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What Would Have Happened?

reviewing and improving estimated baselines for tropical forests and sequestered carbon

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Abstract

Regulations such as the Kyoto Protocol aim to limit worldwide net carbon emissions and could be quite costly for Annex 1 countries. "Carbon trading" could reduce the costs of restricting emissions and has been included in Clean Development Mechanism (CDM) proposals as one part of the implementation of the Kyoto Protocol. For implementing any restriction using carbon trading, "baselines" for carbon are crucial for defining how much carbon can be traded. Useful estimation of forest baselines and their carbon implications has been done, but significant uncertainty about carbon baselines remains. We discuss what has been tried and learned, focusing upon land use and specifically upon deforestation because others in this issue address carbon implications of land uses. Both baselines in small-scale sequestration projects and carbon projections at more aggregate levels are considered here. The latter include the approach taken in our team's integrated Costa Rican forest project.

Keywords

forest; carbon; sequestration; baseline; Kyoto; Costa Rica; tropical

1. Introduction

Regulations such as the Kyoto Protocol have been proposed in order to limit worldwide net carbon emissions. These, or alternative restrictions, could be quite costly for richer countries.[1] "Carbon trading" could reduce the costs of restricting emissions, and has been included within proposals for the Clean Development Mechanism (CDM) as part of implementing the Protocol. In the CDM or otherwise, carbon trading would permit richer countries to loosen their emissions restrictions by paying poorer countries to sequester more carbon than they otherwise would have. If a poorer country sequesters more carbon (e.g., abandons low-return pasture to regrowth, for a payment), the richer country which purchases the carbon can reduce emissions less or emit more (producing more electricity, e.g.). The countries can find a mutually satisfactory price if the gain from the electricity is greater than the loss from reduced pasture. Then carbon trading lowers the costs of emissions restriction, as purchasing carbon costs less than reducing the electricity output.

The Intergovernmental Panel on Climate Change's (IPCC) "Land Use, Land-Use Change, and Forestry" report (Watson et al. 2000), other well-known documents such as UNFCCC 1995 and UNCCCS 1997, and Article 12 in the Kyoto Protocol in particular stress that traded carbon sequestration must be "additional", i.e.add to what would have occurred in the poorer country in the absence of payments (which is labeled "business as usual" or "reference case" or "*baseline*"). Outside of carbon policy, the Global Environment Facility (GEF) stresses additionality as well. Two rationales stand out: first, additional funds should generally be provided only for additional protection of the environment; and second, carbon trading must not permit the effective evasion of agreed carbon emissions limits. Knowing baselines is crucial to achieving these standards.

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[1] We use the terms 'richer' and 'poorer' for 'Annex 1' and 'non-Annex 1' countries under the Kyoto Protocol.

Unfortunately, we cannot observe baselines. Once we have started carbon trading with payments as part of the implementation of carbon-limits policies, "the carbon the poor country would have sequestered in the absence of any carbon payments" describes a purely hypothetical situation. Thus we must *estimate* carbon baselines, i.e. must estimate how much carbon would have been sequestered. However, this type of estimation can be quite challenging. Further, as the estimates will affect carbon payments, some actors may not have an incentive to be accurate. Given those challenges, this paper reviews how such estimates have been done and then suggests possible improvements based on our Costa Rica forests/carbon project (featured in this issue).

1.1 Who Needs Accuracy?

Should we strain to make baseline estimates accurate when the carbon-trading system certainly could function at some level despite inaccuracy? A lobby *against accuracy* could arise as a result of opportunism or self-interest.[2] If 100 tons of carbon are sequestered by the forest in a poorer country during one year, then carbon payments by richer countries will be based on the difference between the 100 tons and the estimated baseline sequestration without payments (e.g., 60 tons). Only the *officially additional* sequestered carbon (40 tons) can be traded. Lowering the baseline sequestration estimate to 20 tons, whether or not that is accurate, could yield twice the payments to the poorer country. Thus, that country may profit from inaccurately low baselines.

Social gains from participation in such trading suggest an argument *for inaccurately low* baselines. Inaccurately low baselines are good for suppliers, as just noted, and will encourage participation in trading.[3] An inaccurately high estimated baseline can lower payments enough that participation may not be worth the supply and the transactions costs for a poorer country. All

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[2] Generally, national and group self-interest is important within agreements on carbon policies. Callaway & McCarl 1996, e.g., in its analysis of carbon payments versus crop subsidies, surely finds solid motivation in U.S. politics.

non-participation, though, would reduce the ability of such trading to lower costs of restrictions.[4]

Even those paying for carbon may approve of inaccurately low estimated baselines, since lacking knowledge of the true baseline and how much sequestration is truly additional the trading system functions with *officially additional* sequestration. Richer countries can emit more for each unit of purchased carbon and poorer countries can trade all of their sequestration that is above the official baseline. Thus, purchasing "hot air" (sequestration which in fact would have occurred in the true baseline but is officially additional to an inaccurately low official baseline) has the same benefits as purchasing truly additional sequestration.[5] Low official estimated baselines increase the amount that richer countries pay, but only because they increase the quantity of sequestration bought and thus the emissions that can be produced from generating more electricity for a profit.

The dominant motivation for accuracy, then, appears to be environmental integrity (i.e., zero hot air). As in the following example, an accurate baseline is necessary for carbon trading to be exactly consistent with the limits upon the net carbon emissions of the richer countries.

1.2 A Simple Example

Imagine a regulatory setting as above, with carbon trading. A richer country, which has no forests, is obliged to emit no more than X tons of carbon from industry during the next year. It could pay a poorer country whose emissions are not limited to sequester more carbon than it would have otherwise. The richer country would then be permitted to emit more than X tons.

Consider the implications for environmental integrity of an *erroneous* estimated carbon

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[3] Once a country participates, though, the carbon price (not the baseline) affects supply incentives at the margin.

[4] A goal of wider participation or, more generally, cost reduction through trading could also generate an argument for uniformity (but uniformity of inaccuracy might work). If baselines are seen to be unequal across participating countries, e.g. inaccurately low for some but not for others, tensions may arise which threaten the trading system.

[5] Further, since the hot air costs nothing to produce, as it involves sequestration that would have occurred anyway, suppliers might be willing to sell those credits more cheaply than additional sequestration, lowering purchaser costs.

baseline of zero sequestration in the poorer country, which has existing forests whose growth would in fact have sequestered 50 tons of carbon in the next year in the absence of carbon policy. Offers to purchase sequestered carbon at a price of P per ton lead to an increase in forest area, so that 60 tons of carbon are sequestered that year. At that point, given an estimated baseline of zero tons, the richer country can buy up to 60 of these *officially additional* tons and emit up to X+60. The richer country would be happy. It would purchase at price P only when benefits of emitting more carbon (greater output from industry) are greater than P. Also the poorer country would be happy, having been paid for up to 60 tons of sequestration while giving up only the agricultural returns from the additional forest area that produced the additional 10 tons of sequestration.

There is a loser here, environmental integrity. Without trading industry emissions are X and poor-country forest sequesters 50 tons of carbon. With trading industry emissions are X+60, i.e. they rise by 60 tons, while the truly additional forest sequesters only 10 more tons of carbon. Thus, trading which was supposed to keep carbon fixed instead increases the total carbon in the atmosphere. Note that an accurate poor-country forest-carbon baseline of 50 would have worked, i.e. net emissions would have been fixed and payments would have been for additional carbon.

1.3 Informational Requirements

To achieve environmental integrity using baseline estimates, what do we need to know? First, which land uses would have taken place in the counterfactual, no-carbon-payments case. Second, how much carbon would be sequestered, at any point in time, in each of those land uses. Particular treaty rules may require other information (in practice, the requirements vary greatly[6]).

While useful work has been done to estimate both land-use baselines and their carbon

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[6] Watson et al. 2000 stresses many possible definitional disagreements in implementing land-use "sinks" of carbon. They and Chomitz 2000 note that definitional difficulties also arise for implementation in other sectors, like energy.

implications, significant uncertainty about baseline estimation remains. This paper discusses what has been tried and learned. Its focus is land uses (deforestation in particular), since other authors in this special issue address their carbon implications. Both small-scale sequestration projects (Section 2) and regional- and national-level projections (Section 3) are considered, the latter including the estimation approach taken in our Costa Rica project, which may contribute to improved regional baselines. Section 4 concludes with research needs and policy suggestions.

2. Small-Scale Projects & Baselines

Small projects are currently the approved approach for putting parts of the Kyoto Protocol into practice. The Watson et al. 2000 volume on land use, land-use change and forestry (LULUCF) provides a good review of small-scale projects aimed at mitigating greenhouse-gas emissions.

2.1 What Has Been Done -- projects and baselines

Existing projects could be grouped as: avoiding a loss of carbon stock (e.g., avoiding deforestation); increasing the carbon stock (e.g., reforestation or afforestation); and avoiding carbon emissions using vegetative carbon to displace energy production. Such projects currently operate under uncertainty about the official future rules. In any case, though, earning credits from each of these types of projects will involve baselines: 'how much deforestation would there have been?'; 'how much reforestation?'; and 'what would otherwise have generated the energy?'.

The LULUCF report describes projects from Africa, the Americas, and Europe. For specific examples, Table 5-2 in Brown et al. 2000a lists features of 41 projects in six groups (afforestation-reforestation-restoration; soil management; forest management or alternative harvest; emissions avoidance including forest conservation; community forest; and agroforestry). The additional-sequestration and carbon-loss-avoidance projects are the most common.

For a more detailed sense of what is being done, consider the projects described in one issue of Biomass and Bioenergy (v.8, n.5). The range of baseline estimation issues is impressive (or perhaps daunting would be a better word). The Tanzanian options for carbon sequestration include forest conservation, woodfuel plantations and agroforestry (Makundi and Ati 1995). Within Mexico (Masera et al. 1995), the management is proposed of a pulpwood plantation, temperate forest and evergreen forest. For India (Ravindrath and Somashekar 1995), both succession and plantation strategies for meeting biomass demands for softwood, hardwood and firewood are analyzed. For China (Xu 1995), twenty cases that constitute relatively large-scale afforestation are considered, with different management options evaluated. And for Thailand (Wangwacharakul and Bowonwiwat 1995), the potentials for national parks, wildlife sanctuaries and watershed areas are considered, as examples of forest protection possible in that setting.

In evaluating such projects, we confront a lack of comparable data and procedures, given the lack of accepted project guidelines.[7] A common approach taken to baselines, however, is a "projection" of past land-use trends. "Models" may be as simple as asserting that all of the forest would eventually vanish due to development, or that some percent of the carbon is lost per year.

One example of assertion is the Rio Bravo Conservation and Management Area project (Programming For Belize 1997), which protects forest and manages for increased sequestration. Their "modeling" of what "would have happened" is a simple extrapolation of past local trends. The Costa Rican Protected Areas Project (Tattenbach 1996) also offered a baseline based upon historical forest trends. The Noel Kempff Climate Action Project in Bolivia asserts that the area "would otherwise have been subjected to continued logging and future agricultural conversion"

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[7] Among many others, see for instance the views within Fearnside et al. 2000 and Moura-Costa and Wilson 2000.

(Brown et al. 2000b, p.99). This land-use claim is converted into carbon values by measuring carbon over time in designated proxy areas, which can provide a locally relevant benchmark.[8]

2.2 Baseline Issues

2.2.1 Leakage

One general challenge for accurate estimated baselines is carbon "leakage". Even if well intentioned, a project's activities to lower emissions in specified project locations may also cause net emissions to rise *outside of the "project boundary"*, i.e. outside of the locations and activities officially associated with the project. Preventing deforestation using a reserve in Location A can cause migration to and increased clearing of forest in Location B. If the latter is not associated with the project, no baseline or measurements will exist and the increased emissions will not be accounted for, i.e. will be leakage.[9] Another example is that a project could have an accurate baseline for above-ground carbon but still create significant carbon leakage because its activities affect below-ground carbon, which is outside of the project boundary (or even if officially within the project boundary, may for practical purposes be outside of it because of a failure to measure).

Small-scale projects are especially vexed by this spatial-leakage problem. Unlike the national-level approach in Section 3, by their nature they leave most of a country unmeasured. Correcting for extra-boundary, unmeasured impacts is extremely difficult. Even if a project were

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[8] Since the papers in this issue that focus on carbon do not address small-scale projects, it is worth noting briefly in this paper (otherwise focused on land use) how projects handle carbon estimation. Local measurements can provide precision in estimating local carbon values that may not be possible from larger-scale modeling (although for large enough projects, carbon modeling of some form is sometimes used anyway). Often plots are designated for carbon measurement. In some projects, control plots 'within but not affected by' the project itself are used to estimate what would have happened to land use and carbon in the absence of the project. In other projects, plots not controlled by the project provide the estimates of the land use and carbon fate of the project area had there not existed a project. Appropriate control plots may not always exist, however, and there is an issue of strategic plot choice (see below).

[9] Note that things could be even worse. If the proxy area being used to estimate the baseline for the project is one cleared at a greater rate, then not only is carbon lost to leakage in the proxy area but also the baseline that would have been appropriate to apply to the project is not observed. Instead, a lower baseline is observed and applied.

to concede the likelihood of such impacts, their magnitudes would be hard to estimate.

Thus, when La Rovere 1998 considers the potential for limiting deforestation in the Brazilian Amazon through carbon payments, a concern with migration-and-clearing leakage is part of the author's rationale for not using small projects. Of course, cases will differ and must be judged on their specific merits. Sathaye et al. 1999, for example, discuss one case in which a shortage of high-value teak may well make land with teak trees resistant to new clearing pressure resulting from any displaced land users. If so, in that location leakage may be less of an issue.

2.2.2 Strategic Behavior

Should each project develop its own baseline, based on local details, as in Section 2.1? Or, instead, should generic approaches be developed that can be applied to multiple projects? [10] An attraction of local detail is accurate estimation for the specific locality of the project. Nearby proxy areas might reflect well what would have happened in the project area, absent the project.

However, a problem with accuracy may arise when the project designers themselves, who often possess good local information, choose proxy areas. That seems beneficial, but may also mean that they can make essentially unobservable choices to lower a baseline strategically. Then for any given carbon outcome the accredited additional sequestration is higher, raising payments.

Is that really a serious issue? In terms of existing latitude in various reporting choices, Brown et al. 2000 say that even standard financial analyses are often lacking for such projects.[11] As to whether the baseline choices could be distorted to raise payments, note their observation that as reporting methods have started to converge, estimated project benefits have tended to fall. Also, Busch et al. 1999 suggest that the carbon baseline originally put forth for the Costa Rican

[10] Section 5.3.2 of Brown et al. 2000 highlights the difficulties of determining additionality, including this question.
[11] Sathaye et al. 1999 see a need for guarantees of performance, including issues of baselines and possible leakage.

Protected Areas Project estimated local deforestation trends in designated park areas incorrectly, and a revision based on alternative trends significantly lowered the estimate of carbon savings.[12]

2.2.3 Transaction Costs of Baseline Estimation

Another perspective on generic versus project-specific baselines is that because any type of information (be that local proxy plots or application of models) takes some effort to produce, it could be overly costly for each project to generate a baseline estimate that withstands scrutiny. That argues for generic baseline rules that can be relatively easily applied to different projects. This has been tried for other sectors (Brown et al. 2000a, p.305). Whether useful generic rules can be developed for LULUCF projects is not yet clear, but one could imagine such standards.

Here, for small-scale projects, we should consider the cost for a given level of accuracy. In that light, generic models estimated at relatively high levels of aggregation might fall short. Detailed sampling of the soil carbon in appropriate (i.e., not strategically chosen) plots may be costly but can be significantly more accurate for specific locations than are the predictions from ecological models. Generally, while simulation (Brown et al. 1999) and econometric (Chomitz 1998) models make explicit their estimation procedures for ecological modeling of carbon or economic modeling of land use, they cannot guarantee good predictions for specific local sites.[13]

2.2.4 Baseline Adjustment

One tough question concerns whether and how to adjust baselines for unforeseen events that are not results of the project. Should a hurricane blow trees down in a project area, it would seem unfair to penalize the developers by maintaining the baseline that was estimated without a hurricane in mind. Surely without the project the hurricane would also have had some impacts,

[12] Note that Busch et al. 1999 specifically recommend regressions, including our project's, for improving baselines.
[13] Examples of relevant modeling include Shively 2001 and a large set of papers discussed below.

lowering carbon storage. Thus, adjusting the baseline for such factors would appear to lower the uncertainty faced by developers. This view is at odds with Brown et al. 2000 (see 5.3.2.1.3).

Note that to permit adjustable baselines is essentially to make baselines into functions. That is sensible in principle, and our approach (see Section 3.2 below) provides such a function. However, strategic behavior is again a potential issue. If project developers can affect a factor for which baselines are adjusted, counterproductive incentives may exist. If baselines were lowered for deforestation due to new roads, then carbon policy would not create the incentive for carbon conservation that would help to shape "greener" development (as is envisioned within the CDM).

This incentive problem does not exist if baselines are adjusted for a hurricane. However, an environmental integrity problem may exist. If trees are knocked down but, through baseline adjustments, the same number of credits can be traded, environmental integrity is hurt because global net emissions rise (alternatively, emissions could fall, e.g. if beef prices fall and pasture is abandoned but, through baseline adjustment, no more credits are awarded). In this situation, to maintain environmental integrity one could estimate the probability of such destructive events, and then simply adjust downward the richer countries' emissions limits in anticipation of losses. This would, for example, eliminate the generation of "hot air" by fires that lower baselines.

All of this raises the possibility that the adjustments of baselines and of richer countries' emissions limits are a way to handle risk. However, others have suggested instead adjusting the credits awarded to a project to reflect the chance that such events occur (if the net effect of events is expected to be significantly positive or negative). The Costa Rican Proteted Areas Project, for instance, has created a 'buffer' of sequestered carbon given the risk that some sequestration will not last or will be cancelled out by leakage. Some estimated offsets from pasture regeneration are reserved against failure. Overall, half the first-year offsets are in the buffer (Chomitz et al. 1999).

Thus, in a fire-prone area, we might award carbon credits for only half of the additional sequestration, because some might vanish. Unlike adjusting baselines and richer-country limits, which tighten constraints on richer countries, the approaches of a 'credits buffer' or 'discounting of credits' put the burden of potential carbon loss upon the carbon suppliers. Some might object, since the developing country suppliers are poorer than the buyers. However, this could provide incentives for project designers to use their local information to design projects for lower risks.

3. National Approaches To Baselines

An alternative to small-scale projects is the establishment of one national-level carbon baseline. Again, payments would be made for sequestration above the official estimated baseline. This in essence makes all of national development in the presence of carbon payments into a "project", one defined relative to the development that would have occurred in the absence of payments.[14]

Working at this scale would introduce the additional challenge of carbon buyers having to somehow interact with the many people involved in carbon supply within the country as a whole. Were a large buyer to have to negotiate with many small suppliers, the transactions costs could be prohibitive. Thus a local institution, such as an agency or an NGO, would have to function to aggregate the supply side, receiving payments and distributing them to the right suppliers. All of the details of the mechanism for doing so while providing the proper incentives would be crucial.

With respect to the four challenges to baseline estimation identified in Section 2.2 above, leakage will be less of a problem for these national-level "projects" because the project boundary encompasses the entire country. Migration of activities across national borders occurs. Leakage

[14] A "national project", with a national baseline, would in theory be perfectly acceptable under the CDM rules.

could occur across borders if, for instance, a large country stops production of a crop to reforest for carbon, which lowers supply and raises the crop's world price, leading other areas to expand production and clear more forest.[15] However, it seems likely that the leakage based on that kind of migration will be less frequent and/or significant than migration of activities in one country.

Baseline adjustment questions are of precisely the same nature for national approaches. This includes the issue of strategic behavior by project designers if a variable they can control affects baseline adjustment. However, strategic maneuvering by designers based on their local superior knowledge may be less significant in this case because national-level baselines can be done using less detailed site knowledge, including because site-specific errors can average out.

This flexibility in averaging out local or site-specific errors in baselines may also mean that for a given level of accuracy within the project boundary the estimation is easier, lowering the transactions costs of baseline estimation. Total transactions costs of estimation are also lower because national baselines don't have to be estimated repeatedly, i.e. for each small-scale project.

Still, the estimation of a national baseline is somewhat daunting, even in simplest form. What would deforestation have been for development without payments (the counterfactual)? Even more challenging, we would like to project not only deforestation but also reforestation, and in fact the transitions between all land uses, since carbon is sequestered in many land uses[16].

However, increasing carbon-baseline accuracy by going beyond net deforestation adds to the estimation costs and this may or may not be worthwhile.[17] In fact most analyses have been of net deforestation, and our project has completed analyses to date only of net deforestation. Below

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[15] Sohngen, Mendelsohn and Sedjo (e.g., 1999) model global equilibrium in timber markets and address precisely the point that there can be external impacts or leakage even for national-level policies if a country is large enough.

[16] While the logic provided here applies to reforestation as well, there may be less useful data for doing estimation.

[17] Whether or not national reforestation baselines are deemed worthwhile, reforestation and afforestation must be

we focus on how others model forest loss and thus could generate forest/carbon baselines, and on how our Costa Rica project empirically analyzes net deforestation and could generate baselines.

3.1 Land-Use Literature and Baselines

Kaimowitz and Angelsen's 1998 broad overview of deforestation modeling categorizes 146 models in a 3x3 typology: three scales (household/firm, sub-national region, and national); and three methodologies (analytical, simulation, and regression). Household-level models might work for small-scale baselines, but for national baselines the regional- and national-scale models are relevant, and are technically similar. We will consider methodologies for regional/national as a single scale. For numerical projections (versus conceptual points about land-use choices), we will not consider the purely analytical models, leaving us with simulation and regression models at regional/national scale. For estimates of counterfactual land-use baselines over time that will never in fact be observed, our focus should be on how careful inference from the observations informs the simulation and regression methodologies and their forest (and carbon[18]) projections.

Recall that these baselines must extend out over some time along the development path. Given that challenge, simple extrapolation might be attractive, e.g. either of: (1) total forest will stay at its current level; or (2) deforestation rate will stay at its current level.[19] Our analyses of Costa Rican development suggest that each can yield large errors. Thus we would like the option of basing our temporal projections on inferences about effects of key driving factors done using data on historical deforestation. While carbon baseline projections then require estimates of the drivers' future paths, a source of cost and uncertainty in projections (see the Kerr et al. paper in this issue for discussion of the uncertainty in such projections), they.can also be more accurate.

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considered. Unlike avoided deforestation projects, currently they are eligible to generate credits under the CDM.

[18] The Kerr et al. paper in this issue compares land-use and carbon errors within the overall carbon-baseline errors.

3.1.1 Regional/National Simulation Modeling

An example of simulation modeling is the DELTA model (see, e.g., Dale et al. 1994). After exogenously determining the immigration levels that in turn determine a local population, it assumes colonists in a given area find what the model says are the most attractive plots of land. Amounts of clearing, as well as subsequent decisions to stay or to move away, are then drawn from assumed probability distributions. Kaimowitz and Angelsen 1998 suggest that this assumes, rather than proves, the effects upon forests of key factors such as access to roads and soil quality. Given these assumed effects, the model examines the implications for forest clearing over time. The key to assessing such projections must of course be whether all of the various assumptions are based reasonably on the data used in calibration, and in a way that is relevant for the future.

A second example, with application to Costa Rica, is provided by the GeoMod2 model (Pontius, Cornell and Hall 2001).[20] This model "extrapolates the known pattern of land use from one point in time to other points" (p.192). To do so, it makes use of stable attributes such as lifezone, elevation, slope, soil features, and rain (these are useful, but unlike payments or roads they are not variables that policies could affect). From one to three of these (paraphrased) rules are used: 1) clearing occurs only near cleared land; 2) clearing amounts are known within sub-regions, such as administrative or planning regions; and 3) clearing is more likely in places biophysically like those that have already been cleared (assuming these features are observed). Crucially, as seen with rule 2), only the pattern and not the quantity of land-use change is being simulated[21], which makes this approach inappropriate for the job of projecting land-use or forest clearing into the future, such that it would not be very useful for projecting carbon baselines.

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[19] The Costa Rican Protected Areas Project, discussed earlier, projected forward certain past deforestation rates.
[20] For those with interest, Hall 2000 provides a great deal of useful perspective on land use over time.

Another approach to simulations is the CLUE model (also applied for Costa Rica), which of late has been used for explorations of scale.[22] This model features a land allocation module, among others.[23] As Pontius et al. 2001 points out, the validation for such models is underway, such that it remains crucial to assess whether empirical model calibration (whether or not it is theoretically grounded) has reasonably made use of the observed data. Simulation rules are not always directly inferred from observations of actual land-use (e.g., forest clearing) behavior.[24]

Finally, computable general equilibrium (CGE) models also assume how clearing and other decisions will react to various drivers.[25] Parameterization often follows from matching the model's outputs to observed aggregates. Such models are useful for working through potentially complex interactions by simulating actors' and markets' reactions to shocks, such that prices and choices are endogenous. Kaimowitz and Angelsen 1998 note that such models require good data and modeling facility to yield actual predictions, which could limit their relevance for baselines (regression models require good data and modeling, but perhaps are more grounded in the data).

3.1.2 Regional/National Regression Modeling

Global regression models use national-level forest outcomes and estimate relationships to observable drivers.[26] The resulting functions aim to be applicable to all countries in the sample, and perhaps to others as well. In light of the transactions costs of building baselines, one generic function that applies to all countries could appear quite attractive. Unfortunately, there are some

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[21] Credit is due the authors for noting this explicitly. It is often hard to discern what others estimate versus assume.
[22] See, for instance, Kok and Veldkamp 2001 and Kok et al. 2001 in the same special issue with Pontius et al. 2001.
[23] Unfortunately, these articles say little about the calibration procedures, making it hard for the reader to evaluate.
[24] For simulating land use *backward* in time to estimate past effects of people upon carbon emissions, e.g., spatially disaggregated information on forests is likely to be lacking for years far in the past while information for roads and cities might be available in some form. A simulation model could assign a location for past forest outcomes on the basis of the social structures but that *assumes* effects on forest, it does not *test* them as we want to do for baselines.
[25] A nice example is the economic analysis for the Brazilian Amazon in Catteneo 2001.
[26] A good recent example is Barbier 2001, which also offers different regressions for different regions of the globe.

serious difficulties with the collection of enough data to reasonably estimate key factors' effects. Further, the absence of many important factors must bias the estimates of resulting coefficients.[27]

Within a given nation or region, the possibilities for data are better. Further, there may be less variation within the underlying forest dynamics, making identifying effects more feasible. Stavins and Jaffe 1990 provide an example of a model that predicts clearing over time and space (given projections of the paths of relevant driving factors, as always necessary for prediction).[28] More generally, as Chomitz 1998 notes, such regression modeling could be useful for baselines.

A crucial point is that such projections are grounded in observed forest clearing, though we must ask how empirical inference yields estimated coefficients.[29] A useful characteristic of regressions is that they produce functions that predict clearing for any situation describable by a combination of the explanatory variables. As below, in our Costa Rica work, this can be useful for adjusting baselines to lower the uncertainty faced by a country hoping to sell sequestration. Also, policy implications are generated when some of those variables can be affected by policies. Good discussions of this approach for the United States include, e.g., Parks and Murray 1994, Bockstael 1996, Geoghegan, Wainger and Bockstael 1997, and Miller and Plantinga 1999. In this approach, projection rules are always directly inferred from observations of land-use behaviors. Hypotheses about how people will, or should, react to drivers can be proven wrong by the data.

This approach has been applied to some tropical settings (see Chomitz and Gray 1996, Pfaff 1999, Geoghegan et al. 2001 and Chomitz and Thomas 2001; Kaimowitz and Angelsen 1998 mention additional tropical regional regression models) that are more directly relevant for

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[27] See, e.g., Kaimowitz and Angelsen, p.88: "In summary, at present, the large majority of global regression models can not seriously presume to estimate the size of the effect of each independent variable on forest clearing…"
[28] Their empirical work takes as its observations forest outcomes for political administrative units, such as counties. There are pros and cons (including high transactions costs) of more spatially disaggregated pixel- or plot-level data.

carbon-trading baselines since those eligible to sell sequestration credits are likely to be tropical. Such regression analysis is becoming more common.[30] Below we describe our project's analysis of Costa Rican deforestation, which extends the regional/national land-use regression literature.

3.2 Regression Analysis of Costa Rican Deforestation

Kerr, Pfaff and Sanchez 2002 provides economic analyses of deforestation transitions over time in Costa Rica. Like Stavins and Jaffe 1990, we use a dynamic theoretical model, although for our goal of projecting land use along a development path we have included in the empirical approach implications of dynamics of development not previously incorporated.

3.2.1 Model & Derived Regression Equation

For details of modeling, specification, and results we refer the reader to the paper cited, and try to provide enough information for the projection examples below to be understandable. In the model, a risk-neutral landowner selects when to clear a plot of forested land, to maximize the expected present discounted value of current and future returns. Returns can be from forest or from non-forest land uses, and are affected by revenues, the costs of clearing and the interest rate. For clearing to occur it must be not only profitable but also more profitable than waiting to clear in a later period.[31] Our empirical approach is based on hypotheses about the effects of factors on profitability now and in the future. At any point, due to shifts in these factors, some land parcels that did not previously satisfy the conditions for clearing will satisfy them, and will be cleared.

Because we do not perfectly observe current returns or all the factors in returns, let alone

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[29] See, e.g., Ahn et al. 2000, or Bell and Bockstael 2000 or Irwin and Geoghegan 2001, which have a spatial focus.
[30] A recent issue of Land Economics (v.77, n.2) is devoted entirely to tropical deforestation, although only a subset of the papers are regional regression models (others have already been cited above). Cropper et al. in that issue is a nice example for Thailand. Other reports of note include Mertens and Lambin 2000 and Geist and Lambin 2001.
[31] A 'profit condition' expresses the former constraint, while an 'arbitrage' condition expresses the latter. If a second-order condition holds, then the arbitrage condition is not only a necessary condition but also sufficient.

observe future returns, true returns vary across land parcels even after we control for observable factors. Assuming a distribution of this unobserved variation permits regression analysis of rates of deforestation transitions (as per Kiefer 1988, Lancaster 1990, Saloner and Sheppard 1995, and the labor and the innovation/adoption literatures we follow) in order to test our hypotheses using data for observed deforestation rates and for observable variables that may be linked to returns.

3.2.2 Dynamic Intuition & Empirical Approach

A more static approach, such as in Pfaff 1999 and many others, predicts how much area will be forested as a function of observable variables, no matter the history of forest clearing. However, in fact there is an element of irreversibility in clearing decisions: once cleared, an area is easily re-cleared for use in agriculture, but takes time (often many years or even decades) to return to a fully forested state. Thus, we separate deforestation and reforestation decisions and here focus on the decision to clear land that is still in forest, i.e. on the transitions out of forest.

The other way we take dynamics or changes over time into account involves changes in variables that matter for forest clearing decisions but are not directly observed. These can not be measured and used directly as variables in regressions, so after hypothesizing about what some key changes are and their effects on deforestation we try to incorporate their effects empirically through the identification and use of measurable proxies, i.e. indirect measures of those changes.

One example is that as development proceeds over decades there can be shocks to returns that are difficult to measure, such as from changes in institutions, in attitudes, or to infrastructure. One implication is that clearing transitions may occur even if the factors in deforestation that we can measure well are fixed (for discrete transitions data, the 'duration' empirical approach (e.g. Kiefer 1988) permits direct testing of temporal trends). One question is how we can use proxies for those changes in the regressions. We currently use time or GDP to represent development.

Another example is that local landowners are likely know more about land productivity than we know. Within observationally equivalent lands, on average the best land will be cleared first. This suggests that the more land already cleared in a district, the lower will be the quality of the remaining pool of uncleared forested land, and the lower the future clearing rate will be. As a proxy for this dynamic story about changing average quality of the pool of uncleared forest land, we use the percent of forest previously cleared in the surrounding area as an explanatory factor.

A third example concerns "adjustment costs". For instance, if frontier labor is scarce, then as clearing rises within a given time period the marginal labor cost may rise, unobservably to us. This will lead to less immediate forest change than we would expect and, instead, future clearing to complete the impact of current shocks. Thus where significant clearing has recently occurred, future clearing may occur as a 'temporal spillover'. A proxy to test the effect of an unobserved change in marginal costs could be deforestation in the previous period, but in early periods this is the same as the percent of forest previously cleared just described above. Thus, we would require good forest data over a number of periods to empirically separate these effects.

This highlights a challenge for empirical testing of these and other dynamic hypotheses: we have only a few points in time. Our data are better than most tropical-forest data sets, and do permit some temporal curve-fitting for projecting forest clearing forward for baselines. However, they do not permit separate testing of all temporal stories. Our approach, though, will increase in value as the number of high-quality satelitte forest observations over time continues to increase.

3.2.3 Data and Variables

Currently, we use forest observations at five points in time (1963, 1979, 1986, 1997 and 2000). Since the time intervals between observations vary in length, to make estimated rates of deforestation comparable we calculate annualized deforestation or hazard rates for each interval.

The data is from several different sources, and is described in more detail in Pfaff et al. 2000.

There are 436 districts, but for observations we use information on ecological conditions to create more disaggregate units. We separate district forest into forest in district sub-units that are distinguished by "lifezone" (or Holdridge Lifezone) -- lifezones are defined by combinations of humidity, bio-temperature, and elevation indicating a level of natural productivity. This yields 1229 of these district-lifezone pairs (i.e., about three lifezones in a district on average) for which we have deforestation observations with greater homogeneity of natural productivity, helping to more precisely estimate the effect of natural conditions and thus also the other effects as well.

We have tried to directly measure the monetary returns to the use of land for each of the four major export crops: coffee, bananas, sugar and pasture. As the data available for this task are limited, we also use proxies for returns in our regressions, including indicators of lifezone. Economic variables include a proxy for market access, the minimum linear distance to the closest of three key markets and ports (San Jose, Puntarenas and Limon). We also include this distance interacted with time, as development over time may improve the transport sector so that a given distance implies less transport cost. As discussed, as proxies for changes in factors that are not directly observed, we include time or GDP per capita (non-linearly to allow effects to evolve), as well as the percent of the forested land within the district-lifezone that was previously cleared.

3.2.4 Results & Their Use For Baselines

Kerr et al. 2002 discusses our empirical results at some length. We summarize them here. First, Figure 1 alone conveys a sense of the importance of natural productivity for forest clearing, i.e. the crucial role of ecological conditions. The least productive lifezones are much less cleared.

In regression results, the time trends suggest that clearing rates rise initially and then fall. The percent previously cleared has a significant effect both in a pooling of all years and in cross-sectional regressions, with the robust story being that more previous clearing is associated with higher clearing. This supports the adjustment-cost story, although as noted until we have more data it will be difficult to separately identify each of various stories (e.g., adjustment cost versus endogenous development following past clearing versus unobserved cross-sectional differences in productivity). Higher productivity life zones tend to have higher deforestation rates, and lower productivity life zones show lower clearing. Both results are robust, while that for soil quality is not, although usually of the expected sign. Distance to markets lowers clearing, and for a given distance this effect diminishes with time as hypothesized. Finally, our direct measure of returns has a positive effect on clearing, especially within the later cross-sections for which the data is better, and of course this performs more strongly when proxies for returns are not included.

For baseline projection, we first project the values the explanatory variables will take, one inevitable source of error (see the Kerr et al. paper in this issue, e.g., for extensive discussion of the details of the projections). Estimated coefficients can be applied to these values to produce a forest projection such as the slightly falling line in Figure 2. Thus, our regressions can provide a measuring stick for determining carbon additionality, if these land-use projections are converted into carbon. This approach and even estimated function can be applied not only for Costa Rica but also more generally to form a generic baseline rule. The exact coefficients would not apply but this type of analysis could yield "rules of thumb" to use with country-specific information.

For baseline adjustment (recall section 2.2.4), for instance if the banana market collapsed, the drop in market prices could be translated into a drop in monetary returns, then the coefficient on returns could be applied for predicted forest and carbon increase (e.g., see Figure 3, where the 95% confidence interval conveys not carbon uncertainty but only regression uncertainty). For a hurricane, we have no estimated coefficient, so a correction would involve simply a one-time rise in the fraction of forest previously cleared (e.g., 1% in Figure 3). Note that the 'CO_2 fertilization' issue might be handled in an analogous way. For countries supplying carbon sequestration, if the atmospheric stocks of carbon and of nitrous oxides raise sequestration by acting as fertilizer, this could (without an estimated coefficient) simply be worked into baseline carbon paths over time.

3.2.5 Limitations and Next Steps

Temporally, we do not have nearly enough observations over time to precisely estimate all of the effects we can hypothesize in theory. However, that may or may not be of significant concern for the carbon-policy issue of projecting reasonable baselines over time. Going forward, more remote sensing observations will be available, and at lower cost, to facilitate the testing of such hypotheses and efforts to use greater temporal variation to improve estimated baselines.

Spatially, the analyses discussed here have not made use of all of the spatial information available. Finer resolution than districts and their ecological subdivisions can be used. However, it is more costly both to organize and to use such more disaggregate data. In light of those costs, in the future our project will explore the gains in accuracy from such further disaggregation.

4. Conclusion

We have discussed why accurate official estimates of baselines, i.e. the carbon sequestration that would have happened without a carbon policy, are not only useful for calculating payments for a carbon policy but also crucial for environmental integrity. Accuracy is challenging but has value.

Different approaches can be taken to "joint implementation" of rich countries' limits on net carbon emissions. Small-scale projects are the only official approach in some areas, so we reviewed such efforts, highlighting generic baseline challenges and the crucial issue of leakage.

Then we reviewed analyses of net deforestation that can generate national-level baselines, noting types of analyses with most promise. This introduced our Costa Rica project's analyses, which fit the regional/national-level land-use-regression category that we think has real potential. After summarizing our theoretical and empirical approaches, we simulated a land-use baseline, including a demonstration of how this approach might handle the issue of baseline adjustment.

All of this suggests, from our point of view, a few general points about doing baselines:

1. consider scales larger than projects, to reduce the difficulties of dealing with leakage
2. consider using land-use regressions, which can be simple and sensible for larger scales
3. make baseline rules simple and clear, to ease monitoring and lower transactions costs
4. permit baselines to be adjusted for unforeseen events, to lessen risk to all the parties, but limit which events are adjusted for, to lessen opportunities for strategic behavior

Acknowledgements

This paper was developed in the context of the Costa Rica Carbon Sequestration project and owes a great deal to discussions with project members, in particular Suzi Kerr. Also Jo Hendy has helped significantly to do the baseline projections correctly, and I thank two anonymous reviewers for helpful comments. In drawing on the project, this paper refers to other articles in this special issue for additional information necessary for baseline implementation, and some sections draw on the Pfaff et al. 2000 overview of our project or Kerr, Pfaff and Sanchez 2002 for our empirical work. I gratefully acknowledge project support from the National Science Foundation, the Tinker Foundation, the Harvard Institute for International Development, NCEAS at UCSB, and the Center for Environmental Research and Conservation at Columbia University. Finally, all opinions expressed are my own and I am responsible for all errors and omissions.

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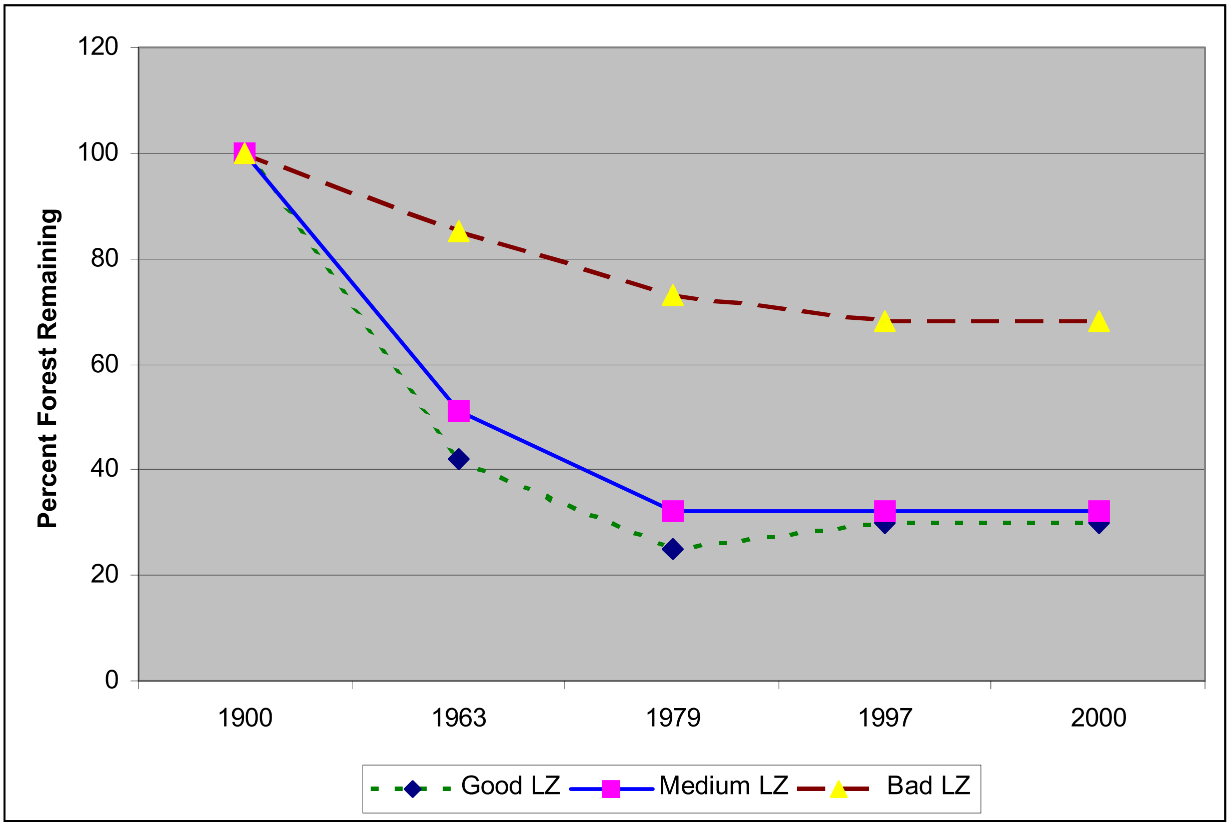
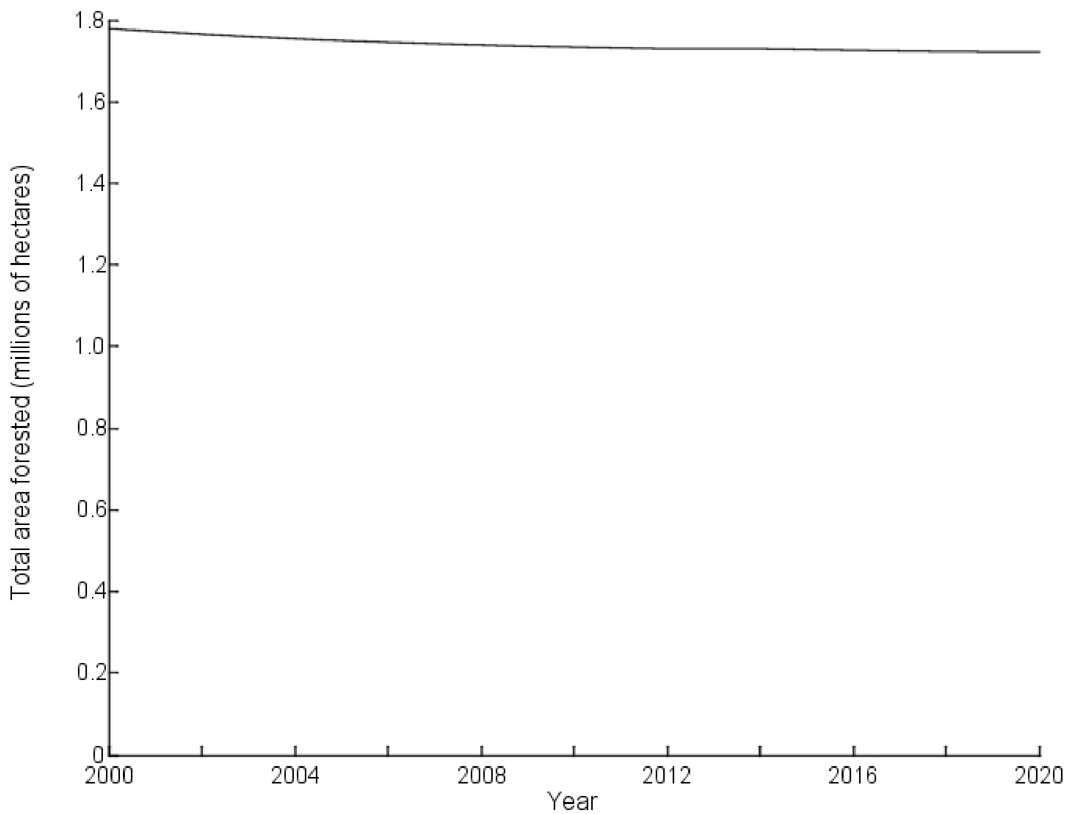
Figure 1 – the importance of ecological conditions for forest clearing*



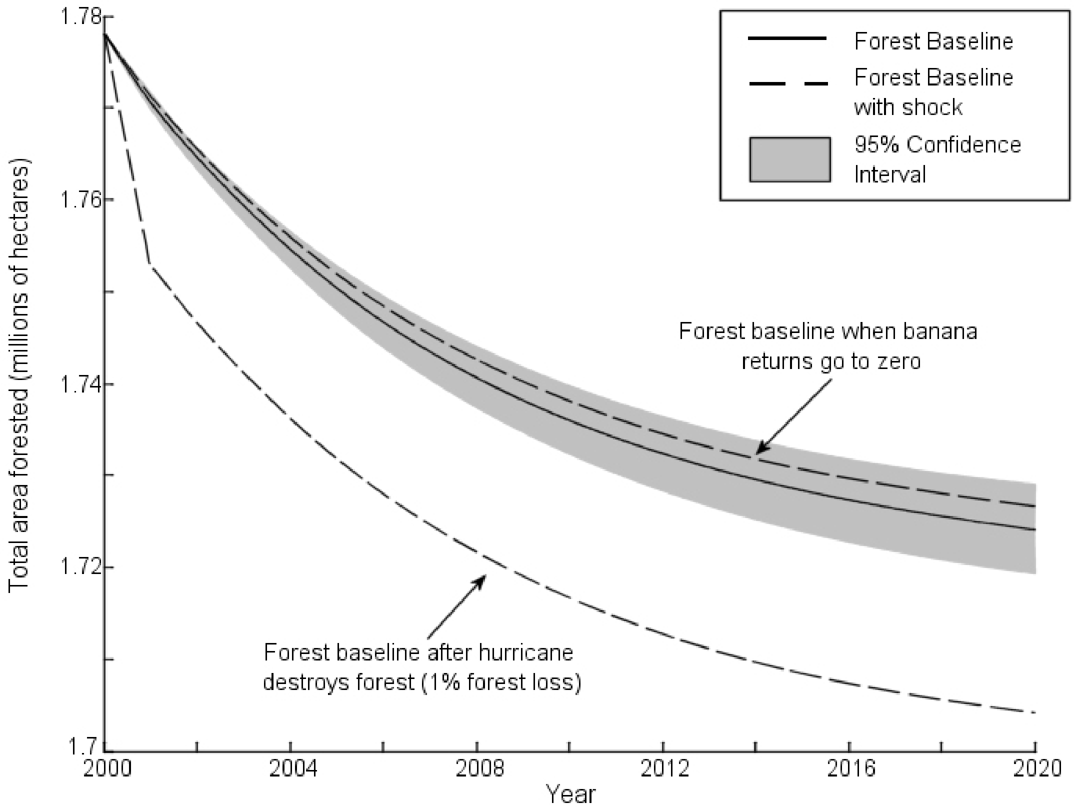
* This chart is designed solely to show that the less productive lifezones are dramatically less deforested. The slopes of these lines over time are somewhat artificial, e.g. the times between the observations differ.

Figure 2 -- a projected forest baseline*



* Applying exactly the same estimated baseline-deforestation function to the appropriate data for other countries, for instance to other developing countries that have different distributions of natural productivity of land or that currently are at earlier points along their economics development paths, would yield very different projections.

Figure 3 -- possible adjustments of the projected forest baseline



<u>Positive Returns Shock To Forest</u> = 1997 returns to bananas set to $0 perpetually.

<u>Negative Hurricane Shock To Forest</u> = 1% loss of forest, uniform over all areas.