measured avoided deforestation A and actual avoided deforestation $\tilde{A}$ have to be distinguished. We assume that measured avoided deforestation is accurate: $E(\tilde{A}) = A$. However, there may be some measurement errors. They are represented by a symmetric distribution centered around $\tilde{A}$, with variance $V(A, P)$: a larger variance is related to larger measurement errors.[3] This variance is impacted by the precision P chosen in the readiness phase: $V_P < 0$, $V_{AP} < 0$. Therefore: $V_{B_1} < 0$ and $V_{B_1 A} < 0$.

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[1] This framework is also valid for a project manager (N) willing to implement a REDD+ project within a rural community (S).

[2] For the remaining of the paper, subscripts refer to first and second derivative.

[3] The case of asymmetric distribution of measurement errors will be discussed in section 5.

An important consideration is whether the variance of measured avoided deforestation increases or decreases with the amount of measured avoided deforestation. In other words, do measurement errors increase or decrease with the area of forests involved in REDD+? First, with a fixed budget dedicated to MRV, increasing the amount of measured avoided deforestation will necessarily lead to a decrease in precision, and thus to an increase in the measurement error. Secondly, several techniques that proved to deliver more precision on the estimation of the carbon stock can only be applied on small-scale areas. Lidar sensors can be envisaged only at project or regional scale as they are too costly for large scale. At larger scales, high resolution images like QuickBird could be used, but they generate more uncertainty and less precision than Lidar airborne sensors (Gonzalez et al. 2010). Finally, intuitively, the heterogeneity of forests increases with the area of a REDD+ project. As a consequence, the larger A is, the larger the variability of forest types (and thus of carbon stocks) and of land use change factors are. It is thus likely that increasing the size of REDD+ implementation increases the risk of measurement errors.

For the remaining of this paper, we will assume that $V_A > 0$. Given that measurement errors are assimilated to a cost for both the North and the South, we assume they take a convex form: $V_{AA} > 0$. [4]

We solve the game backward, starting from the second period.

4.1 Second period: implementation phase

In the second period, the second-period budget $\overline{B_2}$ is given. It is directly related to the (given) first-period budget: $\overline{B_2} = B - \overline{B_1}$. Thus, by construction, precision $\overline{P} = P(\overline{B_1})$ is also given. South and North have to agree upon a measured amount of avoided deforestation A. [5]

The North pays p per unit of measured avoided deforestation, and values it at v (which is for instance the carbon price on other markets or the cost of reducing GHG in the industry), while the South's unit cost of avoided deforestation is c (encompassing opportunity costs and transaction costs from avoided deforestation). Both players maximize their expected utility U_S and U_N: South and North expected utility depends positively on measured avoided deforestation A, which is the result of the South deforestation policy, and negatively on the variance of avoided deforestation

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[4] Note that our results depend on those two intuitive hypothesis. Yet, there is still a need for evidence of the relation between measurement errors and the importance of REDD.

[5] Avoided deforestation is obviously not a command-and-control instrument as efficient as suggested here, and costly policies may be implemented and eventually not bring much avoided deforestation. However interesting and important, this concern is not in the scope of this paper.

measurement $V(A,\overline{P})$.[6] This variance is our indicator of measurement precision, and the result of the degree of precision chosen in the first period. Indeed, both players' expected utility decreases with the importance of avoided deforestation measurement errors: the North does not want to pay for a potentially excessive amount of avoided deforestation (if measured avoided deforestation is larger than the actual one $A < \tilde{A}$); the South does not want to provide avoided deforestation for which it may not be paid (if its measured level is under its actual level $A > \tilde{A}$).

The second-period game thus takes the form [7]:

$$\begin{aligned}
\max_A U_S &= S((p-c)A; V(A,\overline{P})) && (1)\\
\max_A U_N &= D((v-p)A; V(A,\overline{P})) && (2)\\
\overline{B_2} &= B - \overline{B_1} \geq pA && (3)\\
\overline{P} &= P(\overline{B_1}) && (4)\\
v &\geq p \geq c && (5)
\end{aligned}$$

First-order conditions implicitly give the supply A_S and demand A_D for measured avoided deforestation.

$$\begin{aligned}
(p-c)S_A + S_V V_A &= 0 && (6)\\
(v-p)D_A + D_V V_A &= 0 && (7)\\
p &= \frac{\overline{B_2}}{A} && (8)\\
\frac{\overline{B_2}}{c} = A_{max} &\geq A \geq A_{min}\frac{\overline{B_2}}{v} && (9)
\end{aligned}$$

The budget constraint of the second period implies an interval of possible levels of measured avoided deforestation: $A \in [A_{min}, A_{max}]$. The actual level of measured avoided deforestation and the price level will be determined by the shape of the supply and demand of measured avoided deforestation.

Using the implicit function theorem on equations (6) and (7) show that: [8] (1) supply of measured avoided deforestation decreases with the cost of avoided deforestation c, increases with the marginal utility of avoided deforestation S_A and decreases with the marginal cost of larger measurement errors S_V and the marginal impact of the level of avoided deforestation on measurement

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[6] We assume usual characteristics of the expected utility function: $S_A > 0$, $S_{AA} < 0$, $S_V < 0$, $S_{VV} < 0$, $D_A > 0$, $D_{AA} < 0$, $D_V < 0$, $D_{VV} < 0$.

[7] This set-up provides results compatible with a Nash-bargaining game with identical bargaining powers. Extreme situations of bargaining powers can also be considered. If the North has full bargaining power, only equation (2) is maximized. If the South has full bargaining power, only equation (1) is maximized.

[8] Proofs in appendix.

errors V_A: $\frac{\partial A_S}{\partial c} < 0$, $\frac{\partial A_S}{\partial S_A} > 0$, $\frac{\partial A_S}{\partial S_V} < 0$, $\frac{\partial A_S}{\partial V_A} < 0.$, (2) demand increases with the value of avoided deforestation v increase with the marginal utility of avoided deforestation D_A and decreases withe the measurement errors marginal cost D_V and the marginal impact of avoided deforestation on measurement errors V_A: $\frac{\partial A_N}{\partial v} > 0$, $\frac{\partial A_N}{\partial D_A} > 0$, $\frac{\partial A_N}{\partial D_V} < 0$, $\frac{\partial A_N}{\partial V_A} < 0$. It follows that better measurement precision increases both supply and demand of avoided deforestation, as long as it decreases the marginal effect of avoided deforestation on measurement errors: $\frac{\partial A_N}{\partial P} > 0$ if $\frac{\partial V_A}{\partial P} < 0$.

Dividing equation (6) by equation (7), substituting the carbon price by equation (26) and rearranging bring the equilibrium level of measured avoided deforestation $A^* = A^*(\overline{B_1}, P(\overline{B_1}))$:

$$\frac{(\frac{\overline{B_2}}{A^*} - c)S_A(A^*)}{S_V(A^*)} = \frac{(v - \frac{\overline{B_2})}{A^*})D_A(A^*)}{D_V(A^*)} \tag{10}$$

Overall both players trade off their marginal utility of measured avoided deforestation and their disutility of larger measurement errors. At the equilibrium, both N and S have the same marginal rate of substitution between improving measurement quality and increasing the level of measured avoided deforestation, which is the ratio between marginal utility of avoided deforestation and marginal cost of measurement errors. Larger marginal utility tends to increase supply and demand, while larger marginal cost decreases supply and demand. Larger value given to avoided deforestation and smaller cost to provide avoided deforestation unambiguously tend to increase the equilibrium amount. This result is constant with Liu and Meyer (2013), that state that the intensity of aversion to any type of risk can be interpreted as marginal rate of substitution between utility derivatives of different order.

Result 1 : *The first-period budget* $\overline{B_1}$ *has two effects on the second-period level of measured avoided deforestation* $A^*(\overline{B_1}, P(\overline{B_1}))$*:*

- Precision channel*: a larger first-period budget increases measurement precision* $P(\overline{B_1})$*. This tends to decrease measurement errors* $V(A, P)$ *and thus to increase supply and demand of measured avoided deforestation.* **Proof:** $P_{B_1} > 0$, $\frac{\partial A_N}{\partial P} > 0$ and $\frac{\partial A_S}{\partial P} > 0$ for $\frac{\partial V_A}{\partial P} < 0$.

- Budget channel*: a larger first-period budget decreases available budget at the second period. This tends to reduce the amount of measured avoided deforestation in the second period.* **Proof:** *Equation (27) shows that increasing the first-period budget decreases the second period-budget, which has the consequence to decrease the set of possible levels of avoided deforestation:* $\frac{\partial A_{max}}{\partial B_1} < 0$, $\frac{\partial A_{min}}{\partial B_1} < 0$.

The first effect tends to dominate the second when the marginal utilities of additional avoided deforestation of N and S are low compared to their marginal costs of measurement error. The second effect tends to dominate in the opposite case.

From this first set of results, it is then shown that avoided deforestation is directly related to the first-period measurement. Indeed, measurement errors tend to decrease the North willingness to pay and the South willingness to accept for avoided deforestation: if measurement is less precise, there is a risk for the North to pay for some avoided deforestation that actually does not exist, and for the South not to be paid for some avoided deforestation that actually exists.

4.2 First period: Readiness phase

In the first period, South and North have to agree upon a budget B_1, that will be spent to assess the South's forest resources and determine the measurement precision P. We know by result 1 that the first period budget determines the measured amount of avoided deforestation in the second period: $A^* = A^*(B_1, P(B_1))$.

The first-period game thus takes the form:

$$\max_{B_1} U_S = S((\frac{B - B_1}{A^*(B_1, P(B_1))} - c)A^*(B_1, P(B_1)); V(A^*(B_1, P(B_1)), P(B_1)) \tag{11}$$

$$\max_{B_1} U_N = D((v - \frac{B - B_1}{A^*(B_1, P(B_1))})A^*(B_1, P(B_1)); V(A^*(B_1, P(B_1)), P(B_1)) \tag{12}$$

First-order conditions implicitly give the first-period budget and thus the level of measurement precision:

$$(1 + (A_{B_1} + A_P P_{B_1})c)S_A = (V_A(A_{B_1} + A_P P_{B_1}) + V_P P_{B_1})S_V \tag{13}$$

$$(-1 - (A_{B_1} + A_P P_{B_1})v)D_A = (V_A(A_{B_1} + A_P P_{B_1}) + V_P P_{B_1})D_V \tag{14}$$

Equations (13) and (32) describe a simple tradeoff concerning the choice of the first period budget. Overall, B_1 is chosen so that the marginal benefit from increasing it (i.e. increasing measurement precision) equals the cost of increasing it (i.e. reducing the amount of money available in the second period). By increasing B_1, precision is increased, which tends to increase the level of avoided deforestation in the second period. Nevertheless, increasing B_1 reduces the amount of money available to finance the second part of the game B_2, which tends to decrease avoided deforestation in the second period. What is important to know in this case is to which factor the equilibrium level of avoided deforestation is the most sensitive: precision or second-period budget.

The equilibrium level of the first-period budget is implicitly given at the intersection of equations (13) and (32):

$$\frac{S_A}{S_V}(-1-(A_{B_1}+A_P P_{B_1})c) \quad = \quad \frac{D_A}{D_V}(1+(A_{B_1}+A_P P_{B_1})v) \tag{15}$$

The equilibrium level of the first-period budget is found when the marginal rate of substitution of improving quality versus increasing the level of avoided deforestation is equalized between players.

The main variables determining this outcome are the North and South risk aversion coefficients. If North and South are very risk averse, they may prefer to increase the first-period budget in order to increase precision, even if this decreases the second-period budget and thus avoided deforestation. In contrast, if South and North have low coefficients of risk aversion, they may prefer less precise measurement, in order to be able to invest more in avoided deforestation policies during the second period.

It is important to note that equation 15 imposes conditions on v and c in order for the two players to find and agreement:

$$v \geq \frac{-1}{A_{B_1}+A_P P_{B_1}} \geq c \tag{16}$$

Note that this can be the case if and only if the effect of the budget channel is more important than the precision channel as described in result 1.

Result 2 : *As the aversion to measurement errors increases (D_V and S_V), more importance is given to measurement precision, and then more budget is allocated to the first-period budget.*

Overall, this result suggests that, as North and South risk aversion increases, both countries trade off measured avoided deforestation for increased measurement precision.

One may argue that choosing precision in the first period is likely to commit to future recurring costs, related to the cost of monitoring that may be positively related to precision. In this case, equation (19) becomes: $B_2 \geq pA - CF(P(B_1)$. This insight is indeed true, but do not tend to go against our result, as long as this fixed-cost is increasing with precision ($\frac{\partial CF}{\partial P} > 0$). Indeed, introducing this cost in the second period only decreases the second-period budget even more, which tends to exacerbate the effect we describe. As an extreme case, this may even exceed the participation constraint of the sellers, if those costs have not been properly estimated in the first place.

Note that this result directly relies on the fact that the REDD+ budget is fixed from the first to the second period. A way to overcome this tradeoff could be for the North (if it is particularly sensitive to the issue of precision measurement and has stronger risk aversion than the South) to condition part of the second period budget to the quality of measurement decided in the first period. This would consist of modifying the budget constraint of equation (19) to: $\overline{B_2} = B - \overline{B_1} + B_p(\overline{P})$. In this "deep-pocket" case, indeed, the tradeoff existing between precision and the second-period budget would be reduced [9]. However, note that the tradeoff described here is still valid as long as $\frac{\partial B_2}{\partial B_1} \geq 0$. Moreover, such an option would require the North to be able to commit to increase the size of the fund *ex post*, which may be a hard case in times of pressure on public resources.

5 The case of asymmetric distribution of measurement error

In the previous section, we examined what may happen if the distribution of avoided deforestation measurement errors is symmetric (null Skewness). Yet, measurement errors may be asymmetric. In this sense, there is a risk of underestimation larger or smaller than the risk of overestimation. Introducing this distributional asymmetry, the two players may not have the same objectives in terms of measurement errors anymore. Indeed one player can benefit from measurement errors: the North would benefit from underestimation of avoided deforestation, since it would pay for a smaller amount of avoided deforestation than the actual one; the South would benefit from overestimation of avoided deforestation, since it would get rewarded for a larger level of avoided deforestation than the actual one.

In this context, preferences of North and South are thus different: North's (South's) utility is increasing in the risk of underestimation (overestimation) and decreasing in the risk of overestimation (underestimation). We adapt equations (1), (2), (8) and (9) to represent those preferences.

5.1 Second period: : implementation phase

If distinguishing the risk of under and overestimation of avoided deforestation, North and South's utility functions become in the second period:

$$\begin{aligned}
\max_A U_S &= S((p-c)A; O(A,\overline{P}), U(A,\overline{P})) && (17)\\
\max_A U_N &= D((v-p)A; O(A,\overline{P}), U(A,\overline{P})) && (18)\\
\overline{B_2} &= B - \overline{B_1} \geq pA && (19)\\
\overline{P} &= P(\overline{B_1}) && (20)\\
v &\geq p \geq c && (21)
\end{aligned}$$

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[9] It could even be over-compensated if $\frac{\partial B_p}{\partial \overline{P}} \geq 1$.

In this new configuration, $O(A,\overline{P})$ represents the risk of overestimation, while $U(A,\overline{P})$ represents the risk of underestimation. In order to keep a link with the previous analysis, we can consider that:

$$\begin{aligned} O(A,\overline{P}) &= oV(A,P) && (22)\\ U(A,\overline{P}) &= (1-o)V(A,P) && (23) \end{aligned}$$

This specification could be interpreted in terms of Skewness: Skewness is negative for $o < 1/2$, it is positive for $o > 1/2$, and null for $o = 1/2$ (case of section 4). Non-null skewness is generally investigated within precaution analysis and third derivative of the utility function. We chose this peculiar specification, because (i) it gives us the opportunity to clearly link the results in this section (with non null skewness of measurement errors) and in the previous section (with null skewness), (ii) it allows us to combine within the same analysis first-order (variance) and second order (skewness) risk behavior.

The North is assumed to enjoy underestimation, while being averse to overestimation: in the first case, it benefits from avoided deforestation for free; in the second case, it pays from avoided deforestation that did not happen in reality. The reverse is true for the South: $S_O > 0$, $S_U < 0$, $D_O < 0$, $D_U > 0$. Considering that both agents are globally risk averse bring the following condition: $S_O < -S_U$, $-D_O > D_U$, $\forall[O,U]$. The variance of measured avoided deforestation is then decomposed between overvalued and undervalued observations. o can be considered as the degree of overestimation. If $o > 1/2$, measurement errors are biased toward overestimation, if $o < 1/2$ they are biased toward underestimation. By construction, if considering a symmetric measurement errors ($o = 1/2$), we have: $\alpha_S = \frac{\gamma_S}{2} - \frac{\beta_S}{2}$ and $\alpha_N = -\frac{\gamma_N}{2} + \frac{\beta_N}{2}$.

First-order conditions implicitly give the equilibrium level of avoided deforestation:

$$\begin{aligned} (p-c)S_A + S_O O_A + S_U U_A &= 0 && (24)\\ (v-p)D_A + S_O O_A + S_U U_A &= 0 && (25)\\ p &= \frac{\overline{B_2}}{A} && (26)\\ \frac{\overline{B_2}}{c} = A_{max} &\geq A \geq A_{min}\frac{\overline{B_2}}{v} && (27) \end{aligned}$$

What is important here to determine the equilibrium amount of avoided deforestation is the degree of asymmetry and the comparative risk aversion coefficients. For instance, if the risk of underestimation is larger than the risk of overestimation ($o < 1/2$), $(oS_O - (1-o)S_U)$ is negative (as $S_O < -S_U$ insures South's risk aversion), and decreasing in the South's aversion for underestimation, and increasing in its taste for overestimation. This simply means that the South's supply for avoided deforestation decreases with the variance of avoided deforestation (that is with measurement errors). In contrast, $(oD_O + (1-o)D_U)$ may be positive, if the North's aversion for overestimation is small enough or if it's taste for underestimation large enough: $D_O < \frac{1-o}{o}D_U$. It follows in this case that the North's demand for avoided deforestation may increase with measurement errors if its taste for overestimation is large enough compared to its aversion for underestimation.Similarly, if the risk of underestimation is smaller than the risk of overestimation ($o > 1/2$), the North's demand for avoided deforestation decreases in measurement errors (as $-D_O > D_U$ insures North's risk aversion). However, the South's demand for avoided deforestation may be increasing in measurement error if its taste for overestimation is large enough or if its aversion for underestimation is small enough: $S_O > \frac{1-o}{o}S_U$.

Rearranging brings the bring the equilibrium level of measured avoided deforestation $A^* = A^*(\overline{B_1}, P(\overline{B_1}))$:

$$\frac{(\frac{\overline{B_2}}{A^*} - c)S_A(A^*)}{oS_O + (1-o)S_U} = \frac{(v - \frac{\overline{B_2)}}{A^*})D_A(A^*)}{oD_O + (1-o)D_U} \tag{28}$$

Like in the previous section, trade off their marginal utility of measured avoided deforestation and their disutility of larger measurement errors. Yet, measurement errors are decomposed here, in order to emphasized that North and South may not have the same attitude toward them: North dislike overestimation, while South dislike underestimation, and vice versa.

Result 3 : *The equilibrium amount of measured avoided deforestation may increase with measurement errors, when :*

- *Errors are biased toward underestimation of avoided deforestation ($o < 1/2$), and the North's taste for underestimation (D_U) is large enough or the North's aversion for overestimation (D_O) is small enough.*
- *Errors are biased toward overestimation of avoided deforestation ($o > 1/2$), and the South's taste for overestimation (S_O) is large enough or the South's aversion for underestimation (S_U) is small enough.*

Proof: *When o is low, i.e. if measurement errors are biased toward underestimation, the South's supply for avoided deforestation decreases with measurement errors (following the proof of result 1), but the North's demand for avoided deforestation is increasing in measurement errors, if $D_O < \frac{1-o}{o}D_U$. Equilibrium avoided deforestation can then be increasing in measurement errors, if the demand effect dominates the supply effect. Conversely, when o is high, the North's demand* *for avoided deforestation decreases with measurement errors (following the proof of result 1), but the South's supply for avoided deforestation is increasing in measurement errors, if* $S_O > \frac{1-o}{o} S_U$. *Equilibrium avoided deforestation can then be increasing in measurement errors, if the supply effect dominates the demand effect.*

For instance, if the measurement error is largely biased toward overestimation of avoided deforestation, the South may have a tendency to supply larger amount of expected avoided deforestation, while the North will tend to have a smaller demand. If the South aversion for underestimation is not too small or if its taste for overestimation is large enough, the equilibrium amount of avoided deforestation may be increasing in measurement error.

This result is consistent with Eeckhoudt et al. (2009) unifying theory of behavior against risk, that risk-averse individuals mix good with bad risk situations of different order. North don't like measurement errors but likes underestimation: they are thus willing to accepted larger measurement errors (the bad) in order to get higher chance of underestimation (the good). South don't like measurement errors either, but likes overestimation: they are thus willing to accept larger measurement errors against higher chance to get their effort overestimated. The net effect will then depend on the intensity of risk aversion of both players, and the type of asymmetry in the distribution of measurement errors.

5.2 First period: readiness phase

The North and South programs in the first period become:

$$\max_{B_1} U_S = S\left(\left(\frac{B-B_1}{A^*(B_1,P(B_1))} - c\right)A^*(B_1,P(B_1)); O(A^*(B_1,P(B_1)),P(B_1), U(A^*(B_1,P(B_1)),P(B_1))\right) \tag{29}$$

$$\max_{B_1} U_N = D\left(\left(v - \frac{B-B_1}{A^*(B_1,P(B_1))}\right)A^*(B_1,P(B_1)); O(A^*(B_1,P(B_1)),P(B_1), U(A^*(B_1,P(B_1)),P(B_1))\right) \tag{30}$$

First-order conditions implicitly give the equilibrium level of the first-period budget and measurement precision:

$$(1+(A_{B_1}+A_P P_{B_1})c)S_A = (V_A(A_{B_1}+A_P P_{B_1}) + V_P P_{B_1})(oS_O+(1-o)S_U) \tag{31}$$

$$(-1-(A_{B_1}+A_P P_{B_1})v)D_A = (V_A(A_{B_1}+A_P P_{B_1}) + V_P P_{B_1})(oD_O+(1-o)D_U) \tag{32}$$

The equilibrium can be rearranged as follow:

$$\frac{S_A(-1-(A_{B_1}+A_P P_{B_1})c)}{oS_O+(1-o)S_U} = \frac{D_A(1+(A_{B_1}+A_P P_{B_1})v)}{oD_O+(1-o)D_U} \tag{33}$$

Result 4 : *The equilibrium first-period budget* B_1^* *and measurement precision* $P(B_1^*)$ *may decrease with its marginal efficiency* P_{B_1} *if:*

- *Measurement errors are biased toward underestimation* ($o < 1/2$) *and the North's aversion for overestimation* (D_O) *is small enough or if its taste for underestimation* (D_U) *is large enough.*
- *Measurement errors are biased toward overestimation* ($o < 1/2$) *and the South's taste for overestimation* (S_O) *is large enough or if its aversion for underestimation* (S_U) *is small enough.*

Proof: *The proof to result 4 follows the same logic as the one to result 3. Here again, what is important in the first period is the degree of asymmetry and the respective values of tastes and aversions. If the risk of underestimation is larger than the risk of overestimation* ($o < 1/2$), ($oS_O - (1-o)S_U$) *is negative, and decreasing in the South's aversion for underestimation, and increasing in its taste for overestimation. This simply means that the South's preferred first-period budget increases with its marginal impact on measurement error, i.e of the efficiency of one extra dollar invested in increasing measurement precision. In contrast,* $oD_O + (1-o)D_U$) *may be positive, if the North's aversion for overestimation is small enough or if its taste for underestimation is large enough:* $D_O < \frac{1-o}{o}D_U$. *It follows in this case that the North's preferred measurement precision (equivalently first-period budget) is decreasing in the marginal efficiency* (P_{B_1}) *on increasing the first-period budget. Indeed, since the North somehow benefits from measurement errors, it prefers keeping the first-period budget small and then reduce the equilibrium measurement precision. Similarly, if the risk of underestimation is smaller than the risk of overestimation* ($o > 1/2$), *North is willing to invest more in the first-period budget, especially if it improves a lot measurement precision. However, the South's may be willing to invest less in more efficient measurement precision if its taste for overestimation is large or its aversion for underestimation is small:* $S_O > \frac{1-o}{o}S_U$.

In this case, if measured avoided deforestation is largely biased toward underestimation, the North's may be willing to invest less in the first-period budget, especially if the money invested in increasing precision is very effective. This way, the North benefit from more underestimation in the second period.

6 Conclusion

How may REDD+ funding be spent, between the readiness phase and the avoided-deforestation phase? Using a simple two-step and two-players model, this paper tackles this issue. First, we consider that the funding of both phases are related: what is spent in the first phase reduces the amount of funds available afterwards. If, for instance, funders of the Readiness phase are different from buyers of the REDD-implementation phase, our results would be different. Second, we consider that a more precise measure of forest inventories is positively related to the willingness-to-accept by the South and the willingness-to-pay by the North for avoided deforestation.

A simple tradeoff is therefore in place: increasing the first-period budget and thus measurement precision increases the willingness to pay and to accept for avoided deforestation in the second period; at the same time, increasing the first-period budget decreases the available budget in the second phase, which decreases the potential to implement avoided deforestation policies. It is shown that the North and South risk aversion, that is to say the aversion to the risk of over-paying and under-receiving, determines in which direction this tradeoff goes. If both agents have relatively low risk aversion, they may prefer to have lower precision set in the first place, in order to invest more in avoided deforestation policies in the second place.

If a symmetric distribution of the errors is assumed, so that the probability to over and under-estimate emission reductions are similar, North and South are equally affected by error measurement. However, there is an uncertainty in the distribution of the error associated to forestry emissions measurement. Depending on the tools and methodologies used to assess emissions reductions, the distribution of the error could be asymmetric and there could be a tendency to over or under-estimate emission reductions, a case discussed in a second version of the model.

If the measurement methodology is proved to over-estimate emissions reduction, North willingness to pay for avoided deforestation will decrease whereas an incentive will be created for the South to supply more avoided deforestation. In this case, it is possible that the amount of avoided deforestation increases with the marginal cost of increasing measurement precision, especially if the South has a relatively large taste for overestimation (equivalently small aversion for under-estimation). Conversely, a tool which tends to under-estimate emissions reduction will have the opposite effect. In the same manner, if improving precision also tend to reduce the asymmetry of the error's distribution, this can have an impact on the North and South willingness to accept: by reducing the risk of overestimation (underestimation), improving precision increases (decreases) the North's preference for higher precision and decreases (increases) the South's preference for such improvement.

These discussions are particularly in line with the debate between Norway and Brazil at the Conference of Parties in Doha (December 2012). The main bone of contention was about the issue of the verification of emission reductions. On the one hand, Norway - and other donor countries - want robust verifications to ensure that the funds they provide result in real emission reductions. On the other hand, Brazil - representing other countries involved in REDD+ - refuses the establishment of an international verification scheme, arguing that even rich polluting countries are not yet subject to such stringent verification. This debate highlights the risk aversion of both North and South. Both want to choose the way of measuring emission reductions and potentially to control its over or underestimation.

However, it is important to note that the amount actually spent in the Readiness phase are far away from what should be spent in the implementation phase. For instance, the grants of the Forest Carbon Partnership Facility (Bosquet et al. (2010)) to support countries in their Readiness Preparation Plans is of USD3.6 million, based on the cost of essential elements of REDD readiness, while the total FCPF budget is of USD155 million for 37 involved countries. More recent estimations (ForestCarbonPartnership (2013)) give more balanced figures: USD260 million for the readiness phase and USD390 million for the compensation phase. This discrepancy between the two budgets can be considered in the light of our model. If the measurement error is symmetric, the small B_1 compared to B_2 may be related to a low marginal cost of improving measurement precision (precision is high without spending much money) and/or low risk aversions of the North and South (North and South do not care much about precision). It can also be the case that countries do not have much potential to implement proper MRV systems (which in the case of our model would be represented by a rapidly increasing marginal cost curve of increasing precision). In this case, indeed, there may be no point to increase the spending on MRV if it results in low quality improvement. If the measurement error is biased toward overestimation, the small readiness budget may be due to a high taste for overestimation by the South, or a low aversion for overestimation by the North. This may be the case if the North's objective for REDD is to combine environmental and development objectives. If measurement errors are biased toward underestimation, this may be due to a low South aversion for underestimation or a North high taste for underestimation.

The point is, most of the time, the distribution of the error is not known. However, in some cases, a trend in over or under estimating emissions reduction can be observed. First, the use of remote sensing recently provided evidence that deforestation rates in the last Forest Resource Assessment

(FRA 2010) were over-estimated. Over the period 2000-2005, data reported by individual countries in Asia and Africa were found to be approximately twice those derived from moderate and high resolution remote sensing imagery (Hansen et al. 2010). As we have no or few remote sensing images before the 90's, over-estimated historical deforestation rates could be used as the baseline to assess avoided deforestation. If the actual deforestation rates are measured by remote sensing (ongoing step), then emissions reduction will be over-estimated. Second, since the South is in charge of choosing the instrument to estimate emissions reductions, the North can make the assumption that the South will systematically try to over-estimate the emissions reduction, which will decrease North's willingness to pay.

Finally, several standards in the voluntary market (notably the Verified Carbon Standard, or VCS, which is the most used standard in the voluntary market) apply the conservativeness principle: from a certain error, the value for emission reduction which is conserved will be the limit inferior of the interval, which tends to underestimate emission reduction and thus to decrease the South avoided deforestation. This application of this principle reduces the risk of overestimation of the avoided deforestation and thus increases North's willingness to pay.

A better knowledge of North and South risk aversion, and of the measurement error distribution in forestry carbon, would help arbitrating between the funding spent in the Readiness phase and in the following phases of REDD+.

Appendix: Proof of result 1

Equation 6 implicitly describes the supply A_S for avoided deforestation from the South. The implicit function theorem gives us the evolution of supply with respect to our key variables:

$$\begin{aligned}
\frac{\partial A_S}{\partial c} &= \frac{S_A}{-\frac{\overline{B_2}}{A^2}S_A + (\frac{\overline{B_2}}{A} - c)S_{AA} + S_V V_{AA} + S_{VV}V_A^2} < 0 &(34)\\
\frac{\partial A_S}{\partial S_A} &= \frac{-(\frac{\overline{B_2}}{A} - c)}{-\frac{\overline{B_2}}{A^2}S_A + (\frac{\overline{B_2}}{A} - c)S_{AA} + S_V V_{AA} + S_{VV}V_A^2} > 0 &(35)\\
\frac{\partial A_S}{\partial S_V} &= \frac{-V_A}{-\frac{\overline{B_2}}{A^2}S_A + (\frac{\overline{B_2}}{A} - c)S_{AA} + S_V V_{AA} + S_{VV}V_A^2} < 0 &(36)\\
\frac{\partial A_S}{\partial V_A} &= \frac{-S_V}{-\frac{\overline{B_2}}{A^2}S_A + (\frac{\overline{B_2}}{A} - c)S_{AA} + S_V V_{AA} + S_{VV}V_A^2} < 0 &(37)\\
& &(38)
\end{aligned}$$

Equation 7 implicitly describes the demand A_D for avoided deforestation from the North. The implicit function theorem gives us the evolution of supply with respect to our key variables:

$$\begin{aligned}
\frac{\partial A_N}{\partial v} &= \frac{-D_A}{-\frac{\overline{B_2}}{A^2}D_A + (v - \frac{\overline{B_2}}{A})D_{AA} + D_V V_{AA} + D_{VV} V_A^2} > 0 && (39)\\
\frac{\partial A_N}{\partial D_A} &= \frac{-(v - \frac{\overline{B_2}}{A})}{-\frac{\overline{B_2}}{A^2}D_A + (v - \frac{\overline{B_2}}{A})D_{AA} + D_V V_{AA} + D_{VV} V_A^2} > 0 && (40)\\
\frac{\partial A_N}{\partial D_V} &= \frac{-V_A}{-\frac{\overline{B_2}}{A^2}D_A + (v - \frac{\overline{B_2}}{A})D_{AA} + D_V V_{AA} + D_{VV} V_A^2} < 0 && (41)\\
\frac{\partial A_N}{\partial V_A} &= \frac{-D_V}{-\frac{\overline{B_2}}{A^2}D_A + (v - \frac{\overline{B_2}}{A})D_{AA} + D_V V_{AA} + D_{VV} V_A^2} < 0 && (42)\\
& && (43)
\end{aligned}$$

Those results depends on the intuition that V_A, V_{AA} are positive and V_{AP} are negative.

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