Seeing the Forest and Saving the Trees:

tropical land-use change and global climate policy

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1 Introduction

Tropical forests are potentially large stores of carbon and can be used to reduce atmospheric concentrations of greenhouse gases. However their incorporation in global climate change policy is fraught with uncertainty because of the difficulties of designing policies to protect and enhance forests in developing countries. This paper tackles the issues of international climate and land-use policy design. It provides an overview for the contribution to policy design of each of the later articles that deal in detail with remote sensing, ecology data needs, ecological modeling, economic modeling of land use and the implications of uncertainty.

Land use, and land-use change play a significant role in the global carbon cycle and offer important potential to mitigate climate change in both industrialized and developing countries. According to the IPCC (2000), from 1989 to 1998 net emissions from land-use change, primarily from the tropics, amounted to 1.6 ± 0.8 Gt C/yr, which is roughly 25 percent of emissions from the fossil fuel and cement sectors (6.3 ± 0.6 Gt C/yr). However, these deforestation emissions were offset by a terrestrial sink of 2.3 ± 1.3 Gt C/yr, resulting in net uptake in the land use, land use change and forestry sector of 0.7 ± 1.0 Gt C/yr.

The IPCC (2000) projects that globally under business-as-usual, deforestation is expected to lead to emissions between 1 and 2 Gt C per year during the first commitment period. More than half of this is likely to occur in tropical forests, which make up 1.8 out of 4.2 billion ha of forests. Some portion of this deforestation and significant emissions could potentially be avoided through conservation projects and changes in the underlying factors that drive deforestation. Estimates suggest that reforestation could produce sequestration of 1.1 – 1.6 Gt per year, with 70 percent in tropical forests. [2] Additional carbon benefits could be realized through forest management activities to enhance existing sinks. Undertaking projects in developing countries to prevent deforestation and degradation, increase reforestation, and improve forest management could produce important greenhouse-gas (GHG) benefits. Environmentally, these benefits are just as valuable as reductions in GHG from energy use. The science suggests that it is important to find a way to incorporate tropical land use in the global climate effort.

Another advantage of including tropical forests in the climate effort is that some developing countries can potentially benefit a lot from mechanisms such as the Clean Development Mechanism. This potentially advances the process of sustainable development in those countries and also gives benefits to the poorest countries that may not benefit much from energy sector activities. This enhances participation of a wider group of countries and in the longer term as they become wealthier or the agreement develops they may become more heavily involved. In the words of Robert Stavins, it helps allow developing countries to 'catch the train but not pay for the tickets'.[3]

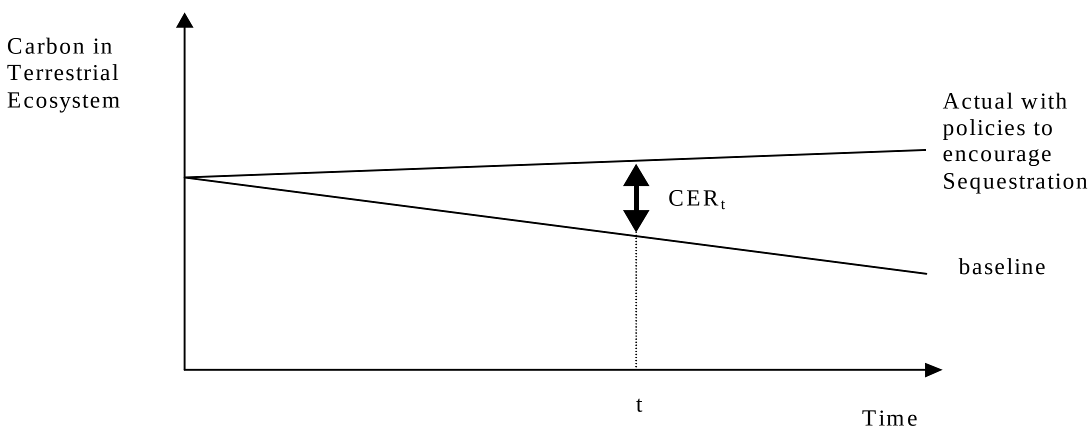
Land use activities in developing countries may produce GHG benefits at a relatively low cost per ton of CO_2 reduced, thereby lowering the overall cost to Annex I

[2] In this paper we use 'reforestation' to cover both reforestation and afforestation.
[3] Boston Globe Op Ed, April, 2001

Parties of compliance with the Kyoto Protocol. They could also provide GHG benefits quite quickly. In particular, avoiding deforestation of forests with high carbon stocks could yield large short-term gains. Land use projects require relatively unsophisticated technology though they may require institutional and political changes to be truly effective in some countries. Investments in conservation and reforestation in the tropics could essentially buy time for the Parties to develop GHG mitigation technologies in other sectors and replace the capital stock in Annex I gradually. Allowing emission reductions to occur as capital is replaced and technology advances is much more efficient than trying to achieve it very quickly.

In order to effectively incorporate tropical land use activities in any climate mitigation effort, we need to be able to identify environmental additionality in every period and provide incentives to land users and regulators in developing countries that reflect those environmental benefits. Figure 1 shows how additional environmental benefit is defined as the difference between actual carbon stored and carbon that would have been stored in the baseline. The key principles that we apply to assess possible approaches are environmental integrity, economic efficiency and simplicity.

Figure 1 Definition of Additional Emission Reduction



Environmental Integrity

Sequestration of carbon in 'sinks' in developing (or Annex B) countries needs to have the same atmospheric effect as the emission reductions that it would replace.[4] The amount of credits given for sink enhancement should depend only on the additional carbon that is removed from the atmosphere (or not put in) and when the carbon is removed.

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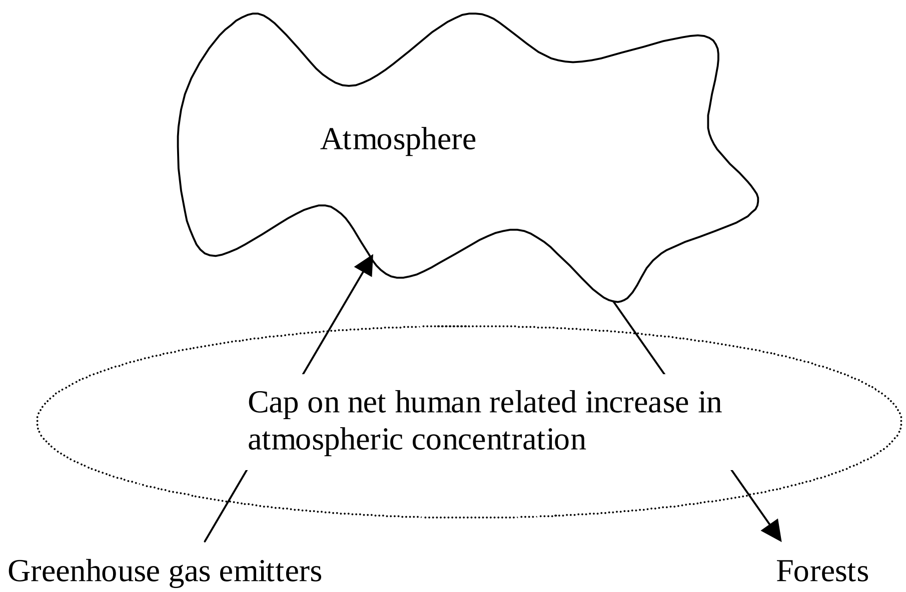
[4] For convenience we use the word 'sink' loosely to mean anywhere that carbon is stored temporarily or permanently outside of the atmosphere in the terrestrial ecosystem. The ocean is also a 'sink'.



Why does it matter when GHGs are removed from the atmosphere given the long lifetime of CO_2? It is important for credibility (will the reductions ever actually occur) and efficiency under fixed targets (reductions today are worth more than reductions tomorrow with a binding cap today). We cannot borrow in an unrestricted way from banks on the basis of a simple promise to repay; nor should we borrow from the environment when our ability to repay is highly uncertain. As long as we base other climate regulation on caps on net emissions during a specified time period (as Kyoto does), net sink emissions should be treated equivalently so that the credits created are fungible.

Efficiency/ Cost-Effectiveness

Efficiency has two key aspects. The first is that incentives should match environmental benefits. Clean Development Mechanism (CDM) credits or equivalent credits under any post-Kyoto system should only be given for activities that produce additional environmental improvements. We essentially want as many actors as possible to internalize the environmental implications of their actions so need to translate these environmental implications into prices. Cheap credits are not more efficient if they don't have equivalent environmental impacts. Subject to the requirement to maintain environmental integrity the rules should allow as much flexibility as possible to facilitate innovation, experimentation and a wide range of different approaches.

Uncertainty makes the matching of benefits to rewards more complex but the simplest rule is that we should endeavor to reward efforts based on their expected impact. As long as people cannot manipulate the rules this will, on average, lead to environmental equivalency with programs that involve certain credit. We discuss the issue of uncertainty in more depth below.

Second, we need to reduce the administrative and transaction costs associated with the program as far as possible. If we can find cheaper ways to certify and monitor projects that maintain environmental quality we should use them. If we can remove bureaucratic hurdles that are unnecessary for environmental integrity we should. Below, we discuss the tradeoff that arises when reducing transaction costs requires some loss of environmental certainty.

Simplicity

The people who actually need to implement climate policies relating to tropical forests are not highly technically trained. The rules need to be as simple as possible to reduce the gap between the intentions of policy makers and actual implementation. A more complex policy may appear to address problems but may actually create more because people cannot understand it and implement something different than that intended.

Second, because these tropical forest policies are part of an international cooperative agreement transparency is critical. People have to be able to observe what each other are doing to build up trust and provide informal mechanisms to assist and pressure people to comply with the intention of the mechanism. If the rules are complex it will be difficult to determine whether a project is really in compliance. The rules need to be designed to minimize the possibility for actual manipulation and the perception of manipulation.

Why might sinks not be incorporated in the CDM despite their potential benefits?

Many Parties have raised significant concerns regarding the use of land use activities for climate change mitigation through the CDM. Some of these concerns also arise in developed countries while others are unique. Considerable work is needed to address these concerns. The benefits from land-use sequestration vary considerably across countries. This creates political difficulties because some countries will receive no direct benefits and hence are not very interested in finding ways to overcome these problems.

In the context of Kyoto, the issue of land use in developing countries has been made more complex by the unusual way that land use has been included for developed, Annex I countries. As a result of poor projections of business-as-usual changes in GHGs as a result of land-use change, countries have found that simply including changes in net sinks in Annex I would provide a significant loosening of targets relative to what some expected when Kyoto was negotiated. This is particularly true for the US targets. To ‘address’ this a number of complex rules have tried to limit the land use that can be counted for compliance to areas where people have deliberately enhanced sinks.[5] The obvious solution, altering the overall commitments to reflect the shift in position, is not

[5] Under Article 3.3, Annex I Parties must account for carbon fluxes from land use change activities (afforestation/reforestation and deforestation) that occur after the base year of 1990. The carbon credits or debits are calculated on the basis of the change in carbon stocks from these activities between 2008 and 2012. These restrictions impose a kind of additionality requirement on the LULUCF credits claimed under Article 3.3; Parties are to claim credits only for activities involving a change in land use after 1990. Under Article 3.4, Annex I Parties have the option to expand eligible LULUCF activities to potentially include activities such as forest management, cropland and grazing land management, and revegetation. This expansion could potentially apply to the first commitment period.

available because it would require renegotiating the targets and timetables, a process many countries are not willing to risk. This issue does not need to arise for developing countries because baselines are not yet set. Much of the discussion of ‘sinks’ in Annex I is not helpful for understanding how to include them in the context of developing countries.

A key issue that is unique to developing countries is the impermanence of GHGs in land use. If Annex I faces a series of contiguous commitment periods that take net sinks into account, any loss of a sink will be automatically accounted for. For developing countries we need to create this compensation mechanism.

A key political issue is that some developing countries are concerned that hosting land-use projects under the CDM will threaten their sovereignty over their long-term land use and sustainable development priorities. The international rules need to allow developing countries to maintain control over their resources. Assistance may be needed to develop domestic regulatory systems that both protect the country’s sovereignty and enhance sustainable development.

Leakage is also a larger issue in developing countries because small projects are possible and not all developing countries will participate. Negative leakage results when land use activities are simply displaced from the project area to another area, and the project benefits are offset as a result. Any land-use project that reduces the supply of a valued resource, such as agricultural land or timber, without reducing the demand will likely be subject to negative leakage. A land-use reforestation project that increases the supply of plantation timber may crowd-out other commercial plantations. Leakage can occur within countries and across borders. Within Annex I, the only leakage of concern is to countries outside of Annex I. If developing countries cannot include land use projects, the leakage from Annex I countries to developing countries will be exacerbated but leakage within and among developing countries would be avoided.

Because non-Annex I countries do not have binding commitments, the additionality of tropical sequestration must be determined by comparing a project's land use activities against a baseline representing business-as-usual projections for land use and associated changes in carbon stocks. Carbon sinks, sources and reservoirs are expected to change with economic development and this change should not be penalized or rewarded. The creation of baselines is discussed in greater depth below.

Finally, developing countries are inherently different because they have different levels of institutional and commercial capability. For example, it is much harder to reliably monitor forest management in a developing country. This might make a simple definition of forest that can be monitored reliably by remote sensing a sensible way to measure land use even though it misses some of the subtlety of different qualities of forest.   Another implication may be that some countries need the ability to carry out very small projects using their limited capability. These will have little global environmental impact but may facilitate learning and provide local benefits as well as strengthening the global cooperative agreement.

International rules vs. domestic rules

In this paper we address the design of international rules only. How developing countries can effectively create programs under those rules is a critical question. Developing countries will face significant challenges implementing policies to take advantage of the international opportunities while also protecting their sovereignty and their own environmental interests to enhance sustainable development. This design problem needs to be the subject of future research. We believe that clarifying the requirements at an international level is a prerequisite for productive research on these domestic policies because they must respond to international institutional structures. We also believe that, despite the importance of domestic sustainable development, domestic policies to promote sustainability can be addressed separately and do not need to affect international policy.

Domestic systems can look quite different from the international system. Measurement approaches and definitions of 'projects' don't have to be the same at an international and domestic level. Individual countries can be left a lot of flexibility in how they implement sinks policy within their country as long as they only receive certified emission reductions (CER – tradable credits created within the Clean Development Mechanism) according to international rules. Developing countries vary enormously in terms of economic conditions, land use, political structure existing regulations and concerns about sovereignty; their approaches to land use and climate policy should also be allowed to vary as long as international environmental integrity is maintained.

For example a government could give landowners very generous baselines to ensure high levels of participation in sink enhancement even through the international baseline for the project that includes this land is not generous. The government would simply be subsidizing the project. A second example could be a domestic tax incentive for forestry. To claim international credit, the government would use the international measurement rules to work out the net additional effect of this policy and claim CDM credits. The value of these credits might offset the cost of the tax credits. Third, a large corporation might implement eco-friendly policies in the rain forest in an attempt to reduce deforestation over a wide area. These policies could include providing seed and technologies for more intensive agriculture, programs to help farmers gain legal title and hence increase tenure security, replanting areas where roads are cut for oil access and protection of particularly sensitive areas. The government of the country could approve the project and allow the company together with local people to claim CDM credits assessed under the international measurement rules.

Structure of Paper

This paper considers only part of the issue of land use and climate change. We only consider forests and only carbon dioxide. Study of other land uses and gases such as nitrous oxide and methane are important but secondary in overall climate impact. We take a long run view rather than focus on the specific short run issues related to the Kyoto negotiations but we do attempt to offer some pragmatic short run options as well. Our focus is almost exclusively on developing country issues, pointing out the relationship to similar issues in Annex I in footnotes where it is relevant.

This paper begins by addressing two issues that are technically solvable in a simple way, permanence and temporal risk. We also discuss the effects of this solution on the concerns about sovereignty. We briefly address the concern expressed about the effects of carbon fertilization and show that this should not be a concern in the CDM. We then consider the more complex problems of monitoring land use, measuring carbon and predicting baselines. We have no perfect solutions to these problems but suggest some ways forward. We discuss ways to think about the tradeoff between reducing uncertainty and the costs of living with uncertainty. We also consider the benefits of larger projects and ultimately national level 'projects' to effectively incorporate tropical sinks. The following section takes a shorter run perspective and proposes alternative ways to deal with the problems that may threaten the integrity of sinks in the short run and lead to their exclusion from international climate mitigation efforts. We consider the sources of risk and different short run approaches to minimize and limit risk. These alternatives aim as much as possible to provide short run environmental integrity and efficiency while also facilitating a transition toward the optimal system in the long run.

2 Solvable Problems

2.1 Permanence and risk[6]

The GHG benefits from land use change can be lost or reversed over time, unlike the GHG benefits from projects in other sectors.[7] This difference requires a different set of rules for CERs from land-use activities and CERs from other sectors.

When choosing among possible rules, we need to consider how they satisfy various desirable criteria. First, the rule should ensure that land-use credits have the same environmental impact as any other CER, assigned amount unit (AAU – Annex I emission units), or emission reduction unit (ERU – created in Annex I Joint Implementation). These different units are all fungible under the cap. The crediting systems should be compared in terms of how they reflect atmospheric GHG levels at every point in time. This principle of environmental integrity means that any risk from reversibility should be borne by the buyer and/or seller (as determined in the project contract), not by the international community. Second, subject to achieving environmental integrity, the rule should maintain maximum flexibility in how the credits are created and hence achieve maximum economic efficiency in climate mitigation. If two rules achieve the same ends both environmentally and economically and one is simpler than the other, the simpler rule would be preferred.

An effective permanence rule should be designed to reflect the following equivalences:

- One ton of permanent sequestration/storage from land-use activities is directly equivalent to one ton of avoided fossil fuel emissions (e.g., from a wind farm).

[6] This section draws heavily on Kerr and Leining (2000).

[7] Some people argue that not emitting fossil fuels is simply delaying emissions on the assumption that all fossil fuel stocks will eventually be used. However, even if this is true and the long run level of exploration and exploitation did not fall, the reversal of the reduction would occur extremely slowly through a marginally lower long run price path. In contrast sink emissions can be rapidly reversed.

- The release of one ton of emissions from land-use activities (e.g., burning forest) is directly equivalent to one ton of emissions from fossil fuel.

Illustration: Wind Farm Project vs. Avoided Deforestation Project

As an illustration, consider a land-use project that permanently avoids deforestation of one hectare and hence reduces atmospheric CO_2 by 100 tons. The Annex I Party that acquires those credits can then emit 100 tons of CO_2 from fossil fuel use. Over time, the project continues to store the carbon, thereby maintaining a lower CO_2 concentration in the atmosphere. In contrast, the Annex I emissions from fossil fuel use are gradually removed from the atmosphere through the global carbon cycle, so the project yields a net benefit as long as the carbon storage continues.

However, note that this is identical to the following non-land-use situation. A wind farm project in a developing country avoids 100 tons of CO_2 emissions. The Annex I Party that acquires those credits can then emit 100 tons of CO2 emissions from fossil fuel use. As time passes, the 100 tons of avoided emissions from the wind farm project are not returned to the atmosphere, so the project continues to maintain a lower atmospheric CO_2 concentration. As in the previous case, the 100 tons of Annex I fossil fuel emissions gradually are removed from the atmosphere, so the wind farm yields a net benefit.

The implication is that if the land-use project yields permanent benefits, it should be treated identically to the wind farm project.

Some people have argued that the decay of emissions should mean that the amount of land-use carbon needed to offset a one-time emission would fall over time. If this were true, it would also be true of all other emission reductions. Therefore, all credits would convey not only the immediate right to emit an equivalent amount but also the right to continue to emit as the initial emissions were removed from the atmosphere. If we do not treat wind-farm credits this way, then we should not treat land-use credits this way either. The removal of atmospheric emissions through the global carbon cycle should be dealt with through appropriate choice of targets for different commitment periods aimed at achieving certain atmospheric concentrations at each point in time.

In each year of a land-use project, the project's level of carbon stocks changes relative to the baseline. Under an optimal system, if the difference in carbon stocks between the project and baseline increased, the CDM would reward the project with more CERs. If it decreased, CERs would be retired. If the forest and therefore the CERs were temporary, a CER still would have value in the same way that money temporarily borrowed from a bank has value. Annex I countries are willing to pay to delay at least part of their need to reduce emissions. Under a system where CERs are retired when project benefits are lost or reversed, environmental integrity can be maintained without requiring that CERs be permanent or that forest be protected forever.

Our first recommendation is for the project's credited GHG benefits to be verified and adjusted (if necessary) at regular intervals.[8] These intervals could be equal to or

[8] This is equivalent to the 'stock-change' approach discussed in the IPCC report (2000). Very similar conclusions have been reached separately by Don Goldberg at the Center for International Environmental Law and Ken Chomitz at the World Bank.

shorter than the period over which caps are defined and emissions are assessed or the 'commitment period'. The contract between the buyer and seller could opt for more regular monitoring and hence evaluation and adjustment.[9] A net increase in carbon stocks relative to the baseline during each crediting period would be awarded credits (certified emission reductions (CERs) under Kyoto). These CERs would be identified as specific to the project. These CERs could be maintained in a registry or used by the buyer Party to achieve compliance. During each crediting period, any net loss of previously credited carbon stocks would require payback of the CERs by the buyer Party.[10] If project monitoring stopped for any reason, the buyer Party must pay all net accrued CERs back. As long as no carbon release occurred and monitoring continued, the CERs would remain valid. Allowing indefinite projects would require that long-term baselines or at least a clear process for extending a baseline be defined in advance in case the project were to continue indefinitely. This would be needed in any case if projects were to be renewed.

The second recommendation is that the obligation to repay expired CERs should be passed on with ownership of the project-specific CERs if the CERs are traded internationally. If a CER is surrendered for compliance, the Party that surrendered it should ultimately be responsible for repayment when the CER expires. In the case where multiple Parties ultimately hold CERs from a project and not all CERs need to be repaid, the Parties should bear proportionate liability to repay the CERs.

Note that here we support buyer liability. This contrasts with our earlier arguments in the context of Annex I trading.[11] The key difference here is that the seller Party is not in Annex I and so does not have binding commitments under the Protocol and is less able to be held liable by the international community. Because seller liability would be extremely weak in this case, the costs of buyer liability would be outweighed by the benefits. To ensure environmental integrity, the ultimate liability at the international level for payback of land-use CERs must be held by Annex I Parties, who will be legally bound by their Protocol commitments and will face penalties for noncompliance. For efficiency, risk should be borne by those who can control it (i.e. those involved in the project not the international community) and beyond that, those who have low risk aversion/high ability to absorb shocks (maybe investors rather than developing country partners).[12] However, Annex I Parties could still choose how to distribute the burden of that liability domestically through specific regulations between the Annex I Parties and their legal entities or the specific contracts between buyer and seller. If the buyer is concerned about moral hazard on the part of the seller if the seller is not responsible they can write a contract to make the seller responsible under domestic

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[9] The increased monitoring burden may be economically justified for large projects.

[10] In the case where a buyer Party had surrendered the CERs specific tot the project for compliance, payback would consist of subtracting the equivalent number of credits (CERs or AAUs) from that Party's registry. In the case where the CERs were still in the buyer Party's registry, payback would consist of the subtraction of those CERs from the registry.

[11] See Kerr, Suzi, (2000) "Additional Compliance Issues Arising from Trading" in Suzi Kerr ed. *Global Emissions Trading: Key Issues for Industrialized Countries* (Edward Elgar Publishing Inc. Glos. United Kingdom)

[12] These issues are discussed in Kerr 1998 in the context of risk to the international community from non-compliance. In that paper and here we propose putting that risk onto the project organisers.

law even though the buyer is internationally liable. Under the terms of the contract, the seller might agree to compensate the buyer if the credits are lost.

The proportionate liability for repaying expired CERs would not be necessary if all CERs from a project were ultimately surrendered by one actor or if all of the carbon were released at the end of the project. With the secondary market and with projects of significant size, the involvement of multiple Parties and partial losses of CERs will likely occur.

We recommend that the permanence rule for land-use CERs should have the following characteristics:

- As sequestration/avoided release occurs, CERs are generated and can be sold. The buyer Party adds the CERs to its adjusted assigned amount.
- CERs should be verified at least once per commitment period with mandatory payback of CERs by the CER holder during the commitment period when credited carbon stocks are lost or monitoring ceases, whichever comes first.
- Liability for payback of CERs should be carried with ownership of the specific CER when it is traded and shared proportionately among the CER holders when partial payback is required.

2.2 Sovereignty over land use

The primary concern with sovereignty is that if a land-use project is permanent, the country cedes permanent control over the use of that land. The issue is identical to concerns about other forms of foreign ownership of resources.[13] If projects are not required to be permanent, a country could agree to conserve an area for 5 years but every five years would have the option of ending the contract and developing the area. There will be no penalty for reversing the sequestration – it is not a breach of contract. The country can gain the benefits of investment in land use projects while maintaining control of their resources. If they want to engage in a long-term contract they still can but they are not required to. Thus the solution to the permanence problem largely addresses the sovereignty problem as well.

2.3 CO2 fertilization and other changes in carbon stocks related to climate change itself

Emissions of carbon and nitrous oxides can actually lead to higher levels of land use sequestration – i.e. the pollution itself acts as a fertilizer and creates sequestration. Some parties have expressed concern that Annex I parties might be rewarded for their own emissions if they are able to claim more land-use credits as a result of this sequestration. This is an issue in Annex I because the fertilization does not alter the commitment levels against which compliance is assessed and was not considered when the commitment levels were initially chosen. This should not be a concern in developing countries however. Land-use credits in developing countries are given only for the difference between actual sequestration and baseline sequestration. Where land use does not change,

[13] Other aspects of the sovereignty issue may relate to foreign investment per se or to issues of bargaining and contracting ability.

fertilisation affects both actual and baseline equally and no credits are created. Where land use does change those who deforest less (reforest more) than baseline should and will be rewarded more because the environmental effect of avoiding deforestation is greater than it would have been with no fertilisation. Efficiency requires that credits reflect the true additional environmental impact, which includes the effect of fertilisation. Equity is not an issue here because those who benefit from the credits are developing countries that are not historically responsible for the bulk of emissions.

3 Harder to solve problems: Current Knowledge and Limitations

To maintain environmental integrity in a CDM project, we need to be able to measure the net reduction of carbon in the atmosphere relative to what would happen without the CDM project. This requires reliably measuring actual carbon in terrestrial stocks and comparing it to counterfactual carbon levels. Three components are required. First, the measurements of the areas in each different land use, second, measurements of carbon stock in each land use and third, predictions of land use in the counterfactual. The same measurements of carbon can be used to assess total actual and total counterfactual carbon.

$$\text{Environmental Benefit} = \sum_i (\text{actual} - \text{counterfactual land use}) \times \text{carbon in land use } i$$

3.1 Monitoring actual land cover

The first question here is what land covers we want to monitor and how to define them. The most accurate definition would include all different types of vegetation and uses as well as the way the vegetation is managed. This would allow accurate incentives to encourage all forms of sequestration as well as protecting environmental integrity. This is infeasible, especially in developing countries. We need to trade off potential bias in aggregate measures of carbon stock, incentives to preserve and sequester carbon in the most important lowest cost ways, and our ability to monitor.

The answers to these definitional questions for the CDM will be different than those for Annex I because of differences in capability and because people are trying to use the definition of forest, reforest etc. in Annex I to substitute for what they see as overgenerous Annex I baselines for land use. In CDM we have the luxury of considering the appropriate definition purely on the basis of feasibility and efficient full carbon accounting.

For carbon sequestration the key difference is between forest and non-forest. There are also important differences among forests. Young regenerating forests contain much less carbon than mature forests; forests degraded by pests or previously logged contain much less carbon than more pristine forests. Forests also vary greatly by their ecological characteristics but this can be measured in different ways – see section on measuring carbon.

Current monitoring can be done in two basic ways: ground based measurement and remote sensing. Remote sensing can relatively easily cover large areas and can be externally verified. It is good for large projects or countries with large numbers of projects. Remote sensing can currently relatively easily distinguish mature forests from non-forest areas (with the notable exception of dry-forest). The quality of interpretation is still very important, especially in areas where forest is highly fragmented. New satellite data and techniques will allow much finer classification of land cover but these are currently too expensive, are only available in a few areas and require an extremely high level of skill to interpret.

If remote sensing is chosen as the approach, several questions need to be answered.[14] What level of canopy cover is classified as forest? Should this be the same across continents? Should we separately use remote sensing to establish the age of regenerating forests? What is appropriate level of resolution? Higher resolution is more accurate but also more expensive. Whatever resolution is chosen, it should be the same for the counterfactual baseline prediction and the actual forest to ensure consistency. The resolution could vary across projects and time as we learn more and costs fall.

Practical issues are what images are actually available from what satellites? Are cloud-free images available for the regions we are interested in? Will satellites continue to provide this data or provide higher quality data? One key issue with remote sensing is that reforestation can take many years to be identified. If remote sensing were used, reforestation projects would not receive any credit until the trees were tall enough to be recognized, whereupon they would receive full credit for forest unless the history of land use is used to identify their age.

Ground-based reporting is the alternative. This is more intensive per hectare but may be more accurate for small areas of land. A domestic program that rewards foresters/farmers directly may need to do this. If a country is doing this domestically it might also make sense to use the same measurement for international reporting. If the domestic system is sound and reliable at the level of each farm, the aggregate measurements based on this will be sound for international purposes. These could be confirmed with remote sensing if they were challenged, accepting that there will be a certain amount of measurement differences between the two approaches.

A short-term approach would be to define forest as land cover with a certain canopy density that can be easily distinguished by remote sensing. We could use the land use history to distinguish age where possible. This approach will not pick up degradation so the carbon number chosen might need to be conservative and assume an average level of degradation. Small projects could be allowed to use ground-based reporting but ensuring that their estimates are conservative relative to what would have shown in remote sensing. In the longer run, a move to remote sensing should probably be encouraged because of its low costs for large areas and because it can be replicated by outsiders if measurements are challenged.

Monitoring should probably be required every five years, particularly if the CERs are seen as temporary as discussed above. Project managers could choose to monitor more frequently if they wanted to collect increased CERs earlier. Periodic monitoring could lead to small amounts of strategic behavior, e.g.: clearing immediately after monitoring, but this would be limited.

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[14] Arturo Sanchez-Azofeifa, Benoit Rivard and Armond Joyce are working on a paper exploring the use of remote sensing for CDM. They are all associated with the NSF project on land use and carbon sequestration in Costa Rica.

3.2 Estimation of carbon and nitrous oxides associated with different land cover and ecological conditions

We need measures of carbon in biomass and soils for a range of ecological conditions and the land covers we choose to monitor (e.g.: forest / non-forest).[15] In Annex I countries, a combination of remote sensing, on-the-ground measurement and modelling of carbon dynamics is used to produce estimates of carbon fluxes from different land uses. Reasonably good carbon models exist in many Annex I countries and have been calibrated to a range of ecological conditions using actual data (e.g., CENTURY). However, a large amount of uncertainty still exists particularly when it comes to fluxes in biomass and soil carbon on land where management practices change without an overall change in land use.

Uncertainty regarding biomass and soil carbon fluxes is even greater in developing countries where ecological knowledge about carbon in natural forests is quite limited. More is known about carbon stocks in commercial forestry because it is directly related to the volume of commercially valuable timber, but even here little is known about soil carbon, below-ground biomass, under-story, and litter. In tropical countries, conditions are extremely heterogeneous so levels of carbon can vary dramatically. Existing estimates of carbon per hectare vary considerably. Relatively little systematic research has been done on carbon stocks across a range of ecological conditions. Within our NSF project we are currently sampling over 100 sites in Costa Rica in 6 life zones to provide a consistent dataset that, together with GIS databases of physical conditions, we will use to calibrate CENTURY to Costa Rican conditions.

At the project level, a developer can relatively easily sample the tree component of carbon stock within each project but cannot easily sample other components such as roots, leaf litter, soil and small vegetation that may vary significantly between forest types and can change significantly as forest is cleared. They may however have difficulty assessing the carbon stock in this land if it were cleared particularly if the project aims to conserve the forest.

[15] Boone Kauffman, Shuguang Liu and Flint Hughes are working on this issue in the context of Costa Rica which has ecological conditions that cover around 75% of the tropics. They are all funded through the NSF project on land use and carbon sequestration in Costa Rica.

Our long run goal is to produce a ‘carbon map’ of the world so that project developers do not need to measure on-site carbon as part of a project. Their reward would be based purely on their location (climate and physical characteristics of the

Simple Illustration

Step 1: Monitor actual land cover in project area.

	Forest (million ha.)	Pasture (million ha.)
Actual use in 2002	2	3

Step 2: Translate the actual land use into levels of carbon in the terrestrial ecosystem for different land uses and ecological conditions.

	Forest	Pasture
Carbon per hectare	100 tons	5 tons

These two combine to give the level of actual carbon in sinks each year.

	Forest	Pasture
Actual use in 2002	2 (million ha.)	3 (million ha.)
Carbon per hectare	100 tons	5 tons
Total Carbon	200 million ton.	15 million ton.

Project level of carbon in 2002 = 215 million tons

Step 3 Compare actual and counterfactual carbon levels

	Forest (million ha.)	Pasture (million ha.)	Total
Prediction for 2002 with no climate policy	1.9	3.1	5
Actual use in 2002	2	3	5
	(Millions of tons)	(Millions of tons)	
Prediction of carbon level in 2002	190	15.5	205.5
Actual Carbon in 2002	200	15	215
CER Credits en 2002			**9.5 million**

The difference between the actual level and the prediction is the estimate of the international environmental gain. The developing country could be rewarded for this environmental benefit with CERs. They could then sell those CERs to developed countries who can increase their emissions leaving the net environmental impact as zero. If each ton of credits led to an annual reward of $5, in the example, the country would receive $47.5 millions in 2002.

location) and the mapped predictions of carbon in different land covers in that location. This would simplify the process and make claims for CERs easily verifiable. More data should continuously be collected to improve the carbon map to make the system more and more accurate and allow us to make finer distinctions among land uses.

3.3 Counterfactual baseline prediction

A baseline attempts to capture what would have happened if there had been no effort to protect or enhance sinks. We do not know what land use would actually have been chosen and will never observe it; we are able only to predict it.

Predictions can be based on a combination of extrapolation of past deforestation or reforestation trends and known socio-economic factors such as roads, population density, level of development (e.g.: GDP per capita or urbanisation), value of agricultural output, value of timber and agricultural productivity of land. Accurate prediction is extremely difficult and is even more difficult for small areas than large ones. In large areas, idiosyncrasy tends to average out. The further into the future the prediction needs to go, the less accurate it is likely to be.

Deforestation Baselines

Figure 2 Baseline Prediction of Carbon Level in Costa Rica with uncertainty

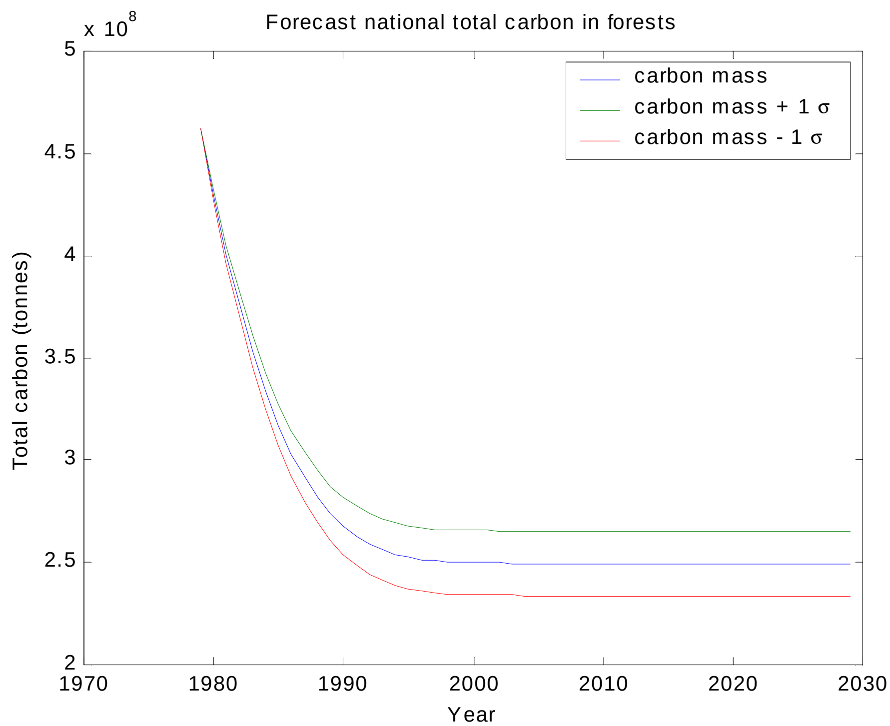


Figure 2 shows a baseline prediction of the carbon level in forest for Costa Rica over 50 years from 1980 that uses all the factors discussed above (from Kerr et al 2001c). The middle line is the best guess while the upper and lower lines indicate a likely range. The actual forest cover in both 1986 and 1997 lies in the expected range so changes in carbon levels are probably similarly accurate.

This baseline forecast was constructed using data that covers the whole of Costa Rica. Details of the process for constructing the baseline are given in Appendix 1. It assumes no reforestation. Baseline projections are made for each of 436 districts and these are then combined in a national forecast. Each of the individual district-level projections will be much more uncertain than the national pattern. The same approach could be applied to any area where similar data could be found.

The level of carbon loss flattens out after the early 1990s for three basic reasons in this model. The first is that within Costa Rica, the highest quality land was all cleared by the mid 1980s so clearing additional land for agriculture was unattractive. Remaining land tends to be high in the mountains, steeply sloped or on poor soils. Second, Costa Rica is beginning to go through the transition from an agricultural economy to an industrialised country and increasingly people are getting work in sectors such as computer chip manufacture rather than clearing more land to farm. Third, the Costa Rica government (and some private citizens) have been very active in protecting forests over the last twenty years. Much of the remaining forest is in national parks or other reserves.

Reforestation Baselines

People often implicitly claim that it is easier to establish a baseline for a reforestation project than a deforestation project. This is unlikely to be true. Over very short periods of time it may be credible to suggest that many areas of land would not otherwise be reforested but over the long periods that we need to consider for climate change reforestation is hard to predict. As an example consider the history of forest cover in the United States. Early in the 1900s the East Coast of the United States was almost completely deforested and used for farming. Today it is heavily forested and there is almost no agricultural land. This did not happen because of deliberate policies but as a natural result of economic development. The development of railways and other forms of transportation made it possible to ship food cheaply to the East Coast from the Mid-West and East Coast farmers who had poor soils could not compete.

For a developing country example, in Costa Rica in the last decade reforestation through land abandonment and natural regeneration has begun to be significant particularly in areas of lower agricultural productivity. In the tropics as a whole, even in the absence of climate policy, as natural sources of timber are depleted, plantation forestry will become more profitable and larger areas will be put into plantations. Plantation forestry also becomes more profitable as internal infrastructure improves so that logs can be transported cheaply.

These natural processes that will be likely to drive considerable baseline reforestation are no easier to predict than the processes that drive deforestation. In some ways they are harder because we have less experience with reforestation in developing countries. We have tried to analyse reforestation in Costa Rica (using similar data to our deforestation study) but have so far had little success in explaining the pattern.

In the short run reforestation may affect relatively small areas, but if the experience of the US (or similar experiences in New Zealand) are repeated in the developing world, large areas of land and hence large amounts of carbon may be affected.

Updating of Baselines

In general, predictions of land use should be done for long time periods in advance. This provides investor certainty and avoids the possibility of strategic behaviour to try to influence future baselines. That said, predictions far into the future are inherently very uncertain. Baselines could be updated with care. More accurate baselines would improve environmental integrity over time and actually increase investor certainty (in contrast to IPCC claims). Updating the baseline takes out uncontrollable changes in underlying conditions and ensures that the rewards for doing the project reflect more closely the real effects of the developer's activities. They will not be held responsible for things that were beyond their control. Baselines might be increased or decreased depending on the shocks that actually occur. Updating removes some of the risk involved in what is essentially a property right allocation. The stakes are very high because this property is potentially very valuable. Establishing an updating process may make all parties happier about creating these property rights in the first place.

A general rule should be that factors that the people affected by the baseline can possibly affect should not be taken into account in updating. For example if the baseline belongs to a country as a whole, a new road or a change in policy that encourages agricultural expansion should not lead to a change in the baseline level of forecast deforestation even if they do increase deforestation. In particular, changes in the observed level of deforestation relative to baseline should not lead to changes in the baseline.

In contrast, factors that are outside the control of actors could be used to update the baseline. For example Central American countries are strongly affected by the international prices of coffee and beef but have little control over these. A rise in the price of beef will likely increase deforestation and could lead to an increase in baseline deforestation. Global or even national economic development could be argued to be a factor that governments do not directly control as part of climate policy. Thus baselines could be tied to GDP and updated as GDP changes.[16] (See for example studies of the relationship between deforestation and population - Cropper and Griffiths 1994 and with GDP - Kerr et al. 2001). Increased biomass as a result of CO_2 fertilization should also lead to an updating of baseline carbon stocks.

Alternative Approaches to baselines for small areas?

Although in small areas specific knowledge about local institutions and players as well as detailed information about local economic conditions might make the local prediction more accurate, the problem of leakage makes unbiased baseline prediction difficult. It is very difficult to ensure that the sum of baselines for small areas will be consistent with an unbiased national prediction. One approach to ensuring consistency is discussed below in the discussion of small vs. large projects.

Direct-human-induced change vs. natural change

A well-defined baseline separates natural changes from human-induced change. The only activities that are credited above the baseline are human-induced changes that occur

[16] This is similar to the concept of 'growth baselines'.

because of climate-related policies. In the CDM we do not need to define human-induced changes on a project-by-project basis.[17]

Errors in baseline forecasts

From an international perspective, environmental integrity roughly requires that the baselines be right for the average plot of land covered by a project and that no leakage occurs outside the project. It does not have to be correct for every hectare. What is needed here more than anything is methods that do not lead to serious bias and that are perceived to be fair. (and that produce results comparable to results in other sectors if the emission reductions are supposed to be fungible across sectors) Because no prediction method will be correct always, the process may be as important as the outcome.

Table 1 shows several examples that illustrate the environmental and efficiency effects of errors in baselines. The first line shows the correct baseline where no CERs are received if no carbon is sequestered and every extra unit of sequestration is rewarded with one CER.

In contrast the second line shows a case where the baseline predicts more deforestation (less reforestation) than really would have occurred. Without doing anything 20 CERs can be claimed. This is an environmental loss because it does not relate to any sequestration but does allow more fossil fuel emissions. If a project is done however, any additional sequestration is rewarded with the correct number of additional CERs so project developers have the correct incentives to create projects.

In the third case the baseline predicted very high levels of forest (little deforestation or lots of reforestation). Assuming that developing countries would not be forced to take losses of CERs when they achieve less than their baseline, if they do nothing the country will simply not create a project or claim CERs. There is no environmental impact from this. However there is an efficiency loss because if a project developer manages to sequester 10 extra units of carbon they will still not be rewarded because the actual forest level will still be below the baseline level. Projects that could create real sequestration will not be done.

Table 1: Effects of incorrect baselines

	True baseline	Estimated baseline	CERs if do nothing = environmental loss	CERs if do small project that sequesters 10	True additional sequestration	Additional CERs awarded
1	100	100	0	10	10	10
2	100	80	20	30	10	10
3	100	110	0	0	10	0

[17] This is an issue in Annex I because of unhappiness in how the commitments were set for sinks. Some negotiators intended the commitments to require a certain level of real emission reduction from BAU. Because they underestimated the net sinks in some Anenx I countries (particularly the US) the commitments are more generous than intended. The discussions about limiting sink credits to ones that are 'directly human induced' are essentially attempts to correct this 'mistake'.

			will not make claim because would be negative	no point in doing project		
				Large project that sequesters 50		
4	100	110	0	40 project may be worthwhile even with less than total credit	50	40

If the concern is primarily with inducing developing countries to use their land in appropriate ways it would be better to err on the side of making baseline too generous and compensating for any environmental loss by reducing total AAUs through more stringent Annex I targets.

3.4 Leakage

Leakage is defined in the *IPCC Special Report* as "the unanticipated decrease or increase of GHG benefits outside of the project's accounting boundary (the boundary defined for the purposes of estimating the project's net GHG impact) as a result of project activities." In the context of land-use projects under the CDM, leakage could occur if the land uses being altered by the project are merely displaced to other areas instead of being replaced altogether. Failing to account for negative leakage (i.e., increases in emissions outside of the project area as a result of activities undertaken by the project) would result in the overestimation of project benefits. Consider the example of a project to conserve primary forest that would otherwise be cleared to create agricultural land. If the project does not address the unmet demand for agricultural land, then the population that needs the land will simply clear forests in other areas to meet their needs and the project benefits will be offset. Because leakage can occur at the regional, national, and international levels, it can be very difficult to predict or measure.

The IPCC proposes a range of approaches to reduce or account for leakage. The most obvious, and least restrictive of project design, is to increase the project boundaries so that side effects occur within the boundary. This is discussed further below in the discussion of the merits of larger projects. As an alternative, without increasing the size of the project, the area monitored could be increased. This would capture leakage into the area surrounding the project but clearly increases the risk to the project developer because they are responsible for activities in areas outside their control. This option is similar to the option of multiple projects within national/regional baseline discussed below.

The reduction of leakage potential can be achieved through project design. For example, a developer can evaluate the likely impacts of the project on the existing supply of and demand for goods and services, and seek to change this supply/demand or meet this supply/demand through alternative actions (e.g.: agricultural intensification or alternative employment nearby). Alternatively developers could require that funds freed up from harmful activity not be invested elsewhere instead (e.g.; logging company investments).

The developer can attempt to predict where leakage is likely to occur, monitor leakage impacts over time (possibly by monitoring key indicators of demand for land such as demand for fuel, timber or agricultural products), and adjust the estimate of project benefits accordingly. Another solution to this problem is the development of leakage coefficients by project type and region that can be used to adjust the estimate of project benefits in a more standardized way to account for leakage (IPCC, 2000).

Alternatively, the Parties could require that baselines be set conservatively to account for leakage. Parties could restrict project eligibility to those activities that address the demand for land related resources, such as agricultural intensification projects that enable afforestation/reforestation or forest conservation as a co-benefit. Such a project would have less leakage than a project that simply restricts the supply of agricultural land without addressing demand.

4 Long term solutions

These problems are complex and we will never find perfect solutions. We need to search for simple, standardized, externally replicable methodologies that will lead to unbiased outcomes even if they do not reward all actions efficiently and accurately. In the short run, land cover could be estimated using low resolution remote sensing with simple classifications. Rather than measure carbon directly on each plot where C sequestration is being rewarded, a very costly process, carbon numbers would ideally be based on the climatic and ecological conditions in the project area and the land use history all of which can be known from GIS databases. Baselines could also be based on a series of historical GIS and other databases including some socioeconomic information. Then baseline forecasts and carbon estimates could be made from anywhere in the world and crosschecked by other analysts without the need to actually visit the regions in question.

Large projects, ultimately at national level, are more likely to lead to unbiased estimates of land cover, carbon and baselines and hence are more likely to support environmental integrity. In the long run, these problems will be reduced only by additional research and by learning by doing and evaluation of our efforts at all stages.

If we use these simpler measures of land cover, carbon and baselines what are the costs of doing so? What level of accuracy is necessary and desirable?

4.1 Uncertainty and climate policy efficiency: Costs and benefits from more accurate measurement and prediction[18]

If simplified forest area and carbon stock estimates were compared to very accurate estimates we would observe forecast/measurement errors. The land use baseline predictions will also be incorrect relative to true counterfactuals although these cannot be observed. By definition we cannot observe what would have happened without the reward if the land managers did in fact receive the reward. Thus, when land managers are rewarded for carbon sequestration, their rewards will be incorrect by an unobservable amount. These errors in baseline predictions and carbon measurement have real social

[18] Much of this material draws on Pfaff et al (2000) and Kerr et al (2000).

costs even when we cannot observe them. What is the nature of these costs and how do they compare to the benefits from low costs and easy auditing of rewards available by using a model such as the one we create for Costa Rica?

If rewards are based on incorrect measures and forecasts, these errors create three costs. First, the inaccurate rewards will lead to aggregate environmental outcomes that differ from those desired. Overstated measurements of sequestration would lead to real increases in emissions when the sequestration credits are sold to a developed country. Aggregate net emissions would rise. What matters here are errors in aggregate additional sequestration relative to baseline for the whole country (or even globe)? The cost will depend on how far the aggregate actual additional sequestration under the inaccurate rewards differs from the aggregate credits generated for sale. The global cost of each excess credit could be measured as marginal environmental damage minus avoided marginal abatement cost. Producing too many credits is likely to be perceived as a greater cost than producing too few, though if global targets were chosen efficiently both would be concerns.

Second, land managers would have faced inappropriate and hence inefficient incentives to sequester carbon. The cost of the sequestration that did in fact occur would be higher than necessary. Some will sequester too much and others too little. Our model can estimate these costs in dollar terms. Third, land managers that sequester equal amounts of carbon will be rewarded differently creating equity concerns. This could affect the acceptability of the system. Unacceptability is not measurable but the marginal costs will increase with the size of errors whether positive or negative. Both of these costs depend on errors in plot level rewards. Efficiency costs simply depend on errors relative to reality. Equity costs depend on how forecasts vary across plots that are really identical. Even if the forecasts correctly credit aggregate sequestration, inefficiency and inequity could be problems.

Costs of reducing uncertainty

These gains from reduced uncertainty need to be contrasted with the qualitative values of greater simplicity, which translates to lower costs of participation in trading and lower potential corruption through greater transparency and verifiability in the application of crediting rules.

A first obvious cost of increasing accuracy is an increase in direct costs of the analyses (in pilot sequestration projects, it has been observed that generating acceptable C measures can be a significant cost). In developing countries with low capacity, the scarce skills needed to do high quality remote sensing, baseline development or carbon measurement may be unavailable or my be better employed elsewhere. Second, both direct costs and uncertainty about the outcome of the certification process will discourage potentially valuable projects. Fewer C trades will take place, so some gains from trade will be lost.

The third cost of using more data and more complex computations is an increased scope for manipulation. Complex rules may become non-transparent black boxes. This makes decisions ambiguous and difficult to challenge. In contrast to the pilot phase of activities implemented jointly the CDM would involve real financial gain. Project developers and managers would have a financial incentive to bias their estimates in their own favor and these biases may be difficult to identify or challenge by an outsider. If the analysis uses specific local information it is impossible for outsiders to replicate and check without a large cost. As more complex rules involve more costly data collection, this may reduce monitoring efforts by third parties to check claims by CER producers. Ironically, then, increased effort and complexity to reduce some errors may in fact lead to others.

Clearly, if it costs nothing to increase certainty we should. However, attempts to reduce uncertainty could actually increase it and could also disproportionately reduce the possible benefits from sinks.

4.2 Costs and benefits of small and large projects.

To date, most land-use projects have been relatively small compared with the nations that submit them. In the longer run, however, to realise the full potential of sinks we probably need to move toward more comprehensive projects that cover large areas. The scale of the climate problem is large and a very large number of small projects is probably unwieldy. Each project has a high fixed cost of organising, monitoring etc. Although larger projects have large organisation costs there are almost certainly economies of scale.

National or regional projects can take a wide range of forms that can look quite different from most of the current projects. Having a very wide area included allows rewards for policy efforts that have quite diffuse effects but ones that are important when summed over large areas. National projects can include familiar projects such as those to create or protect national parks, but can also include policies that may not be recognised as climate policies but that may have significant effects. Examples include reducing subsidies for pasture, improving security of tenure, facilitating the diffusion of technology and access to capital that allow intensive agriculture, tax incentives for commercial forestry, strategic location of roads, population control and development of industrial employment opportunities that encourage people to leave the rural areas where they are putting pressure on forest resources and move to cities. These policies are not easily rewarded in the context of projects that cover small areas but may be the most important in the long run.

In this section we first explore the advantages of large projects, then consider the benefits from small project. Then we discuss ways that some benefits of small projects could be achieved while gaining the international benefits from national baselines and monitoring. Finally we discuss the effects that large projects might have on the negotiating process itself.

Advantages of large projects

1 Averaging out of heterogeneity and idiosyncrasy over large areas.

Most processes for prediction of baselines, remote sensing of forest and estimation of carbon stocks in different ecosystems will make random errors on each individual site because people and ecological systems are very heterogeneous. For example, for reasons that we cannot easily observe some people will clear poor quality land that we would not expect to be cleared while others will preserve high quality land. Some land with the same rainfall and temperature will happen to have unusual soil characteristics and will store much higher or much lower carbon than the average site with that rainfall and temperature. Remote sensing at low resolution cannot observe small cleared areas or pieces of forest but with an appropriate rule for interpreting the data the gaps and fragments that are missed should balance each other out.

Careful statistical work can make sure that the processes are not biased over large samples and that these errors will average out to give very precise estimates over large areas. These errors cannot be avoided in small areas without enormous effort. Small area estimates generated using the same methods will tend to be quite inaccurate.

2 Prevent environmental bias because of project selection

Suppose there are two areas in a country. The same baseline approach, that generates unbiased accurate national baselines, is used for both. It creates a favourable baseline for one area (low level of forest expected) and an unfavourable baseline for another simply due to errors in the baseline process that average out at the national level. If a project developer can observe factors that are not included in the baseline calculation and hence knows that the baselines are incorrect, she will choose to do a project in the area with the favourable baseline. She will gain credits not only for the real sequestration the project achieves but also for the difference between the calculated baseline and what would really have achieved (the 'true baseline'). If only this area is used for a project environmental integrity will be lost.

If one larger project covered both areas, the favorable baseline in one area would be offset by the unfavorable one in the other and environmental integrity would be ensured.

3 Reduce problems with 'leakage'

Leakage is likely to be less of a problem with large projects because it can only occur outside the project. As more areas are included in a project, more side effects are automatically included in the project monitoring.

Figure 3 Leakage and Project Size

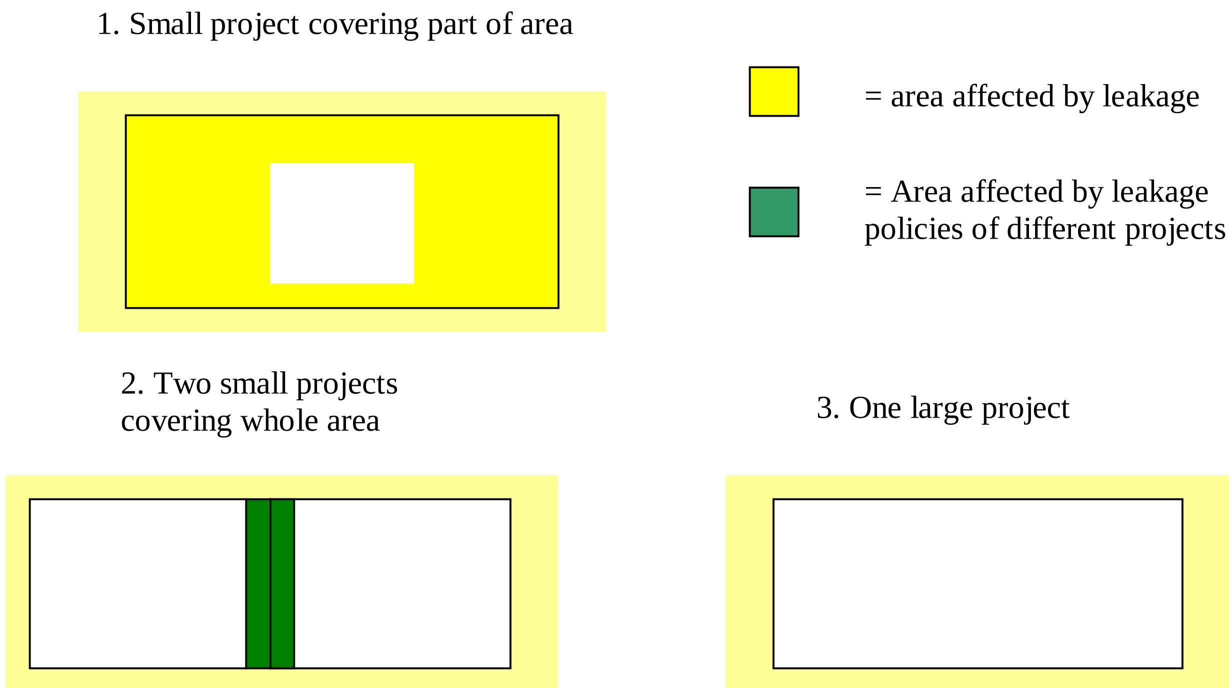


Figure 3 shows some different leakage implications of different sizes of project. The dark line indicates the regional or national boundary across which leakage is likely to be reduced. The first example has potentially a lot of leakage and will require this to be built into its baseline and the scope of the area monitored (see discussion below of ways to address leakage in small projects). The second example has no major problems of leakage outside of the project area (all leakage is into other countries or regions) because some project is responsible for all carbon outcomes. This could require some coordination among projects if one project precedes another. If leakage is taken into account in the first project it will reduce the obligations of the second project or lead to net environmental over-compliance. The third example is the simplest case where leakage occurs only outside the region.

In any case we need to define the project boundaries carefully so that most of the side effects are contained within the project not just across the border. Leakage probably decreases with distance. The project border ideally goes through land where land use will be relatively unaffected by the project. If the project has little effect, leakage will also be small. E.g.: having the boundary on a road is a bad idea because deforestation tends to be high near roads and the boundary may mean that deforestation on one side of the road simply shifts to the other side creating significant leakage. Leakage across a national border is likely to be weaker than leakage within a country because of market barriers and reduced labour mobility across frontiers.

4 Costs of organizing and monitoring projects

Every project, regardless of size, requires the same basic components. The cost per hectare of monitoring forest, estimating carbon levels and predicting baselines all reduce with increased project size. Large projects will cost less for the international community for the same amount of additional sequestration.

Advantages of smaller projects

1 Can be more accurate on each hectare

With very small projects a very different approach can be taken to the monitoring, estimating and predicting functions. This could involve a lot more specific information and hence could be more accurate on a hectare-by-hectare basis. This could provide more efficient incentives to land users. The potentially higher inaccuracy at a plot level is only a problem for large projects if the international rewards are directly passed through to individual land users. This level of accuracy could be achieved in large projects but only at costs that are usually considered unreasonable. If they are unreasonable on one large project, they should also be unreasonable on a number of small projects that achieve the same total sequestration.

2 Less area per project affected by mistakes

As discussed above, the costs of errors probably increase with the total amount of errors. For example the damage from small levels of inequity or potential manipulation is probably small but may grow rapidly with the size of gains by particular groups until it is perceived as unacceptable. Similarly, small deviations in aggregate environmental are insignificant but large deviations may reduce confidence in the agreement as a whole.

If this is true the total level of error matters as well as the error per ton of CER created. If each CER is systematically biased to produce less true sequestration than is credited, a project that creates a large number of CERs will lead to a large bias. Small projects simply produce fewer CERs so even if they are more risky per ton the total risk is lower. No one associated with the project can make a very large illicit gain.

3 Lower total cost of organisation and monitoring

Greater total resources are needed for setting up a large project even if the average cost per unit of sequestration is small. If the project is being subsidized as an experiment, it is much cheaper to subsidize a small project. If the project is profitable the relevant cost is the average cost of organisation and monitoring.

4 It can be very difficult to coordinate a large project.

In the short run, particularly in the least developed countries, small projects may be essential if we want these countries to participate. They are unlikely to have the capability to organize sound projects at a national level. Least developed countries face an acute shortage of the entrepreneurial and managerial capability necessary to design and implement large projects. Large projects would need to be organized through governments which are sometimes unstable and always focused on more pressing issues. In contrast, NGOs or foreign companies with the support of local communities could facilitate small projects.

5 Independence from government

Following from this, another advantage of small projects is that they require only approval from the host-country not active participation. NGOs and companies or sub-national domestic organizations in communities or states can organize them. This will reduce the demands on often-stretched governments; it will also reduce problems of government level corruption. In contrast, national level programs almost inevitably involve government in a significant role.

6 Equity – side benefits from participation

Often, those who do projects with foreign investors receive non-monetary benefits such as technology transfer, foreign exchange and access to additional capital. In less developed countries these can be benefits that are hard to access directly so the project has considerable side-benefits. If the least developed countries cannot organise large projects they could be excluded also from these side-benefits. Thus, creating rules that ensure that every country can have at least some projects could be equitable.

Making small projects more feasible is one approach. This is part of the rationale behind the Pronk proposal to give preferential treatment to small projects. However this will advantage all small projects, not simply those in countries that have difficulty participating. Alternatively if the goal is to help less developed countries and those who have no experience with projects participate in the CDM, these groups could be targeted directly with international programs to help them build capacity to create projects.

Part of the motivation for the concern about equity is the expectation that CDM will be somehow capped in total. If there is a total cap it might be expected that the largest, most efficient projects will be done and the small least efficient projects may not compete. This would not be a concern if small projects were efficient. If there is no cap on total CERs (or those from sinks) any project where the costs are lower than the value of the CERs created will be feasible and will find a buyer. We discuss the reasons for and against a temporary cap on CERs from sinks below.

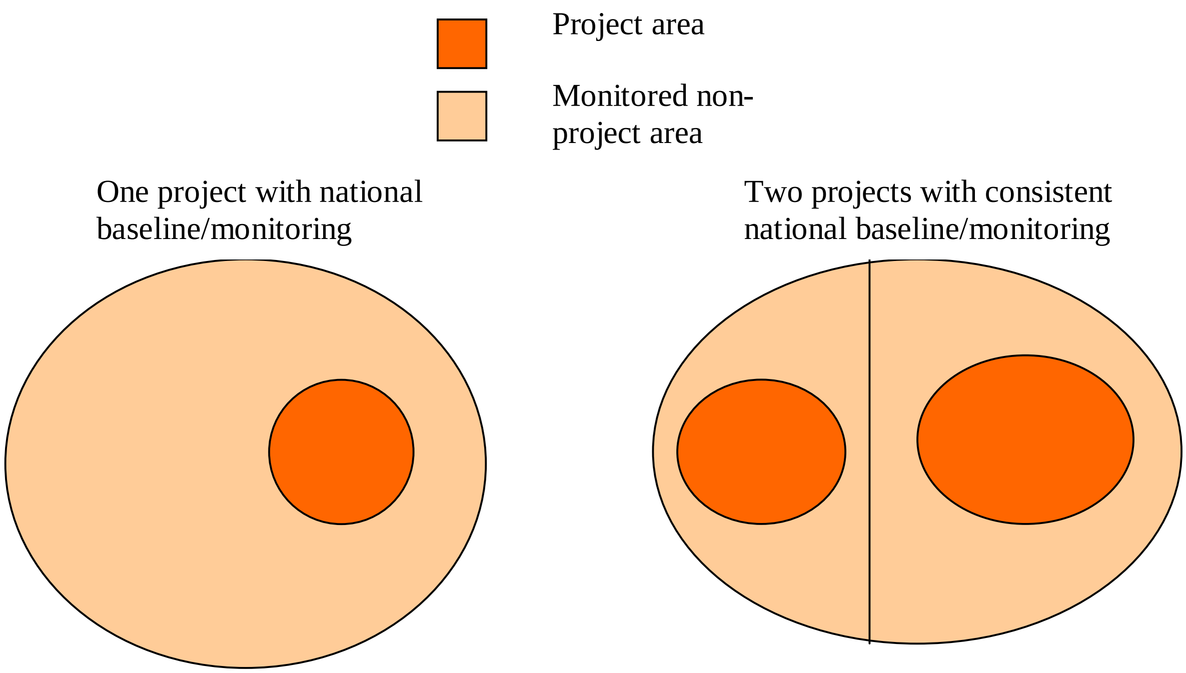
8 Learning

Probably the most important argument for allowing small projects despite the risk they create is the contribution they can make to learning. This includes learning by the project developers, by the host government and by the international community. Because total risks and total organisation costs are lower for small projects we could afford to experiment with a range of different project designs at little cost.

Individual projects within a nationally/regionally consistent baseline and monitoring system

An alternative approach that allows sub-national projects while gaining the international advantages of national/regional projects would be to establish ‘national’ baselines and monitor on a national level but have the ‘national’ project broken in several projects which are jointly consistent with the national monitoring but can be considered separately for compliance.

The same methodology would be used to create baselines for the project area and the nation/region. Monitoring of land use and estimation of carbon changes would be done at a national/regional level. When assigning credits the international rules would assume that all the area outside the project is at baseline level and hence allocate all CERs generated in the nation/region as a whole to project. If there were two or more projects they would have to have a prior agreement on how to share credits. A logical approach might be to assign all of the area outside of the projects to specific projects.



Effects of regional or national baselines on future commitments

Creating regional or national baselines has some clear advantages for reducing leakage and reducing the uncertainty in land use projects. Some developing countries have expressed concern however that creating such baselines would disadvantage them in future negotiations.

At the same time there are high international costs from the uncertainty about how DC commitments will be established in the future. As long as basis for future commitments is not clear it is difficult for developing countries to create appropriate policies to address growth in their greenhouse gas emissions. Developing countries have strong incentives to behave strategically because their current actions are likely to affect their future obligations. Ideally all developing countries (and Annex I countries) would now begin to behave as though they face a price for the use of carbon. They would take the global implications into account in every decision about land use. Taking on a regional/national baseline would facilitate this because the CDM would reward all efforts to sequester additional carbon.

If developing countries believe however that future emissions targets will depend positively on future emission levels, countries could even be induced to increase their rate of deforestation or defer reforestation. This is the opposite of what is ideal. In this case they would also resist regional/national baselines and in fact the CDM as a whole.

If developing countries want to avoid commitments altogether they may also resist regional/national baselines because they will make it much easier to bargain toward commitments. Baseline estimates would provide an obvious focus on which to base commitments. If baselines have been calculated and accepted by the developing country it will be harder for them to delay commitments by stretching out the negotiation over levels of commitment.

Will future commitments depend on future emissions? Will doing CDM projects on a large scale affect future bargaining? Unfortunately they may unless explicit decisions are taken to avoid this. In Annex I this was clearly the basis for negotiations and although 1990 emissions were used as the standard, the differentiation around that did depend in part on the growth in emissions between 1990 and Kyoto. Changes in emissions since Kyoto have led to attempts to alter commitments (discussion on hot air).

Essentially negotiations tend toward finding outcomes that impose similar costs on similar people. If a country carries out a lot of CDM projects and has an efficient system with a regional/national baseline between now and 2012 they will be able to control emissions at lower cost after 2012. In contrast, an initially identical country that does not do anything about climate change will face much higher costs of achieving similar emissions levels after 2012. The country that engaged in CDM and took on regional/national baselines will tend to face higher commitments.

Can these effects be prevented?

These adverse effects could be prevented by a clear agreement that future commitments will not be based on future emissions and hence will not penalize developing countries that act early. For example language in the agreement could state that future commitments will not be based in any way on levels of actual emissions after 2000. Commitments could still depend on factors that influence emissions such as economic growth or population growth.

4.3 Straw-man Proposal for an operative system to incorporate tropical forests in the global climate mitigation effort

Land-use CERs should be credited as sequestration occurs and tracked so that if the sequestration is reversed in the future they (or equivalent AAUs) expire. This solves the problems of deliberate or accidental loss of sequestration as well as providing sovereign control over the long-term use of land in developing countries.

To avoid concern that current efforts to control emissions will backfire on countries by leading them to face more stringent pressures in the future explicitly state that if developing countries ever accept commitments, these will not be determined on the basis of any measure of emissions or sequestration after 2000.

On the more difficult issues of monitoring land cover, measuring carbon and predicting baselines we propose one possible solution as a starting point for discussion. These details are not intended to be the best possible but we believe the overall structure is appropriate.

We propose two sets of rules. The first is for national/regional level projects where estimates will tend to be more accurate because of the wide scope and there are no problems with strategic selection of project locations or with leakage. The second is for small projects recognizing that at least in the short run there are reasons why national/regional projects will be impractical and inappropriate for some actors and some countries.

4.3.1 Proposed National / Regional Project Rules

Monitoring Land Cover

- Monitor only forest / non-forest.
- Distinguish forest from non-forest with a fixed canopy cover rule (e.g.: 50%). This could be chosen initially for reliability and consistency of remote sensing.
- Resolution of remote sensing would be set to a given level (e.g.: 3ha, or 1km) with a 'majority rule' fixed to account for fragmentation of forest.
- For reforestation the age of the forest would be monitored (using the history of remote sensing) as well as the canopy cover. Reforestation projects would not receive credit until they passed the canopy cover level.

Refinements of this could allow more levels of forest (different levels of canopy cover) and choices about the level of resolution. Higher-level resolution would have different majority rules associated with them to maintain average forest cover estimates for the same forest.

Measuring carbon in forest and non-forest

- Use temperature and precipitation (or other readily observable factors) to identify different zones in each country.
- Estimate average carbon per hectare for forest with more than the required canopy cover in each zone globally.
- Estimate non-forest carbon per hectare for each zone (if it varies significantly – otherwise use one number)
- Set carbon number for non-forest areas at high end of likely range
- Deforestation: set carbon number for forest at low end of range.
- Reforestation: credit only increase in carbon in above-ground biomass. Use lower end of estimates of annual sequestration rates.

Refinements could allow nation-specific carbon numbers to account for factors other than temperature and precipitation. This would be particularly important if variation in soil carbon was included.

Predicting Baselines

Deforestation Baselines

- Calculate past deforestation rates by temperature/precipitation zone
- For least developed countries, assume this rate continues within each zone.
- Decrease this rate by a proportion for higher income countries. E.g.: countries with income above US$3000 per capita could have it reduced by 20% and above US$6000 by 50%.

Reforestation Baselines

- Assume positive percentage of cleared agricultural land (could refine to land not used for permanent crops).
- Increase this percentage as GDP per capita rises.

4.3.2 Potential Rules for small projects

Monitoring land cover

- Use same canopy rules as national/regional project
- Allow ground based monitoring as alternative
- Use higher resolution if using remote sensing

Measuring carbon

- Use same rules as national/regional projects but discount difference between non-forest and forest to account for problems of strategic site selection.
- Allow local measurements as alternative but then discount because measurements are not easily replicated.

Predicting Baselines

Deforestation:

- Use local historical deforestation rate for that temperature/precipitation zone but make less generous to account for selection.

Reforestation Baselines:

- Use same assumptions as for national/regional projects but discount to account for strategic project choice.

Leakage

- Either discount all CERs (by a decreasing amount as project size increases); or
- require active anti-leakage policies; or,
- create baselines and monitor forest cover on larger area than project and reduce credits by measured leakage outside project.

5 Short Run Solutions to Risk

The environmental integrity risks associated with including land-use activities in CDM are real and significant. They arise from problems with monitoring land cover and leakage, with measurement/estimation of carbon stocks on land, and with prediction of baselines. These risks will probably decrease over time with improved knowledge, but in the short run if we want to include these activities we need to think about ways to reduce the risk involved.

We are concerned about risk for two basic reasons. First, the environment integrity of the agreement as a whole may be endangered so that global emissions do not fall as far as planned. There is a concern that land-use projects would be systematically biased toward providing more CERs than they really sequester additional carbon.

Second, even if the aggregate effect on environmental integrity is small, inequity could be a concern. Large differences in the CERs given to projects that in reality have similar environmental impacts will create concern among those who feel they are disadvantaged. If these differences could be caused by deliberate manipulation by those who gained the greater number of CERs the sense of unfairness will be exacerbated. To the extent that these concerns are about perception of lack of integrity or inequity, even small risks could have quite large impacts. If the concerns were only about real changes in environmental outcomes, the risks would have to be quite large before they have a global impact.

The disadvantages of policies that would reduce risk are that real opportunities for environmental and economic gain as well as the collateral benefits of CDM projects such as technology transfer and capital access will be lost. In addition, opportunities for learning, and hence long-term risk reduction, may be lost. If policies were implemented to reduce risk, it would be important to ensure that these limitations do not affect some groups disproportionately. Different countries should have similar opportunities to benefit from CDM and to make the investments that will allow them to participate fully in the longer term.

Thus the challenge is to reduce risk and the perception of risk while, as far as possible, maintaining some benefits from sinks and encouraging learning that will facilitate a transition to the optimal system in the long run.

5.1 Delay Inclusion of Sinks

One extreme response to the risks involved in CDM projects is to simply delay the inclusion of sinks in the CDM until a later COP. This completely avoids the risk and avoids the risk of creating bad precedents by making bad rules that are hard to change later. It completely eliminates any possible gains until the decision is made, however. Given the length of time that afforestation/reforestation projects require to create any significant credits, delaying the decision until a later COP would effectively remove any gains from these projects even if land-use activities become eligible by the time of the first commitment period. Investors are unlikely to develop significant projects until the rules are clearer. Learning could still occur through research and through pilot projects that may not be credited, but would be limited to the type of learning that occurred under the Activities Implemented Jointly pilot phase.

5.2 Limit Risk

A risk-reducing strategy should trade off reductions in risk against the lost real sequestration and loss of opportunities to learn. Before deciding what limitations could be put on land-use projects under the CDM to reduce risk, we need to consider where the risks come from and where they are likely to be higher and lower. We should aim not only to reduce total risk but also reduce average risk per ton of carbon benefit. If average risk falls, we can gain more benefits for the same level of total risk.

The risk can be thought of in terms of risk per ton of CERs claimed and the number of total tons potentially involved. The risk per ton depends on the accuracy of land cover monitoring, the accuracy of carbon measurements and the accuracy of the baseline. The number of tons depends on the cost of avoiding deforestation and encouraging reforestation over large areas. It could depend on factors such as the area of forest, the value of additional agricultural land or timber and hence the level of threat to forest, the ease with which the threat can be avoided, and the area of land that might be available for reforestation and the cost of reforestation. A large risk that affects a small number of tons of CERs may not be considered that important.

Total Risk = risk per ton $\times$ number of tons

Different types of projects will have different risks per ton of credit created. Conservation projects tend to lead to more total risk simply because large amounts of avoided release are involved. Mature forests contain much more carbon than areas that are reforesting (10x or more in the early years of reforestation). In addition, the areas of existing forest that are threatened and hence could be conserved are much larger than the areas that are likely to be reforested in the short run. Thus even small risks per ton in conservation projects blow up into large total risks. At the same time, the large amounts of avoided release also mean that the potential benefits from conservation projects are very high.

It is not necessarily true, however, that conservation projects face more risk per ton of credit created. It is arguably easier to predict baselines for deforestation than reforestation (see earlier discussion). Levels of carbon in tropical mature forest are better understood than levels in forest that is growing (with the exception of well-understood plantation tree crops). The extent of mature forest is also easier to monitor by remote sensing than is reforestation.

Large projects may face less risk per ton of carbon than small ones because many of the uncertainties in measurement and prediction average out over large areas. Large projects also avoid concerns that project developers have strategically chosen sites that have favorable baselines. Larger projects face fewer problems with leakage. Projects that create large amounts of credit per hectare could probably create at least a small amount of credit per hectare with very little risk. However, the total scale magnifies any risks on a large project.

Average risks do not necessarily increase as a particular country produces more CERs (or decrease if the number of CERs from each country declines) because there is no reason why less risky projects would be done first. Concerns about inequity, however, could be a function of the amount of risk created by each country. If all countries impose similar risks and receive similar benefits, the concerns may not be so great as if some countries benefit disproportionately from biases in the CDM system.

Two basic strategies could be used to control risk, cap total credits and cap risk per ton. These could also be used in combination.

5.2.1 Indirect Limits on Risk

The first possible approach would reduce the risk on every CER created. This approach would not directly limit total risk but, by lowering the risk on every ton and reducing the number of profitable projects, would reduce total risk as well. This could be done in two ways: conservative rules for CER creation and exclusion of risky activities.

Conservative Rules to limit risk per ton

Making the rules for monitoring, measurement and prediction extremely conservative would ensure that on average we can be sure that fewer CERs are created than additional sequestration is achieved, i.e. create a positive environmental bias.

Within the proposed policy rules discussed in section 3.5 there are a number of places where the rules could be made so that they systematically create fewer CERs for every unit of sequestration. For example, non-forest carbon numbers can be set high and forest carbon numbers low relative to the range of international estimates. The rules might allow only a small fraction of past deforestation rates as the baseline deforestation rate. For example a country with 2% annual deforestation over the last decade might only be allowed to claim 0.5% deforestation as a baseline for the next decade. Small projects could have their credits highly discounted to reflect their higher average risk.

Imposing these types of restrictions would probably result in the loss of some good projects. Most projects lost should be marginal ones that are probably also more risky. It would lower (or conceivable even remove) the average risk per project as well as reducing the total number of projects that will be profitable. Both of these things will reduce total risk. It will not however, completely block any particular country or any sort of project that could have potential. It will facilitate learning while controlling risk. If these conservative rules were based on what we think optimal rules will look like, they can gradually be made less conservative as information improves and risk reduces.

Excluding Some Activities

Some Parties have proposed excluding activities that are perceived as having a higher risk. For example, several proposals (including the Pronk Presidency Paper (April 9, 2001)) have suggested not allowing natural forest conservation (or regeneration) to be eligible for CDM projects. What would be the implications for the environment? First, as discussed above, it is not clear that this would lower average risk. Conservation projects may actually have a lower risk per ton of carbon sequestered. It is clear that it would reduce total risk because a large amount of potential carbon sequestration (and hence a lot of aggregate risk) relates to avoided deforestation.

Excluding conservation projects could, however, have some unfavorable side effects. If actors can cut natural forest and replace it eventually with plantations and receive a reward for the plantations, the level of carbon in the atmosphere will rise. This would be hard to avoid in the long run because land use baselines have not been set in developing countries.   In terms of efficiency, not including natural forests would be missing a major opportunity to sequester carbon. Natural forests in the tropics contain very high levels of carbon that are lost almost immediately when original forest is cleared. In contrast, carbon is sequestered relatively slowly in new forests, particularly when the land has been cleared for a long period due to soil degradation.   Other implications of excluding natural forests would be the loss of opportunities to gain co-benefits such as conserving biodiversity, maintaining the culture of indigenous people, protecting watersheds and guarding against floods. Any policy that excludes some types of projects would limit total risk but would not necessarily lower average risk and would not facilitate learning about how to deal with excluded projects.

5.2.2 Direct negotiated limit on total sink credits

The simplest approach to limiting total risk while allowing some CDM land -use activity is to limit the total number of land-use CERs. This would put an upper bound on total risk at the maximum risk per ton $\times$ the CER cap. Because land-use CERs can be temporary, any limit should be on the land-use credits created net of land-use credits that have expired during the commitment period.

A cap makes the ability to create CERs scarce and valuable. A key question is who will get to create the limited number of profitable CERs and what quality those CERs will be. The worst possible thing that could happen under a cap is that, because the least environmentally sound projects are the cheapest to create, they will be done first and will be the only projects done under the cap. Each of these CERs will generate profit. Once a CER has been created it is 'gold plated' so will sell at the international price even though it may have cost little to produce. Buyers do not benefit from credits being created more cheaply, only the sellers (creators) do.

Any fixed cap requires some type of rationing system. This could be done in four ways.

- A process-based rationing system controlled by the CDM Executive Board
- A previously agreed cap on each seller country.
- First-in-first-served: projects would receive credit until the cap is reached.
- A previously agreed cap on each buyer country.

A rationing system operated by the CDM Executive Board would need to be based on a set of agreed criteria. It would likely mimic a combination of a country cap, first-in-first-served and the type of indirect limits discussed in the following section. Direct caps at a country level tend to lead to government control because there needs to be rationing within each country. Government control can reduce innovation and can also lead to corruption because of the power it gives bureaucrats. Under first-in-first-served, projects would have to be accepted before sequestration begins to provide some certainty to developers. As projects are accepted, the credits they anticipate creating would need to be saved by the Executive Board so that as the project progresses the credits can be given out. First-in-first-served with a strongly binding cap will tend to disadvantage the least developed countries and concentrate activity in a few countries and maybe a few large projects.

It would be hard to find fair rules for distributing a limited and strongly binding cap under either the CDM Executive Board or through seller caps. Caps on buyers do not inherently relate at all to the way the benefits under the cap are distributed because sellers receive the benefits.

The easiest way to make a cap work and function as a total limit on risk would be to combine it with conservative rules about the creation of CERs. These conservative rules would automatically reduce the total number of CERs and hence make the cap less binding. With a weakly binding (or non-binding) cap the benefits from being able to sell CERs would be small and therefore equity would be less of an issue and we could just use first-in-first-served to allocate the cap. In addition the conservative rules would raise the average quality of CERs and reduce risk even further.

Conservative rules may exclude some countries, and particularly the least developed countries from creating viable projects. This equity and learning concern could be addressed through use of the adaptation fund. Projects could be subsidized through technical and practical assistance so that even under the strict rules they can qualify and bring benefits to their host countries. If the conservative rules inhibit certain types of learning, individual countries, companies or the UN could subsidize these as part of a deliberate research and learning strategy.

6 Conclusion

I conclude that it is possible to incorporate sequestration and storage in tropical forests in the CDM or a similar instrument. The problem of lack of permanence of sink credits is easily solvable with a requirement for the buyer to pay back credits when sinks are removed. This solution also provides the seller with more control over their land use and hence reduces problems related to sovereignty. CO_2 fertilization is not an issue in the context of developing countries because, handled correctly, it affects baselines as well as actual sequestration.

The measurement of land use and carbon are not so easily solvable but bias and manipulation could be avoided by using standardized rules that can be crosschecked. For example the definition of forest could be chosen so that the forest area claimed can be checked using remote sensing. Carbon numbers in forest relative to non-forest could be standardized and chosen to be conservative with respect to highly uncertain carbon stocks such as soil carbon.

Baseline prediction is probably the most difficult issue. Creating baselines is similar to allocating property rights. The high level of uncertainty about the true business-as-usual path means that updating baselines to reflect exogenous changes that affect land-use will benefit both project developers and the international community. Baselines are probably easier to predict for larger areas simply because of the greater variability in historical data that allows key coefficients to be estimated. Reforestation baselines are similar in difficulty to deforestation.

By the law of large numbers monitoring of land use, measurement of carbon and prediction of baselines are likely to yield more precise estimates when they are done on a larger scale. Thus larger projects will have lower risk per unit of credit. Larger projects also face less leakage because many of the side effects occur within the area of the project. In addition, if a large area is completely covered by a project there is no opportunity for developers to strategically choose to put projects in the areas where the rules are most favorable to them. Large projects are less likely to create bias and excessive credit creation. However, during the period of experimentation and in order to enhance participation of the least developed countries smaller projects may need to be facilitated. In small projects the rules may need to be more conservative to account for the concerns about bias, and credits could be discounted to account for leakage unless this can be directly addressed in the project design.

Overall, the keys to good rules in the face of uncertainty are simplicity, consistency across projects, and replicability. The rules need to avoid upward bias in the creation of credits and need to be perceived to be fair. In the short run, to minimize total risk we might want to deliberately bias the rules to make them more conservative to guarantee net environmental gains from the inclusion of sinks. These rules could be relaxed as we learn more and perceptions of risk fall. Because of short-run perceptions of high risk the total amount of sinks could also be capped. If this were done at a level that would be unlikely to be binding with conservative rules well applied, it would not limit the market too much or require a complex rationing system.

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8 Appendix 1 – Generating Land cover baselines on a large spatial and temporal scale

The baseline example given in the text was developed by an interdisciplinary research project led by Alex Pfaff (Columbia University) and Suzi Kerr (Motu) and currently funded by the US National Science Foundation. The details of the derivation are given in Kerr et al (2001c) and the project as a whole is described in Pfaff et al (2000).

The goal in creating this baseline deforestation forecast was to find a way to generate long run, unbiased projections that cover broad areas while using relatively little data. The forecast is done based on a model for the whole country so that we can realistically assume that most of the causes of deforestation are derived within this area, most market interactions occur within area and institutional structures reasonably common across the area. We would not expect significant leakage from Costa Rica to neighboring countries. We do not currently study reforestation because it has only occurred recently and is in addition more complex to model (see discussion in text). With improved data we hope to add analysis of reforestation.

To forecast deforestation we begin by trying to understand why people clear forests. In Costa Rica the primary cause is agricultural extension rather than logging (only the high quality timber is removed and this does not clear the forest). If we want to forecast for long periods we need to understand the causes of deforestation. Short-term patterns may persist for a while and give some ability to forecast but they are unlikely to persist over 20 years or more as conditions change.

Our model of human choices is based on individual decision-making. We think about humans as doing the best that they can for themselves and their families while they are faced with constraints on their ability to borrow (either for investment or to cover short term needs such as education or medical help) and a lack of information. We do not assume that we can perfectly predict their behavior. Because human behavior is complex we want to model average observed behavior rather than building a model of specific parts of human behavior that we can study even if they yield a biased total picture. By studying past human behavior under a range of different conditions, however, we have some ability to predict the direction of response to new conditions and whether the response will be large or small. For example, if a new road is built and in the past people have always cleared land near roads, they are likely to do so again.

8.1 Data

Our basic data are from remote sensing coverage of all of Costa Rica: early 1960s, 1979, 1984, 1986 and 1997. These data distinguish forest and non-forest in all years and in 1997 distinguish reforested areas from existing forest. For the current study the data is aggregated to the level of 436 districts. These data allow us to identify the patterns of deforestation across space and a long period of time.

To explain these patterns we use a range of variables. At a national level we use GDP per capita and population growth. We expect that as people become better off, at first they will use more land to produce more but later they will start to move toward producing service (e.g., tourism) and industrial goods (e.g., computer chips) that demand less land. In addition, as people become wealthier they begin to value the environment more and their government gains more capacity to protect it. Thus GDP growth will initially raise deforestation pressure but in the long run will reduce it. As a second measure of the development of the economy, recognizing that this varies significantly between regions, we use the % of population urbanized in each district. Temperature and precipitation in the district is summarized through the use of 'life-zones' that characterize different ecological conditions. These and measures of soil quality affect the likely agricultural productivity of the land.

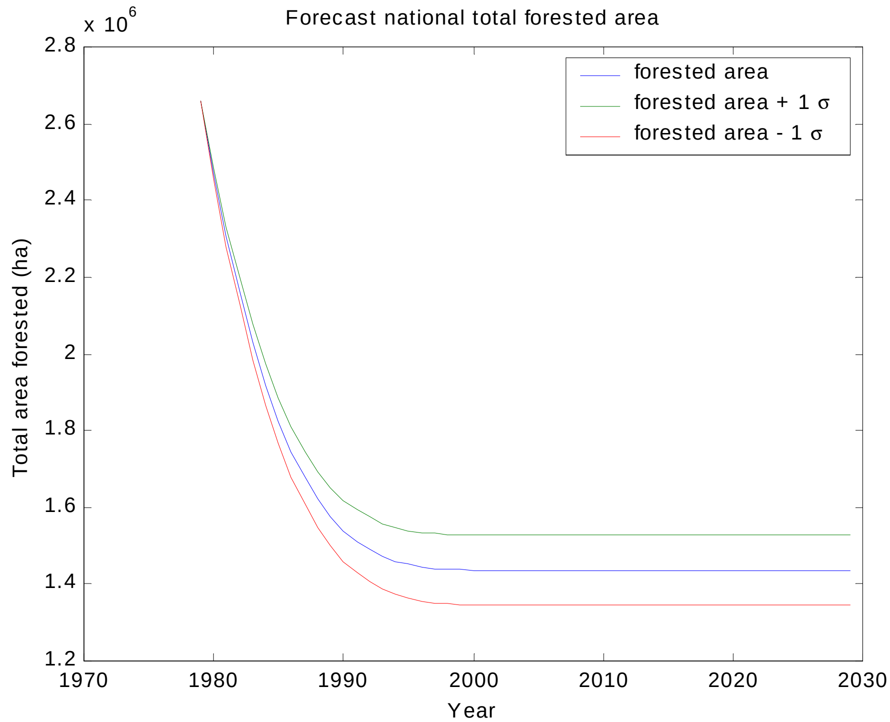
We also directly estimate the likely profitability of crops that can be grown in the area. As another measure of the quality of land that has not yet been deforested and also the overall level of development of the district we use the percentage of land in the district that has already been cleared. For example, we expect that flat land will be cleared first so remaining land is more likely to be on steep slopes and hence less attractive. We use the deforestation rate in the last period to account for ongoing development toward the region's potential (this is the basis of model that simply extrapolate past deforestation rates) and the effects of existing deforestation on access for clearing more land. Finally we use distances to key locations (cities and ports) and the density of roads in a district to indicate the ease of access that farmers that cleared land in the area would have to local and national/international markets.

8.2 Method

To relate the history of deforestation to the behavior of individuals that causes it we use regression techniques (Grouped logit). We aggregate the implications of individual decisions to the district level and then relate observed changes in land use with the characteristics of those districts.

The results of this statistical analysis allow us to create a forecasting model that predicts future forest levels in each district (These are aggregated to the national level in Figure 4). We then use ecological data on the amount of carbon in different types of forest to translate levels of forest into levels of carbon to give the baseline carbon forecast in the text.

Figure 4 Predicting forest levels from 1979



8.3 Generalizability

These results cannot be directly applied to other countries that have different ecological and economic characteristics. The method we developed can be applied, however. Our new knowledge on the important characteristics that drive deforestation and the nature of changes over time as development occurs would allow us to develop reasonable forecasts with considerably less data and work than was required for this first analysis. Most countries have at least one year of remote-sensing coverage, many have life-zone maps and soil data, all have GDP and population data, and many of the other variables can be easily generated with a map. All our analysis could be replicated from anywhere in the world.

While this analysis requires some data and skill, the work involved is considerably less than that required to collect local data and do other onsite work to predict baselines. Locally generated baselines may be appropriate for small areas but are not feasible on a broad spatial scale. In particular use of local knowledge may be more appropriate for domestic policies where aggregate environmental integrity is not so critical (because it is already ensured at the international level by international rules) but local equity is key. They will tend to be more precise on a site-by-site basis but are probably biased in aggregate.