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ESA Working Paper No. 04-20

November 2004

www.fao.org/es/esa

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Abstract
We review claims about the potential for carbon markets that link both payments for carbon services and poverty levels to ongoing rates of tropical deforestation. We then examine these effects empirically for Costa Rica during the 20th century using an econometric approach that addresses the irreversibilities in deforestation. We find significant effects of the relative returns to forest on deforestation rates. Thus, carbon payments would induce conservation and also carbon sequestration, and if land users were poor could conserve forest while addressing rural poverty. However, we find poorer areas are less responsive to returns. This and transaction costs could lead carbon payments policies *not* to be focused upon the poor. Other practical considerations may also dampen an understandable enthusiasm for service-based payments addressing both environment and inequality. Nonetheless, as the poor live in areas with more forest, they may benefit most from payments.

Key Words: Land Use, Deforestation, Poverty, Climate Change, Development, Costa Rica.
JEL: I32, O13, Q51, Q54, Q56, Q31.

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1. Introduction

Several land-use choices can reduce carbon emissions or increase carbon sequestration, including reducing deforestation or soil degradation and doing afforestation, reforestation, agro-forestry or rehabilitation of degraded forests (Tipper 1997, Niles et al. 2001). According to Niles et al. 2001, their potential for sequestering carbon is substantial. In particular, reducing deforestation in developing countries has the most potential, while rehabilitation of forest lands (see also Trexler and Haugen 1995) adds to the possibilities for forest management. Agricultural land management also has significant although less potential (depending on definitions of sustainable agriculture), especially in Asia. In all, Niles et al. 2001 estimate that atmospheric carbon could be reduced by 2.2 billion tons by 2012 through these land-use changes.

These categories of land use involve a wide range of different practices on the ground, and there are other such categories which may generate mitigation. Within each broad category, there are land-use systems relevant for small-holders. Some of these have already been a focus of sustainable development efforts. For example, the adoption of agro-forestry activities as well as community forestry management have been widely promoted by development agencies as useful vehicles for reducing rural poverty and, generally, for "sustainable economic development".

Along these lines, payments for carbon sequestration via land use appear to be attractive both for local incomes and for ecosystem services, and a "win-win" is possible (see Section 2). However, there are tradeoffs. For instance, the policies that most alleviate poverty may not be the same policies as those which most cost-effectively generate carbon sequestration, leaving choices between those two objectives. In reviewing proposed payments policies and in considering the policy implications of our empirical analyses below, we endeavor to highlight such tradeoffs.

There is little empirical research on the supply response of poor land users, and we know of no econometric studies which explicitly consider the impact of poverty upon supply response. Economic analyses of the supply response to carbon payments exist, employing approaches from point estimates of average costs to engineering least-cost models to revelation of preferences by studying past land-use behaviors (Parks and Hardie 1995, Callaway and McCarl 1996, Stavins 1999, Plantinga 1999). However, most are focused solely upon the U.S. and not upon the poor.

Revealed-preference methods have resulted in higher estimates of the marginal costs of carbon sequestration than other methods (Stavins 1999, Plantinga 1999). Least-cost engineering models may not capture all of the costs landowners face, including option values or non-market benefits not captured in benefit-cost analyses or various barriers to switching. Econometrics-or behavior-based estimates of marginal cost curves for carbon sequestration have also indicated considerable heterogeneity in land quality and in carbon productivity and thus also considerable variation in the marginal costs of providing carbon sequestration. (Plantinga 1999, Stavins 1999).

We adopt a revealed preference approach to estimating the potential supply response to sequestration payments and the effects of poverty. We use data on Costa Rican forests for five points in time and a partition of the country into 436 district observations over space, along with a poverty index from FAO and data on land-use returns, to estimate the responsiveness of deforestation to returns and to simulate a supply curve for avoided deforestation for Costa Rica. We find that, in general, land users will respond to payments, but that the poor will respond less.

After a review of potential sources for payments in Section 2, Section 3 presents a model of land-use choice and reviews related literature on the constraints low-income land users face in responding to payments. This suggests an empirical approach to impacts of payments and poverty upon carbon. Section 4 describes our data, Section 5 presents results, and Section 6 concludes.

2. Payments for Sequestration Services

There are several potential sources of payment for carbon sequestration generated through land-use change. Their foci differ, in terms of the degree to which they aim to (cost-effectively) sequester or to target poverty. Their specific criteria along these and other dimensions determine what activities are considered for funding and with which other activities they compete for funds.

The Clean Development Mechanism (CDM), under Article 12 of the Kyoto Protocol, allows investors from industrialized countries with binding emissions-reduction commitments and whose greenhouse-gas emissions surpass their commitment levels to obtain a carbon credit from developing countries who cut their emissions or increase carbon sinks (Olsson et al. 2002). In November 2001, the Marrakesh Accords confirmed reforestation and afforestation as activities generating such credits but excluded conservation of standing forests (i.e., avoided deforestation) and farming-based soil carbon sequestration for the first commitment period ending in 2012.

For low-income and small-holder participation in land-use-based CDM activities, a key question at the COP 9 of the Kyoto Protocol is whether agro-forestry is an accepted activity. Generally, for low-income and small suppliers being competitive will be an issue, as potential supply of carbon credits under the CDM may be large relative to demand, though niche demands for credits that satisfy particular rules (e.g., specific definitions of "sustainability") may exist.

The Biocarbon Fund recently established by the World Bank, with capitalization of $100 million for its first phase (from a mix of private-sector entities and development agencies), is another source of funds for carbon-sequestration payments. The fund will in part target land-use changes that qualify under the CDM but also in part aim to finance a broader menu of land uses including both avoided deforestation and soil-carbon sequestration. It explicitly requires that projects contribute to improved local livelihoods and yield cost-effective environmental impacts.

While a non-party to Kyoto and thus not a potential source of demand for CDM credits, the U.S. could generate significant demand through bilateral programs given states' legislation concerning emissions and investor pressures (see, e.g., Ball 2003 and brownback.senate.gov/ LICarbonFarm.htm). Currently, the Chicago Climate Exchange facilitates carbon-credit transfers between US companies and Mexico, with the inclusion of land-use activities for sequestration.

The Global Environmental Facility is also a source of grant financing for sequestration through land use with 'sustainable development' as a specific objective. While its climate-change operational area is limited to energy and technological efficiency, its integrated ecosystem management considers sequestration through land-use change. This program is designed to fund activities which generate multiple environmental benefits including biodiversity conservation, water conservation, pollution prevention and net emissions reduction (GEF 2000). GEF estimates that a total of $200 million annually will be needed by 2010 to support this operational category.

Over 30 land-use-change projects under the AIJ[1] program may qualify for CDM credits (Nasi, Wunder and Campos 2002), including some targeting small and low-income producers. Costa Rica's payments for afforestation, reforestation and avoided deforestation could affect up to 700,000 hectares at full operation (Chomitz et. al. 1999). Under its Forest Environmental Service Payment program, one NGO has enrolled 371 clients, some with holdings under five hectares. The Scolel Té Project in Chiapas, Mexico (De Jong et al. 2000) brokers credits from small-farmer forestry through a trust fund which also provides technical and financial assistance.[2]

Any such transactions will be affected by the form and stability of a global market for carbon offset credits. Significant market uncertainties exist on the demand side, e.g. due to the

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[1] Activities implemented jointly which was created under...

U.S. withdrawal from the Kyoto Protocol (Black-Arbelaez 2002). On the supply side, uncertainty exists regarding when and how Russia will enter the CDM market as a supplier. A full-scale and immediate entrance of Russia into the market could drive market prices down by a third (Black-Arbelaez 2002), though extensive banking of credits for future commitment periods could reduce supply in the first period and thus raise prices. At present, estimates of CDM-based credit prices are in the range of $3.5 to $5 per ton. This may increase to $10/ton, depending on the resolution of several issues raised above, noting that this is significantly lower than previous estimates of the market-clearing price between $15 to $20 per ton of carbon (Smith and Scherr 2002).

3. Land-Use Decisions, Economic Returns, Payments and Poverty

This section draws heavily on Kerr et al. 2003a, an economic analysis of deforestation over time in Costa Rica. Like others (e.g., Stavins and Jaffe 1990), we use a dynamic theoretical model, but we emphasize irreversibilities and the dynamics of development in our empirical approach. We feel this is important for understanding and projecting land use in a developing country, including projecting the effects of providing carbon sequestration credits to developing countries.

The potential for carbon markets to achieve poverty alleviation depends on the degree to which the poor will be willing and competitive suppliers of credits. Opportunity costs are the key to supply, i.e. profits lost or risk taken on or labor occupied in providing sequestration determine who decides to sell sequestration. Some users who would otherwise gain from supplying may face institutional, financial and social barriers. For others, private benefits are simply higher from their current land use than from supplying sequestration credits. Understanding such micro-level details of land-use-switching decisions, e.g., will clearly be important for carbon policy design.

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[2] Others include Profafor in Ecuador (Cacho et.al. 2002) as well as the RUPES (Rewarding Upland Poor for the

Within our formal model below, e.g., without receiving payment for it land users have no incentive to provide the public good of carbon sequestration unless its provision also generates a private benefit. A carbon payment raises private returns to forested land uses (ecotourism, non-timber forest product extraction, etc.), i.e. lowers relative returns to cleared land (e.g. agriculture, cattle pasture). Thus, along with many other factors, it can induce changes in land-use choices.

3.1 Dynamic Model Of Economic Returns, Land Use And Deforestation

The manager of each hectare j, risk neutral by assumption, selects T, the time when land is cleared, to maximize the expected present discounted value of returns from use of hectare j:

$$\text{Max}_T \int_0^T S_{jt}\, e^{-rt}\, dt \; + \int_T^\infty R_{jt}\, e^{-rt}\, dt \; - C_T\, e^{-rt} \tag{1}$$

where:

S_{jt} = expected return to forest uses of the land

R_{jt} = expected return to non-forest land uses

C_T = cost of clearing net of obtainable timber value and including lost option value

r = the interest rate

Two conditions are necessary for clearing to occur at time T. First, clearing must be profitable. However, even if so, it may be more profitable to wait and clear at $t+1$, so (2) must hold:

$$R_{jt} - S_{jt} - r_t\, C_t + \frac{dC_T}{dt} \; > 0 \tag{2}$$

and if a second-order condition holds[3] this necessary condition is also sufficient for clearing.

Following our model, we separate deforestation from reforestation because deforestation has irreversibilities, since trees take time to grow and incurring the costs of development changes marginal returns. Thus, we distinguish and focus upon deforestation transitions (in contrast to the forest-share equations that explain how much forest is present regardless of past deforestation).

Deforestation transitions for parcels occur when condition (2) is satisfied but have not been so previously. When this occur differs across space due to different returns, from variation in exogenous land quality and access to markets, and across time for exogenous and endogenous reasons. These individual decisions determine the aggregate patterns of deforestation over time. However, we observe not discrete clearing of individual parcels but continuous rates of loss in larger areas. Aggregating the model's predictions for these areas yields our empirical approach.

For such aggregated data, it is clear that we do not perfectly observe the variables in (2). Forest outcomes and explanatory returns and costs are measured for larger areas (i.e. districts), while actual returns and changes in costs vary across parcels for which the observable measures (X_{it}, i = the district) yield the same estimated net benefits from clearing for the entire district. Thus, X_{it} imperfectly measure parcels' net benefits from clearing as given by the variables in (2). We explicitly acknowledge that we do not measure returns perfectly, such that clearing occurs if:

$$R_{ijt} - S_{ijt} - r_t\, C_t + \frac{dC_T}{dt} \;=\; X_{it}\beta \;-\; \varepsilon_{ijt} \;>\; 0 \qquad (3)$$

where again i refers to an area, j to a specific parcel, ij to a specific parcel j known to be in area i, and ε_{ijt} is a parcel-year-specific term for the unobserved relative returns to forested land uses, so:

Probability (satisfying (3) so that cleared if currently in forest) = Prob ($\varepsilon_{ijt} < X_{it}\beta$) (4)

Since the X_{it} are the same for each parcel in a subdistrict, the predictions from the model are effectively for subdistricts' rates of deforestation during any given observed time interval.

The predicted clearing rates depend upon the X_{it} as well as on the assumed distribution of the ε_{ijt}. If the cumulative distribution of ε_{ijt} is logistic, then we have a logit model for each parcel:

$$F(X_{it}\beta) \quad = \quad \frac{1}{1+\exp(X_{it}\beta)} \tag{5}$$

For our grouped data, we estimate this model using the minimum logit chi-square method also known as "grouped logit".[4] If $\hat{h}_{it}$ is an area's measured rate of forest loss, then we estimate:

$$\log \frac{\hat{h}_{it}}{1-\hat{h}_{it}} = X_{it}\beta + \mu_{it} \tag{6}$$

The variance of the μ_{it} (referring to areas, not parcels) can be estimated by $\dfrac{1}{I_{it}\hat{h}_{it}(1-h_{it})}$, where I_{it} represents the number of forested parcels within area i at the beginning of interval t, and the estimator is consistent and asymptotically normal.[5] This is estimated by weighted least squares.

3.2 Poverty, Land Use, and Response To Services Payments

Existing studies of the relationship between poverty and land use have found multiple linkages although not a single, unambiguous conclusion regarding the direction of causal effects. Kaimowitz and Angelsen 2002 summarize the economic literature on the causes of deforestation. They find that income levels, or poverty, have indeterminate theoretical and empirical effects. Wunder 2001 summarizes the economic literature on poverty and deforestation and concludes that two effects are in opposition. Capital endowments rise with income, enabling deforestation, but as returns to other economic activities rise with development, deforestation is less attractive. Below we consider a number of specific factors that may influence poverty-forest relationships as prelude to empirically estimating the supply response of land users and in particular the poor.

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[4] Berkson 1953, cited in Maddala 1983. See also Green 1990 for explicit discussion of heteroskedasticity.
[5] Maddala 1983, p. 30.

3.2.1 Poverty & Frontiers

Empirical and theoretical studies indicate that population density is positively correlated with deforestation, fitting the Malthusian vision, though over time density may trigger changes that lessen pressure on forest, per Boserups' vision. For the poor unable to compete for choice jobs or land parcels, increased densities may push them to the agricultural frontier, perhaps far from markets and perhaps on marginal lands (Kerr et al. 2003b give evidence that poorer areas in Costa Rica have characteristics that lower returns and thus also clearing). FAO estimates indicate that tropical forests are home to approximately 300 million people who depend upon shifting cultivation, hunting and gathering (FAO 1996). Thus the poor may be found near forest frontiers. This proximity has been noted in citing the potential for carbon services payments to the poor.

Institutional arrangements on frontiers may be dominant conditions for of deforestation. Remote forests under collective or state ownership that are difficult to monitor can be accessed without paying for right to use the land. In such areas, the poor may have few options to produce other than converting forest lands (highly skewed land distribution patterns may support this, as even on the frontier large fractions of the land may be owned by richer actors who live in cities). When property titles can be obtained through land clearing, clearing incentives are even stronger. Thus, the location of the poor may be correlated with forest clearing, but it could be that within a frontier setting the institutional features are sufficient for clearing, i.e. poverty is not the cause.

A related case is when the creation of new infrastructure, such as roads, generates access to forest. It may result from public or relatively wealthy private actors, as both transport and agricultural subsidies for livestock or agricultural production found to be important drivers of deforestation (Binswanger 1991, Deacon 1994, Chomitz and Gray 1996, Nelson and Hellerstein 1997, Pfaff 1999) may primarily benefit relatively wealth actors such as ranchers and loggers.

Small and poor producers may then participate in deforestation on lands abandoned by the large landowners or on small settlements at the frontier following new roads. A positive correlation of poverty and deforestation on frontiers may then exist even if poverty is not the main local cause.

3.2.2 Poverty & Barriers To Adopting New Land Uses To Supply Carbon

Poverty has been shown to create a wide array of barriers to adoption of new technologies in general and in particular to those involving returns that lag investments. Key issues include: (i) risk; (ii) high costs of capital and lack of investment capacity; (iii) poor property rights; (iv) transactions costs; and (v) relative efficiency in the production of carbon sequestration to supply. These factors may cause the supply response of the poor to be lower than that of other land users.

(i) Risk

Productive activities not only generate income or products, they also provide security in the face of risks of unexpected events like crop failures or sickness. Risks to food security are an important issue when assessing the opportunity costs of adopting carbon-sequestering land uses. Giving up the right to 'liquidate a forest asset' for needed income during difficult times, e.g., is potentially an important opportunity cost of receiving payments for carbon services from forests (for more discussion of such effects of risks the poor face see, e.g., Rodriguez-Meza et al. 2003).

This point has implications for the design of carbon-services payments. If they can be structured to increase security, as does insurance, they will be more widely adopted. If instead they represent a new source of uncertainty, then they may be ignored by risk-averse land users.[6]

A quite different risk issue may also impact the poor. The reversibility of sequestration activities (e.g., if forests succumb to fire) may cause credits to be discounted as a function of the

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[6] Lemos et al. 2002, e.g., document a case of potential users not changing land decisions based on rain forecasts.

perceived risk of reversal. There are many proposals for handling reversibility, but in any case a key issue for the poor is that they may be perceived as at higher risk of reversing sequestration.

(ii) Limits On Capital

Poor farmers may not adopt land uses that offer higher productivity over the long term due to an inability to invest in the short term when resource are required up front. This may be more relevant for investments in agro-forestry or reforestation than for avoided deforestation. The poor lack assets and obtaining financial services in the informal sector may be more costly, discouraging the poor from borrowing to invest (Fafchamps 1999, Lipper 2001). This suggests that carbon payments programs be structured to help users overcome investment constraints.

(iii) Property Rights

Frequently poor land users do not hold secure individual title to their land. In addition, more than one type of property right may exist for a given parcel (e.g., rights to trees, water, post-harvest residue, etc.). Uncertain or complex property rights reduce incentives of land users to invest in new land uses to sequester carbon, as the private rewards from this will be uncertain. Sequestration payment programs wishing to include the poor might include rights clarification when land uses are intended to change, e.g. from pastoral production to agro-forestry activities. However, this is clearly a challenging area to include within the design of such carbon programs.

(iv) Transactions Costs

Transaction costs are the costs of completing a contract, including the costs for buyers and sellers to find one another, the costs of bargaining, and the costs of monitoring and enforcing contracts. High transaction costs for the poor in payments programs can arise from small scale and remoteness as well as a higher degree of uncertainty in their rights to land-based property.

Cacho et al. 2002 find project costs per hectare and costs of sequestration per ton were negatively correlated with project size, though their sample size make this evidence anecdotal or suggestive.

Coordinating supply among groups of poor landholders (such as farmers' associations) can reduce such costs. The potential from coordination is illustrated by the FACE Foundation projects across the globe, the largest being Profafor in Ecuador with 22,500 hectares reforested (Cacho et al. 2002). Other cases are described in Smith and Scherr 2002 and Orlando et al. 2002. In many cases cost is reduced through the activities of an intermediary, most frequently an NGO.

It is more difficult to overcome the problem of complex and unclear property rights. The Scolel Té Pilot Project provides evidence of communities with intractable internal conflicts being uncompetitive while communities featuring successful resource management were competitive, with costs as low as $52/ha versus up to $325/ha for those in more conflict (De Jong et al. 2000).

(v) Efficiency In Sequestration

Low-income land users are expected to have a lower average rate of return to their land. Thus the payment necessary for them to forego these returns to sequester is likely to be lower. However, for supplying sequestration competitively, biophysical conditions matter as well. In general it is assumed that the poor have lower quality land, which supports less sequestration, but little empirical evidence exists on a broad scale (Lipper 2001; see Kerr et al. 2003b for results). If richer land users own large amounts of land, the quality of parcels under their control may vary considerably and at the margin rich owners could have a lower opportunity cost of switching (though eventually higher quality lands would be involved, i.e. their supply curve may be steep).

Existing studies (including in IPCC Climate Change 2001) suggest that some types of land-use change are more competitive than others. Avoiding deforestation and native forest regeneration are relatively efficient, though land uses' costs vary considerably across countries.

Cacho et al. 2002, for four agroforestry systems on degraded lands in Sumatra, found systems associated with smallholders to be competitive with plantations. Smith and Scherr 2002 note that costs of carbon from smallholder systems have been quite variable, with the opportunity cost of the land and scarcity of tree products as a major determinant, and that when smallholder costs are higher non-carbon benefits may offset this disadvantage. Tomich et al. 2001 studied in detail the costs of carbon sequestration in land-use systems in Sumatra and found competitive smallholder sequestration but questions about relative profitability. These questions will require further study.

4. DATA

Below we describe the forest, poverty and economic returns variables that we use to empirically examine the linkages between service payments and poverty and ongoing rates of deforestation (for a summary of Costa Rican clearing, and further details about the data, see Kerr et al. 2003a).

4.1 Deforestation Variable

We observe forest cover at five points in time (1963, 1979, 1986, 1997, 2000). We use the separation of the country into 436 political districts, and can use as unit of observation a form of sub-district. Specifically, in each district we can distinguish each 'lifezone' that is present (the Holdridge Life Zone System (Holdridge 1967) divides Costa Rica into twelve ecological 'lifezones' reflecting levels of precipitation and temperature). On average there are about three lifezones present in a district and thus we can in principle use up to 1229 observations per year, although because the poverty index described below is for districts, we will focus upon districts. Our dependent variable (more below) is the annual percentage loss during a given time interval from the area of forest present within a given district-lifezone at the beginning of the interval. As some district-lifezones become fully deforested, over time the observations per interval fall.

The data for the dependent variable are from several sources. The 1963 data are from aerial photos (translated into maps) digitized to distinguish forest and non-forest. The 1979 data were produced from Landsat satellite images by the National Meteorological Institute of Costa Rica (IMN 1994). The 1986 and 1997 data were also derived from Landsat satellite images (see FONAFIFO 1998) and distinguish forest, non-forest, and mangroves, while also indicating secondary forest (land classified as forest in 1997 but not 1986). The 2000 Landsat images were processed by the University of Alberta EOSL to be consistent with the 1986 and 1997 data sets.

For each district-lifezone for each time interval, we calculate the area deforested. The 1986, 1997 and 2000 maps all have clouds so we calculate these areas deforested (and thus also rates of loss) from the visible portions of each observation, using pairs of images with consistent clouds. For intervals before 1986-1997 we cannot distinguish the gross from net transitions, and assume gross deforestation equals net.[7] If the measured gross deforestation is negative, since we are analyzing deforestation we use a value of zero. After 1986, we know the gross deforestation.

Our dependent variable, the deforestation rate, is the area deforested during an interval divided by the area within the district-lifezone of the forest "at risk" at the start of the interval. Areas with no forest at the start of an interval are dropped, as there is no risk of deforestation. We assume that forest in national parks and biological reserves is not at risk of deforestation (it was not in fact cleared[8]). We also drop areas for which we do not have poverty data (see below). Finally, because our time intervals are of varying lengths, for comparison we use annual rates of deforestation. If λ_{it} is the deforestation rate (area deforested over area at risk) for a given interval and n is the number of years in that interval, our annual deforestation rate dependent variable is:

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[7] Anecdotes suggest reforestation was not widespread before 1986, so that this is probably not a major problem.
[8] For discussion of the parks and their forest outcomes see Sanchez et al. (2003).

$$\hat{h}_{it} = 1 - (1 - \lambda_{it})^{\frac{1}{n}} \qquad (7)$$

Thus we implicitly assume that this annual deforestation rate was constant during each interval.

4.2 Explanatory Variables

4.2.1 Direct Measure of Economic Returns

The annual return r_{jkt} to a given hectare j in crop k at time t is the crop price p_{kt} times the annual yield per hectare y_{jkt} minus the costs of production $cost_{jkt}$ minus the transport cost t_{jkt}. For each year, we estimate the returns for the four major export crops: coffee, bananas, sugar and beef. We have data from 1950 onward although its quality improves significantly in later years. For each interval, returns are averaged across the years for an average return (in 1997 US\$) to crop k on one hectare of cleared land during that interval (see Appendix on data and techniques).

Any parcel is used for one crop at a time. We define s_{jk} as the probability of a crop being chosen as the use of newly cleared land. For larger areas, these probabilities imply expected shares of the area in each crop, to be used as weights in our measure of expected annual return:

$$R_{it} = E(r_{ijt}) = \sum_{k} s_{jk} r_{jkt} \qquad (10)$$

We calculate the s_{jk} using data on production patterns in the 1970s and 1980s and information on the suitability of different lifezones for different crops. For example, in a humid, lower-montane area we represent land choices by assuming that cleared land will be used for coffee or a similar return. The resulting R_{it} is our returns measure, AGRETURN. Higher returns should raise clearing, such that payments for forest that lower relative returns to agriculture would lower deforestation.

4.2.2 Poverty Index

Here we summarize Cavatassi et al. 2003's poverty index estimation for Costa Rica. Without sufficient household-level data for a 'small area estimation' approach, they chose to use

'principal components analysis' (PCA). The necessary data are available from the census over four decades, permitting a poverty index that can be matched with the deforestation observations.

The data are variables common to multiple censi, at district level. Seventeen variables are common to 1973, 1984, and 2000, of which twelve are common to the 1963 census as well. See Cavatassi et al. 2003 for discussion of judgments about variables' economic meanings and roles in explaining the overall variance in these data. Variables chosen include demographic, labor, education, housing, infrastructure and consumer durable variables. Some examples are the percentage of dwellings without heaters, or without bathrooms, or without electricity. Others are the average number of occupants per bedroom and percent of people receiving job remuneration.

In PCA, eigenvectors of the correlation matrix for these variables indicate the direction and weight of variables in the index. Cavatassi et al. 2003 find that greater values of variables that should be positive correlated with poverty (% with dirt floor, % without refrigerators) have positive signs in the poverty index, as expected, while the wage remuneration and education variables have negative signs, as makes sense. The weights are used to create a poverty index[9]:

$$\textit{Marginality (or Poverty) Index}_j \; = \; W_1*(a_{j1}\text{-}a_1)/(s_1) + ... + W_n*(a_{jn}\text{-}a_n)/(s_n) \qquad (8)$$

where W is the weight for a variable (among variables 1 to n in (8)), a_j is the jth district's value for that variable and a and s are the mean and standard deviation of the variable across the districts.

This method is first used to create year-specific poverty indices for 1963, 1973, 1984 and 2000. Such indices, however, are not comparable over time. Each is based on a scale relevant only to that year. In other words, the indices' units vary, precluding comparison between years. Thus, as a second step, Cavatassi et al. 2003 also pool all years' data to estimate a single PCA for 1973-2000 using the seventeen variables and one for 1963-2000 using the twelve variables. For

these pooled PCA estimations, a change in the marginality index arises only from changes in the levels of variables over time, not changes in the relative importance of each variable in the index.

As noted above, some observations must be dropped because of a lack of poverty data. The reason is that the number of districts changes each census year (from 334 in 1963 to 406 in 1973, to 459 in 2000) as older larger districts are split to form newer smaller districts. When they knew how such a split has occurred, Cavatassi et al. 2003 are able to use the poverty values for older larger districts for each of the smaller newer districts into which they split. However, for some districts they were unable to track these changes over time, and thus districts are dropped.

Finally, we make use of these indices in our regressions in a number of ways. First, we do work with both the 1963-2000 and the 1973-2000 indices to explore the tradeoff between more variables and more observations over time. We match this data to our intervals as follows. For the 1963-2000 measure, for 1963-1979 we use the 1963 values, while for 1979-1986 we use the 1973 values, for 1986-1997 we use the 1984 values and for 1997-2000 we use the 2000 values. We also try using the 1984 values for the 1997-2000 interval so that we are using lagged values. For the 1973-2000 measure the difference is that for 1963-1979 we have only the 1973 values.

A final matching step is to the 436-district structure used by the University of Alberta to organize the forest data and some explanatory data (some data are spatially specific, so that they can be parsed into any district structure within a GIS). For years before 2000 we must match the smaller number of census districts to these 436 while for 2000 we match the 459 districts to 436.

We use the indices directly, in their continuous form, but also create variables to reflect possible non-linear relationships (logarithms, quartiles) between poverty and deforestation since some of the theory concerning poverty's effect concerns extreme poverty, e.g. pure subsistence.

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[9] This formula is based upon Filmer and Pritchett 1998.

5. Carbon Supply from Avoided Deforestation: Empirical Results

In the following section, we present empirical estimates of the relationship between poverty and

the potential supply response to sequestration payments for Costa Rica. We draw also upon the

empirical results in Kerr et al. 2003b (which estimates poverty's direct and indirect effects on

deforestation) for a land-use baseline in the absence of environmental services payments. This we

can convert to a carbon baseline using the estimated carbon values presented in Table 1 below.

5.1 Carbon Supply In Response To Payments

Table 2's column I presents our first result to address the issue of whether environmental

services payments should be expected to induce changed land uses and sequestered carbon. The

significance of returns is evidence that the relative returns to forested land uses do affect clearing.

It is worth noting the absence of other variables in this regression. Since our returns

measure, as noted, certainly does not capture all possible elements of actual returns, we might

wish to include variables controlling for potentially omitted elements. For instance, as transport

costs are notably missing from our direct returns measure, we might include the proxy for access

to markets from Kerr et al. 2003a, the distance to the closest of three major Costa Rica markets.

However, all regressions in Table 2 include district fixed effects. These control for fixed

differences, such as distances to major markets, but mean that we can not separately include the

factors in clearing which vary only over space such as distances and other important factors such

as fixed ecological conditions. However, again, fixed effects control for their effects. Further,

they will also control for the effects of fixed spatial differences that we can not directly observe.

Given this result that payments can induce carbon supply, and the fact that some land

users who could potentially deforest are poor, we can imagine that the hypothetical 'win-win' is

feasible. Carbon-services payments could generate environmental gains and lessen rural poverty. Whether to target the poor or not, e.g. because they respond more or less, is another question.

5.2 Carbon Supply by the Poor: Baselines & Poverty's Effect On Supply

5.2.1 Poverty's Direct & Indirect Effects on Deforestation

Below, in section 4.2.2, we examine whether deforestation in poor areas is more or less responsive to carbon rewards. Even for the same rate of deforestation, however, because poorer areas contain a large share of the forest, they are responsible for more clearing and, similarly, with the same responsiveness to carbon payments they would supply more total sequestration.

One reason that more forest remains in those areas appears to be that the characteristics of the land in poorer areas are less favorable for earning returns from cleared land uses like crops. Kerr et al. 2003b, e.g., provide evidence that the difference between poorer and richer districts in characteristics that affect deforestation would lead to lower deforestation rates in poorer areas.

However, controlling for observed and unobserved land characteristics, Kerr et al. 2003b find that poverty raises deforestation. Figure 1's baseline simulation of deforestation and carbon storage is based on this, with a poverty effect consistent with our Table 2 below, which focuses on the effects of returns and the interactions of returns with poverty that we explore below.

5.2.2 Poverty Effect On Supply Response

Columns II through IV of Table 2 bring poverty indicators into the supply regressions, employing the 1963-2000 measure using its 1963, 1973, 1984, and 2000 value for the intervals. The first result of interest is that, as in Kerr et al. 2003b, controlling with fixed effects (i.e., for observed and unobserved characteristics of land), poorer areas have higher deforestation rates.

Columns III and IV, though, present the evidence that is novel and of greatest interest. The interaction term for poverty and returns is negative and significant. This suggests that poorer

people will respond less to carbon payments, as seen in Figure 1 (this type of result arises for the other continuous poverty indices as well, but is less strong for the poorest-quartile dummies). Column IV conveys that including other controls, i.e. other factors that affect deforestation rates (see Kerr at al. 2003a for extended discussion of the past clearing variable and its interpretation), leaves the interaction term essentially unchanged. As noted, because we are using fixed effects to control for fixed differences across district-lifezones, we do not include other fixed factors that affect deforestation, such as a distance proxy for market acces or fixed ecological conditions.

This result suggests a lack of empirical basis for focusing carbon payments programs on the poor *if* the goal is efficient generation of carbon sequestration (of course, if a program directly favors poverty reduction as an objective, then targeting the poor will remain the obvious choice). Even should the poor be more desperate for marginal income than those with greater wealth, as noted above they may face a range of barriers to switching land uses which discourage supply. On the other hand, this interaction is not a large effect and in general land users will respond. The Discussion section below considers further the potential for the poor to receive carbon payments.

5.3 <u>Simulating Carbon Baselines & Carbon Supply</u>

Though we have already referred to the figures, from our simulations of carbon outcomes, here we explain our simulations. To calculate carbon we multiply the amount of forest in each district by the amount of carbon that district's forest can potentially store. The carbon storage numbers used in this study are given in Table 1. For further explanation, see Kerr et al. 2003c.

We then forecast deforestation when net returns to land clearing are lower by the amount of the carbon return (i.e., carbon price x carbon/hectare). Our predictive equation becomes:

$$y(t) = \ln\left(\frac{h}{1-h}\right)$$

$$= \sum \beta_s x_{static}(i) + \sum \beta_d x_{dynamic}(t,i)$$

$$+ \sum \beta_{returns}(returns - carbon\ price \times carbon\_per\_ha(i)) + \sum \beta_t D(t)$$

where h is the measured district-lifezone deforestation rate, x_{static} are the solely spatially varying explanatory variables (distances, lifezones, soils), $x_{dynamic}$ are spatially and temporally varying explanatory variables, $D(t)$ is a function of time estimated using a time-dummies version of the regression in question from Table 2, and β are all of their regression-estimated coefficients.

The difference between the carbon stocks in this case and in the baseline is the additional carbon induced by the carbon return. We can then calculate supply for each value within a range of carbon prices by projecting forward as we did for the baseline projections. Doing so maps out a supply or cost curve. This can be used to predict the likely responsiveness of sequestration in tropical forest to carbon rewards (the horizontal distance to the curve at each price). It also can be used to estimate the cost of sequestering a given level of additional carbon (the integral under the curve up to the chosen level of carbon).[10] The earlier units supplied are cheaper to sequester, and then the carbon gets increasingly expensive as more valuable agricultural land is protected.

Supply is measured as an annual stock, the cumulation of several years of reduced deforestation. It could differ depending on the year a program starts. We present this way partly to avoid misinterpretation if we presented it as an increase in the stock each year. Also, carbon

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[10] Supply is measured as an annual stock, the cumulation of several years of reduced deforestation. It could differ significantly depending on the year a program starts. We present this way partly to avoid possible misinterpretation if we presented it as an increase in the stock each year. Also, carbon sequestration is reversible and defined relative to a changing baseline, such that incremental supply could be negative in some years. We do not want to create the impression that the supply is created once and is then secure. If the program were stopped, a lot of the gains could be rapidly lost as land than was protected from deforestation is suddenly cleared once clearing incentives change.

sequestration is reversible and defined relative to a changing baseline, such that incremental supply could be negative in some years. We do not want to create the impression that the supply is created once and is then secure. If the program were stopped, a lot of the gains could be rapidly lost if land protected from deforestation were suddenly cleared once incentives ended.

Figures 1 and 2 provide two ways to see the implications of Table 2's land-use results when they are jointed with the carbon-per-unit-forest values in Table 1. Both follow from the results in column III of Table 2. Figure 1 conveys that payments that change agricultural returns, relative to returns to standing forest, will increase the carbon stock retained in forests over time yet also that the poor are estimated to be less responsive to payment. This makes a difference.

Figure 2 is different in two ways, conveying some of the different ways to view results of this kind. First, it presents actual carbon supply curves, i.e. levels of increase in carbon storage relative to the baseline, in both poorer and richer areas, as a function of the level of the payment. This demonstrates the kind of information that could inform decisions about whether or not to participate in a market for carbon services, as the potential benefits can be computed in advance.

Second, it presents the results on a *per capita* basis. The fact that there is more forest per capita in the poorer areas is seen in Figure 2 to outweigh the lower responsiveness of the clearing in poorer areas. This raises again the idea that payments policies could potentially provide some significant benefit to the poor while protecting forests, something that we discuss further below.

6. Discussion

In this paper, we adopted a revealed preference approach to estimating both the potential supply response to sequestration payments and the effects of poverty upon the level of responsiveness. We used data on Costa Rican forests for five points in time along with a poverty index from FAO

to estimate responsiveness and to simulate the supply of avoided deforestation for Costa Rica, finding that, in general, land users will respond to payments, and that the poor will respond less. This is consistent with findings from the literature on general agricultural response to incentives. Despite the latter result, since users respond in general, some land users are poor, and much of the forest is in poorer areas, there seems to be potential for payments that would at once support the conservation of forests and effect transfers to poorer people to address concerns about equity.

A caveat concerning transfers to the poor concerns the current details of the CDM. Avoided deforestation, as noted, is currently excluded from the activities that generate credits. Thus being in an area with a lot of forest and keeping it in forest would not be rewarded with carbon-services payments under the CDM. This limits the advantage, with respect to carbon payments, that the location of much of the forest within poorer areas could otherwise convey.

Considerable work remains to finalize the rules under which sequestration programs such as the CDM will operate. The way these are settled is likely to have considerable importance for the potential of such programs to reach the poor. Another key issue for the poor in the adoption of a new technology, such as changing land use for payments, is the risk within the policy design.

A risk that arises in the market for carbon sequestration services comes from the uncertainty of actual sequestration levels meeting projected sequestration potential. Thus land users may enter into a sequestration agreement but find that they have not met expected levels, even though they have followed recommended practices. In addition, the setting of the baseline involves some uncertainty, particularly if these are allowed to be updated over time as proposed.

The way in which carbon contracts are designed and monitored will determine to what extent this risk will be shared between buyers and sellers. If land users are paid on a per hectare basis for the adoption of practices, the seller would assume the risk of falling short. Alternatively

of land users are paid for carbon sequestered they assume the risk. The efficiency of adopting either scheme will be determined by the relative costs associated with monitoring land use practices versus monitoring carbon tonnage, as well as the heterogeneity of biophysical and economic conditions which impact sequestration supply. (Antle & McCarl 2001). In terms of the potential impact on poor land users' participation in carbon markets, the adoption of contracts based on a per hectare adoption of land use practices is clearly more beneficial. Poor land users are unlikely to be capable of bearing the risk associated with carbon supply shortfalls.

Finally, an important caveat is necessary, given that our data on poverty and clearing are not for households but for districts. It is possible that even in poorer areas, where a large fraction of the inhabitants may be relatively poor, those who own the land are not nearly as poor. Should that be the case, then if services and service payments are roughly proportional to land holdings the payments flowing to *poorer areas* would not be received by the *poorest people*. Such a situation with respect to land ownership could hinder efforts to support forests and equity. This suggests the value of repeating exercises such as that carried out here but using household data.

In sum, payments for environmental services can be an important way in which poor land users can be assisted while contributing to global goals. But there may be conflicts between the multiple goals many have in mind for such payments programs. Projects maximizing poverty alleviation may be quite different from projects maximizing carbon sequestration. For efficiency of the latter, more about the distribution of sequestration potential can help, as would information on when provision of environmental goods and services also yields private production benefits to farmers. In those settings, required payments should be lower. And leveraging carbon payments with payments for other environmental services could be efficient.

However, both equity and efficiency goals were intended within the agreements reached at Rio in 1990. The idea then was that it is neither fair nor effective to demand the provision of environmental services from the poor unless this also offers the potential for better livelihoods. But for this to be the case, more focus on that goal and efforts to achieve it will be necessary.

The analysis presented in this article suggests that poor land users are not necessarily going to be the major beneficiaries of environmental services payments. Nonetheless, carbon sequestration payments could help to address poverty while also satisfying others' environmental goals, which could function as a new means of financing rural development efforts. But again, for this to occur focused efforts will be necessary. Structuring payment programs to address the insurance needs of the poor and their investment constraints is one important means to promote poor land user participation in environmental service payment programs. Facilitating group coordination of land management and strengthening property rights institutions is another key measure that may be needed to channel benefits of environmental service provision to the poor.

References

Antle, J. M. and McCarl, B., 2001, The Economics of Carbon sequestration in Agricultural Soil, in Volume VI of the *International Yearbook of Environmental and Resource Economics*, edited by Tom Tietenberg and Henk Folmer, published by Edward Elgar

Ball, Jeffrey. April 16, 2003   Wall Street Journal "Global Warming is Threat to Health to Corporations" Section A. Pg. 2.

Beckerman, W., 1995, *Small is stupid - Blowing the Whistle on the Greens*. London, Duckworth.

Bass, S., O. Dubois, J. Ford, P. Moura-Costa, M. Pinard, R. Tipper, C. Wilson (1999) Rural Livelihoods and Carbon Management: An Issues Paper available for download from http://www.ecosecurities.com

Black_Arbelaez, 2002, *Applying CDM to Biological Restoration Projects in Developing Nations: Key Issues for Policy Makers and Project Managers,* available at: http://www.gefweb.org/documents.pdf

Callaway, J.M. and McCarl, Bruce. The Economic Consequences of Substituting Carbon Payments for Crop Subsidies in U.S. Agriculture. *Environmental and Resource Economics,* January 1996, 7(1), pp 15-43.

Chomitz, K. E. Brenes, L. Constantino "Financing environmental services: the Costa Rican experience and its implications" *The Science of the Total Environment* 240 (1999) 157-169

Ciesla, W.M., 1995, *Climate change, forests and forest management: an overview,* in: *FAO Forestry Paper, (FAO)*, no. 126 / FAO, Rome (Italy).

Committee on Abrupt Climate Change, O. S. B., Polar Research Board, Board on Atmospheric Sciences and Climate, National Research Council (2001). *Abrupt Climate Change: Inevitable Surprises*. Washington D.C., National Academy Press.

Ehrlich, P.R. and Ehrlich, A.H., 1996, *Betrayal of Science and Reason - How anti-Environmental Rhetoric Threatens Our Future,* Washington D.C.: Island Press.

GTZ, Deutsche Gesellschaft für Technische Zusammenarbeit, (2001), *On track towards climate protection*. Eschborn, Germany.

Harrison, Susan 1991 Population Growth, Land Use and Deforestation in Costa Rica, 1950-1984 Interciencia March-April 1991 Vol. 16 No. 2 pp. 83-93

Intergovernmental Panel on Climate Change, IPCC, (2001b). *The Science of Climate Change 2001*. Report of the Working Group I. Available on line at: http://www.usgcrp.gov/ipcc/default.html

Intergovernmental Panel on Climate Change, IPCCC, (2001a). *Climate change 2001: Impacts, Adaptations, and Vulnerability.* Report of the Working Group II. Available on line at: http://www.usgcrp.gov/ipcc/default.html

Kerr, Suzi (2001) "Seeing the Forest and Saving the Trees: tropical land-use change and global climate policy" in *Can Carbon Sinks Be Operational? RFF Workshop Proceedings*, Roger A. Sedjo and Michael Toman July 2001 Resources for the Future Discussion Paper 01–26 www.rff.org

Kerr, S., A.S.P. Pfaff and G.A. Sanchez-Azofeifa (2003a). "Development and Deforestation: evidence from Costa Rica". Requested revision resubmitted (and see www.motu.org.nz).

Kerr, S., A.S.P. Pfaff, R. Cavatassi, B. Davis, L.Lipper, G.A. Sanchez-Azofeifa, and J. Timmins (2003b). "Effects of Poverty on Deforestation: distinguishing location from behavior".

Kerr, S., J. Hendy, S. Liu, A.S.P. Pfaff (2003c). "Uncertainty and the Contribution of Tropical Land-use to Carbon Mitigation".

Kishor, N.M. and Constantino L.F. 1993 Forest Management and competing land uses: and economic analysis for Costa Rica, World Bank: LATEN dissemination note no. 7, 1993 cited in Kenneth Chomitz, E. Brenes and L. Constantino 1999 "Financing environmental services: the Costa Rican experience and its implications" The Science of the Total Environmentl 240 (1999) 1570169.

Lal, R., Kimble, J. M., Follett, R.F. and Cole, C.V., 1998, *The potential of US cropland to Sequester Carbon and Mitigate the Greenhouse Effect*, Chelsea, MI: Ann Arbor Press.

Levia, D. F. 1999. Land degradation: Why is it continuing? *Ambio* 28(2):200-201.

Meyers, N. and Simon, J., (1994). *Scarcity or abundance? A debate on the environment.* New York, W.W. Norton.

Nasi, Robert, Sven Wunder and Jose J. Campos (2002) "Forest Ecosystem Services: Can They Pay Our Way Out of Deforestation?" Discussion paper prepared for GEF for the Forestry Roundtable New York, March 11, 2002. Available at http://www.gefweb.org/documents.pdf

National Research Council (NRC), (2001). *Climate Change Science: An analysis of some key questions.* Washington, D.C., National Academy Press.

Parks, Peter J. and Ian W. Hardie (1995) Least Cost Forest Carbon Researves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forests. *Land Economics* 71(1): 122-36

Plantinga, Andrew, Thomas Mauldin and Douglas Miller 1999 An Econometric Analysis of the Costs of Sequestering Carbon in *Forests American Journal of Agricultural Economics* 81 pp. 812-824.

Simon, J. L. (1995). *The State of Humanity*. Cambridge (Mass.), Blackwell.

Stavins, R. 2000. The costs of carbon sequestration: A revealed preference approach. *American Economic Review.*

Tipper Richard (1996), *Mitigation of Greenhouse Gas Emissions by Forestry: A Review of Technical, Economic and Policy Concepts*, Working paper, Institute of Ecology and Resource Management, University of Edinburgh, Scotland.

More References

Aguilar, J., Carlos Barboza, and Jorge Leon. 1982a. *Desarollo tecnologico del café en Costa Rica y las politicas cientifico tecnologicas.* Consejo Nacional de Investigaciones Cientificas y Tecnologicas, Costa Rica.

———. 1982b. *Desarollo tecnologico en la ganaderia de carne.* Consejo Nacional de Investigaciones Cientificas y Tecnologicas, Costa Rica.

Arias, Jose, and Rafael Corrales. 1992. El sub-sector carne (ganaderia bovina) de Costa Rica, su sistema agroindustrial, comportamiento, limitaciones y fortalezas del mismo. Taller de Evaluacion Economica Centro de Politicas y Economia Aplicada, INCAE.

Barboza, Carlos V., Justo F. Aguilar, and Jorge S. León. 1982. *Desarollo tecnologico en el cultivo de la caña de azucar .* Consejo Nacional de Investigaciones Cientificos y Tecnologicas, Costa Rica.

Chaves-Solera, M. A. 1994. *Organizacion de la agroindustria azucarera costarricense y costos de produccion agricola de la caña de Azucar.* DIECA 59p. San Jose, Costa Rica.

Chavez-Solera, M. A., et al. 1998. Area cultivada y rendimientos agrícolas de la caña e azúcar en Costa Rica. 12th Congreso de ATACORI.

de Graaf, F. 1986. *The economics of coffee.* Economics of crops in developing countries no. 1 Wageningen: Dudoc.

Consejo Nacional de Produccion, Costa Rica. Unidad de analisis de politicas, carne de vacuno "Principales variables estadisticas 1980–1995."

Mendez, Nora Bermudez, and Rosa Maria Pochet Coronado. 1979. La agroindustria de la caña de azucar en Costa Rica: Modificaciones economicas y sociales (1950–1975). Informe de Investigacion, Confederacion Universitaria Centro Americana ESUCA Program Centroamericano de Ciencias Sociales

Ramos Mendez, R. A., and Aguzzi G. Brenes. 1997. Distribucion de la produccion de café por cantones y provincias, cosecha 1996–1997. Instituto del Café de Costa Rica: Departmento de Estudios Agricolas Economicos y Liquidaciones.

Vargas, J.R. and O. Saenz. 1994. *Costa Rica en cifras 1950–1992.* MIDEPLAN PNUD.

Vigne, Alain. 1974. *Costos de produccion en ganado de carne Costa Rica.* Ministerio de Agricultura y Ganaderia: Departmento de Economia y Estadisticas Agropecuarias. San Jose, Costa Rica.

Appendix – direct measure of returns from beef, coffee, sugar and bananas

Units: crop price is in $/kg; yield is in kg/ha; production cost is in $/ha; transport cost is in $/ha.

Observations: 436 districts in Costa Rica from 1900-1997 in principle, but 1950-1997 in fact. The limitations on historical data mean that we do not have good measures for years before 1950 and more generally even within 1950-1997 the quality of the data is higher for the later intervals.

Prices: though some production is sold domestically, Costa Rica is a small country and we use exogenous export prices (in 1997 US$). Price data are taken from two sources, the Costa Rican Ministry of Planning (Vargas and Saenz 1994) and the Central Bank of Costa Rica website.

Yields: crop yields vary over time because of technological change, and across space because of differences in general productivity and in suitability for particular crops. While lifezones and soils proxy for this variability, here we estimate yield. For instance, in some areas the yield for a particular crop is effectively zero since it would never be grown there. Our data is of two types.

 For some crops we have data on yield per hectare: for bananas, county level for 1977-1997, and given no obvious trend we assume this to be constant before 1977; for sugar, province level for several years between 1950 and 1977 and for county level in 1998, and we apply the province-level trends to extrapolate the yields for all counties within a province before 1998.

 Else we observe production (kg) and area in production (ha) and divide to get the yields. For coffee we have production from 1974-1992 and 1996 at county level and area at county level from the census for 1950, 1955, 1963, 1973, and 1986. We assume production is fixed pre-1974 and area is fixed post-1986, and then interpolate the coffee areas before calculating yield ratios. For pasture we use national production from 1950 to 1995 and divide by census estimates of area for a national yield estimate. We create county-level variation by utilizing the ratio of number of cattle to pasture in the census data, assuming this variation is related to productivity. In locations where the yields for particular crops are undefined within our data, we assume that they are zero.

Costs: we estimate operating costs on an annual basis, although the data are sparse. For coffee, we observe costs only in 1979 and 1981 by coffee zone. For beef we have a single reliable estimate from 1974 at the national level. For sugar, data is better although still at national level, with estimates from Barboza, Aguilar, and León 1982 and Chaves-Solera 1994 for 1963, 1966, 1972, 1977, 1979 and 1994–96. For bananas we have a technical estimate from Hengsdijk (personal communication, Wageningen Agricultural University) for 1997, but no previous data. These are assumed constant outside the period within which they are observed and interpolated. For transport costs, lacking direct measures, currently we rely upon the proxy described above.

Crop Shares: to predict how likely each of the four crops is to be chosen, we use a combination of census and satellite land-use data to estimate the share of each crop in each district. While the satellite data are more precise, they distinguish not crops but simply land uses (permanent crops, pasture, and forest). The data is from 1973 and 1984, and our shares do not change over time.

We combine the district shares with the crop returns for expected annual return per district-year, following (6) above. Then we average the returns across intervals to generate mean returns to which we assume our estimated constant annual interval deforestation rate will have responded.

Table 1 Carbon Stocks by Lifezone

Life zone	GEMS	
	Mean	Std dev as % of mean
Premontane moist	159	43%
Lower montane moist	134	45%
Tropical Moist	156	24%
Premontane wet	156	32%
Lower montane wet	113	54%
Montane wet	119	34%
Tropical Wet	336	40%
Tropical Dry	96	41%
Premontane rain	120	49%
Lower montane rain	116	58%
Montane rain	96	86%

We estimate potential carbon storage in primary forests with the General Ensemble Biogeochemical Modeling System (GEMS) that incorporates spatially and temporally explicit information of climate, soil, and land cover (Liu et al. 2002a; Liu et al. 2003). GEMS is a modeling system that was developed for a better integration of well-established ecosystem biogeochemical models with various spatial databases for the simulations of the biogeochemical cycles over large areas. The well-established model CENTURY (Parton et al. 1987; Schimel et al. 1996) was used as the underlying plot-scale biogeochemical model in this study. It uses a Monte-Carlo-based ensemble approach to incorporate the variability (as measured by variances and covariance) of state and driving variables of the underlying biogeochemical models into simulations. The mean values and their corresponding standard deviations of aboveground biomass carbon density simulated by GEMS are listed in Table 1.

Table 2 **Regression results used as basis of supply simulations**

	Grouped Logit			
	I	II	III	IV
Dependent	annualised	annualised	annualised	annualised
Variable	def. prob.	def. Prob.	def. prob.	def. prob.
Explanatory Variables	Coefficients			
	(standard error)			
RETURNS	.00010	.00009	.00011	.00009
	(2.8)	(1.4)	(1.6)	(1.4)
POVERTY		0.13	0.17	0.17
		(2.6)	(3.2)	(3.2)
RETURNS * POVERTY			-.00008	-.000066
			(-2.9)	(-2.5)
%CLEARED				1.2
				(1.3)
%CLEARED^2				-3.3
				(-3.5)
TIMEDUMMY 1979-1986	0.55	0.88	0.95	1.1
	(10)	(8.3)	(8.8)	(8.8)
TIMEDUMMY 1986-1997^2	-0.51	-0.24	-0.18	0.095
	(-7.4)	(-1.3)	(-0.98)	(0.44)
TIMEDUMMY 1997-2000	-1.6	-1.4	-1.4	-1.1
	(-13)	(-4.6)	(-4.8)	(-3.6)
CONSTANT	-3.2	-3.6	-3.7	-3.5
	(-110)	(-18)	(-18)	(-16)
FIXED EFFECTS	F = 7.8	F = 7.8	F = 7.8	F = 6.4
	(P = 0.00)	(P = 0.00)	(P = 0.00)	(P = 0.00)
ADJUSTED R^2	0.69	0.74	0.75	0.76
N	1621	973	973	973

Coefficients reported with t statistics below them in parentheses (except for the fixed effects, where F reported above with P value below).

Figure 1 -- Carbon outcomes for richer and poorer districts in response to a $10 annual carbon payment, post 2000
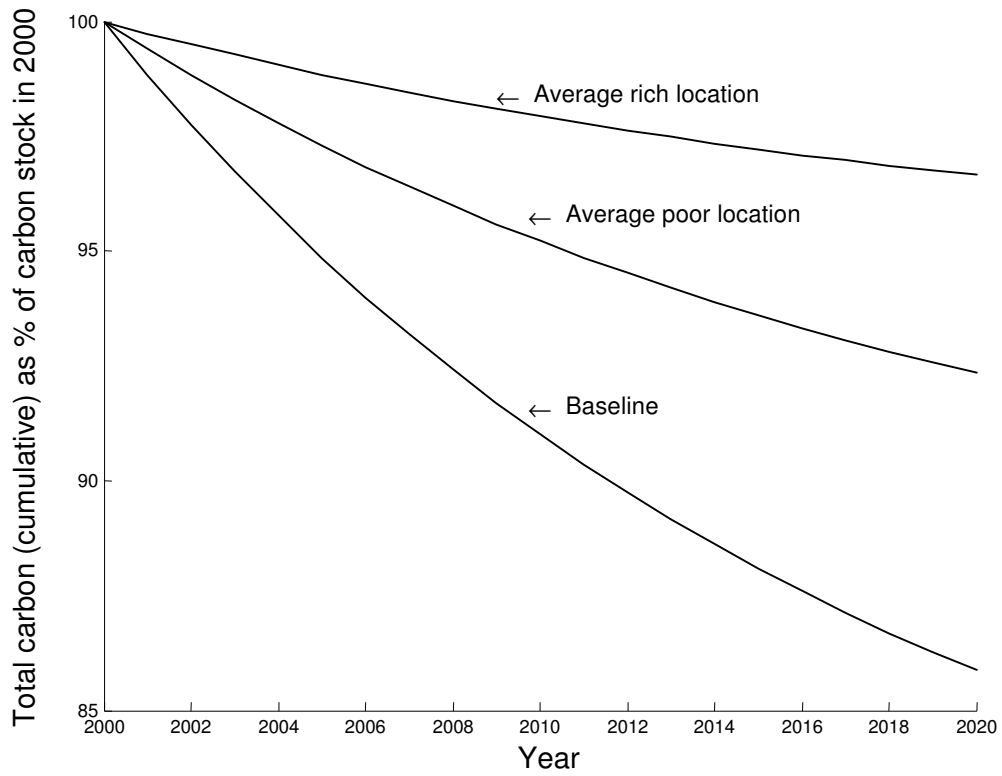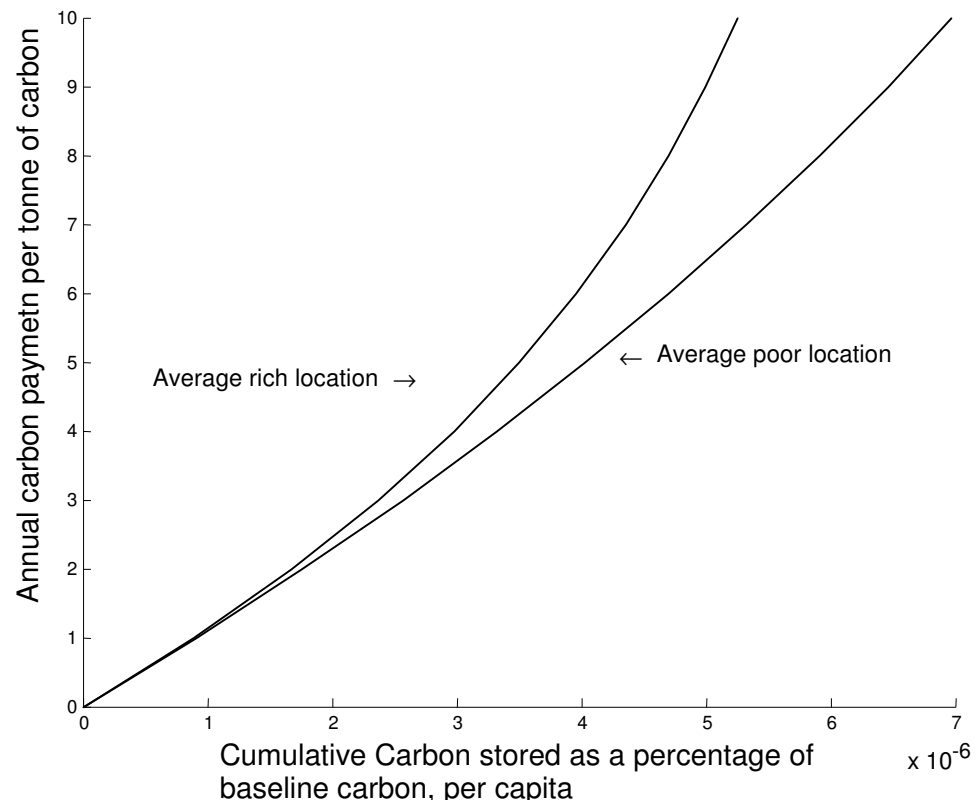
Figure 2 **Carbon supply per capita for richer and poorer, post 2000**

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