Chapter 15

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The Dynamics of Deforestation and the Supply of Carbon Sequestration:

Illustrative Results from Costa Rica

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Introduction

This chapter aims to contribute to the effective design of the rules that could allow low-cost carbon sequestration efforts in any number of tropical locations to replace high-cost emissions-reduction efforts in developed northern countries.[2] The Clean Development Mechanism (CDM) of the Kyoto Protocol could potentially create such a market. This market could provide benefits for the tropical countries both directly, through profits from the sale of certified emissions credits (CERs), and indirectly, through side-benefits from forest protection, including biodiversity protection, watershed protection, and increased tourism potential. Creating the rules for such a market, however, involves considerable fixed costs. Participating in the market involves large costs on the part of the countries producing CERs. Can the market generate sufficient supply of CERs to justify the costs of its creation? What will the effect be of including tropical carbon sequestration on the global carbon price?

The integrated analysis in this paper provides an illustration of a methodology that can be used to estimate the potential value of CERs from the protection of existing forest, and form a dynamic supply function. The model can also indicate which local characteristics are likely to contribute to high values from participation in the land-use component of the CDM. We use data from Costa Rica to estimate the model and simulate results.

The simple economic model estimated here addresses what would happen to primary forest cover in various counterfactual scenarios, for example, with a baseline (no international

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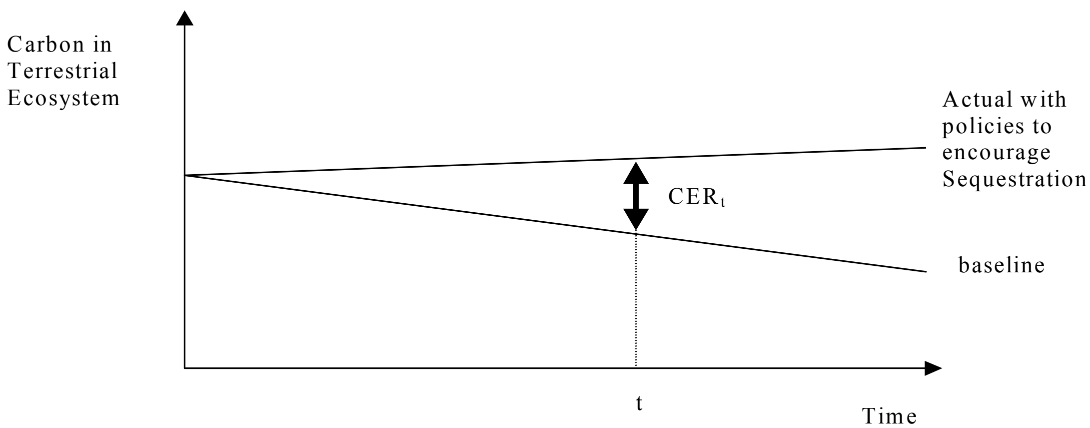
2 ‘Annex I countries, primarily the OECD states, have commited to greenhouse gas limitations between 2008 and 2012, but these limitations could be eased through purchases of credits from elsewhere through the Clean Development Mechanism.

policies to encourage forest protection) in relation to different international carbon prices in different years. We combine these forest-cover predictions with ecological estimates of carbon stocks in forest to estimate the way the carbon stock will vary under the different scenarios. Figure 15-1 below indicates how certified emissions reductions (CERs) for carbon sequestration efforts are ideally defined relative to a baseline of expected carbon stocks in the ecosystem with no carbon payments. CERs are defined only above a baseline level of sequestration because they have to be "additional" to what would have occurred otherwise. Each CER created allows an increase in equivalent emissions; if a CER were given for sequestration that would have happened anyway, global emissions would rise as a result of the trade.

Our estimates are done at a national level and yield a national supply curve. Although we do produce district-level deforestation predictions under different scenarios, these should not be used as the basis of baselines for individual projects in the absence of a national program. Because of leakage and general equilibrium effects, isolated local projects are likely to yield different levels of supply than the same area in the context of a nationwide program.

Figure 15-1. Definition of Certifiable Emission Reductions (CERs)



Forestry and land-use projects are valuable to combat climate change insofar as they generate certified emission reductions by putting land into or keeping land in a forested state. These CERs are rather like negative emissions of carbon; in the case of a reforestation project, the number of CERs produced is based on the level to which the forest sequesters carbon. The CERs are ultimately for sale to those whose carbon emissions are constrained as a result of policy decisions to limit global carbon emissions, i.e., the Annex I countries, which are basically OECD countries. If a seller and buyer have been able to find a mutually agreeable price, it is generally assumed that this price is greater than the seller's return from alternative uses of the land, and less than the costs of the buyers' other mitigation options, with a difference between the two greater than the transaction costs. Thus, a trade reduces the buyer's costs by more than the supplier's lost opportunities.

If the CERs are real and permanent, this trade has no net effect on greenhouse gas emissions. However, because a forest will grow for a number of years and then store its carbon until it is cut, we need to account for how CERs that are sold relate to actual inter-temporal emissions. Land and forestry CERs must be made comparable with other ways to reduce net carbon emissions, such as lowering fossil fuel emissions.

A CER created through carbon sequestration is not directly equivalent to a reduction in fossil fuel emissions. Because land-use changes can be reversed, CERs can disappear. At each point in time, the true amount of additional carbon sequestered is the difference between the quantity of carbon storage or accumulation attained if the project occurs, and the quantity expected in absence of the project (i.e., in the baseline). For example, if in the baseline a piece of land with climax vegetation will be cleared, but due to the project the forest remains intact, the CER generated by the project is the difference in carbon stock between climax vegetation and cleared land. Carbon stored in climax vegetation and rates of accumulation vary by the physical and climatic characteristics of the site; baselines and project impacts will have to account for such factors.

In many cases, however, the CER will be temporary. This is the case with a plantation of crops that is harvested upon reaching maturity—where deforestation is delayed but not permanently avoided.[3] When land is protected, a CER is created and fossil fuel emissions can rise by the same amount as the CER. If the land is later cleared, fossil fuel emissions in the later year will have to be reduced to compensate for the resulting fall in the stock of sequestered carbon. Even a temporary CER, however, can be valuable to a buyer in a developed country, through allowing compliance with short-term obligations. Otherwise, necessary emissions reductions (e.g., based on fuel switching or improvements in energy efficiency) can be delayed until technology change lowers the cost of such improvements. Thus, temporary CERs can be a way to permit a transition period, and save costs, by loosening a binding constraint.

With international trading, the total value of a permanent CER will be roughly equal to the cost of reducing the equivalent amount of carbon emissions in an alternative way. This will be the price of a carbon permit, defined as one unit of permanent CER.[4] Because of the temporary nature of sequestration CERs, we model the problem as though landowners are paid a lease price for every period that the carbon remains sequestered. The risk-adjusted present discounted value of these annual payments is the international carbon permit price.

This would be one way to deal with the problem of impermanence in the Clean Development Mechanism. The developed-country buyer of CERs could be made legally liable for replacing the CER if the forest is cut at a later point. This would not be a punitive provision but would simply recognize that the CER is leased, not bought outright. The buyer would then have an incentive to obtain a long-term contract with the country that produced the CER. If buyers have use of the CER for only five years, they will probably not want to pay the price of a permanent CER. The CER-supplying landowner will receive the price and contractual terms agreed to by the buyer. Payments may be spread over time, either as the trees grow or because land use is uncertain.[5] The developing country could maintain the option to develop the land at a later date. This would simultaneously address environmental concerns about the permanence of land-use–based CERs and developing country concerns that their land is being locked up by carbon sequestration projects, thus limiting their future development options.

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[3] In this case, however, it may be argued that harvesting the plantation will provide raw material that would otherwise be extracted from other sources (e.g., existing natural forest).

[4] We say "roughly" because uncertainty about the permanent nature of the permit may lower the value.

[5] The "landowner" could contract with the permit buyer to get all the value immediately and have the buyer deal with the delay in the creation of the offset and bear any uncertainty.

We consider the effect of increasing the carbon price for forest on all plots of land in the country. Landowners receive the payment as long as the carbon remains in the ecosystem. This is not intended to represent a real policy, although a national incentive program could potentially be devised to approximate this, but rather to provide an upper bound on the potential of such systems. In reality, poor design, monitoring, and transaction costs are likely to reduce gains relative to their potential.

In this chapter we consider only potential gains derived from preventing deforestation. (Alternatively, the CDM could create significant gains through incentives to refores—this will be the subject of future research.) This chapter draws heavily from information from Chapter 14: Tropical Forests in Climate-Change Mitigation. It uses the same economic model and econometric technique and the same land use/land cover data. It also uses the carbon stock estimates presented there. The key difference is that, instead of using proxies for land-use returns such as ecological characteristics related to higher productivity, we attempt to directly estimate dollar-valued returns. We use these as an independent variable to explain and predict deforestation patterns. This allows us to simulate the potential supply of carbon sequestration in response to dollar-valued returns for certified emissions reductions.

Payments for CERs will reduce deforestation by lowering the net return from forest clearing. The loss of the reward for carbon sequestration will partially offset the positive return from agricultural uses. To estimate the effect of such payments on deforestation, and hence CER supply, we need to estimate the response of deforestation to changes in returns to land use. An increase in agricultural returns is empirically equivalent to a reduction in carbon CER payments.

Thus, we construct a variable that estimates the potential return of a plot of land if it is cleared. We construct a variable that varies across space (different crop suitability and yields) and time (changes in export prices, technology, and labor costs). We then use this variable in our econometric estimation. The results are used to calculate a supply curve of CERs.[6] These results are illustrative only.[7] They are produced as part of an ongoing effort at estimation (Kerr, Pfaff, Hughes et al. 2000) and are used to show some underlying features of a dynamic supply curve.

A Simple Model of Deforestation

Following the model in the previous chapter, the land manager of each hectare j faces the following dynamic optimization problem. We have added here the role of potential carbon payments. The land manager selects T, the time when land is cleared, to maximize the present discounted value of returns from the use of hectare i.

$$\text{Max}_T \int_0^T (S_{it} + p_c F_i)\, e^{-rt}\, dt + \int_T^{\infty} R_{it}\, e^{-rt}\, dt - C_{iT}\, e^{-rt} \qquad (1)$$

where

[6] Earlier studies (Stavins (2000) and Plantinga, Mauldin and Miller (1998)) have used a similar approach based on econometric studies to create static supply curves in the United States.

[7] The current results are based on poor-quality data that is highly aggregated. In future work we are incorporating more data on land-use returns, more years of land-cover data, and more disaggregated land-cover data. We are also working to produce independent, more reliable estimates of carbon stocks and flows. In addition, the methodology we are using is still in development.

S_{it} = Potential return (rent) to forest uses of the land

r = The discount rate

p_{ct} = CER lease price = r * international carbon price at time t

F_i = Carbon stock per hectare of standing forest in location i

R_{it} = Maximum potential return to non-forest land use

C_{iT} = Cost of conversion to agricultural land, net of obtainable timber value and including lost option value

To be comparable with the estimates of annual agricultural returns, carbon prices are expressed as annual cost. Thus p_c is the payment for maintaining one additional ton of carbon for one year. In contrast to fossil fuel emissions, where one ton of fewer emissions is considered a permanent CER, this is a temporary CER and the payment is more a lease payment.[8] One of the first order conditions of this problem, the "arbitrage" condition, is sufficient for the solution if agricultural returns are growing relative to private forest returns and net costs of conversion are always falling at a decreasing rate.[9]

$$R_{it} - S_{it} - p_{ct}F_i - rC_{it} + \frac{d}{dt}C_{it} \geq 0 \tag{2}$$

Note that the return to carbon enters linearly with the return to agricultural uses of the land but with the opposite sign. This means that their coefficients can be constrained to be equal. By estimating the response of deforestation to observed agricultural returns, we can infer the likely response to carbon payments.

In the case of Costa Rica, standing forest is primarily virgin forest with the highest-value timber already removed.[10] The annual private return to holding such forest is assumed to be low and constant. The main reason for a private landowner to hold it is that the land may in the future yield agricultural or other non-forest returns. (Altruistic landowners are the exception rather than the rule.) Thus, S_{it} is assumed to be low and constant across locations. What exactly is R_{it}?

Construction of the Agricultural Return Variable

To construct a rough estimate of land returns we follow the approach used by Stavins and Jaffe (1990). The annual return to a piece of land i, used to grow crop j at time t, is the crop price per kilo, $p_{jt,}$ times the annual yield per hectare, $y_{ijt,}$ minus the costs of production per hectare, cost_{ijt}, and transport cost per hectare, t_{ijt}.

$$\text{Return}_{ijt} = r_{ijt} = p_{jt}.\, y_{ijt} - \text{cost}_{ijt} - t_{ijt} \tag{3}$$

Any plot of land that is deforested will only be used for one crop at a time. Thus, we need to predict how likely each crop is to be chosen. We cannot predict the probability of every use, so we chose the key agricultural land uses. We assume that land not used for these purposes must

8 The permanence of fossil fuel reductions might be contested given that fossil fuel unconsumed is still available for later consumption.

9 This assumption seems reasonable for Costa Rica, especially in the period up to 1986.

10 Our remote-sensing data cannot distinguish intervened and climax forest.

be receiving a similar (or greater) return in its alternative use; otherwise the landowner would have chosen a different use.

We use the crop shares in each district, s_{ij}, as a prediction of the likelihood of each crop being chosen for newly cleared land. These shares are used as weights to create an expected annual return for each district and year.

$$E(r_{it}) = \sum_{j} s_{ij} r_{ijt} \tag{4}$$

We observe only cumulative deforestation over a period of many years. We assume that the cumulative deforestation (translated into a mean annual rate) responds to the mean of returns during that period. This could be interpreted either as annual deforestation responding to annual returns if the response is linear, or annual deforestation responding to a combination of rational forward and adaptive backward-looking expectations about returns. For example we assume that deforestation from 1979 to 1986 depends on mean returns in that period.

$$R_{it} = \text{return}_{i1986} = \sum_{t=1980}^{1986} E(r_{it}) / 7 \tag{5}$$

Econometric Model

The econometric modeling is identical to that in the previous chapter. (We repeat the material for the benefit of those who have not read the previous chapter.) From equation (2) we can derive a hazard rate function that depends on R, $\overline{S}$, C_t and $\frac{d}{dt}C_t$. Given that $p_c = 0$ for all past periods, we cannot observe the response to carbon returns. The hazard rate is defined as:

$$h_{it} = \frac{f(e^*(X_{it}, t))}{1 - F(e^*(X_{it}, t))} \tag{7}$$

where $F(.)$ is the cumulative distribution function for ε.

Economics and other disciplines have often used a class of hazard models called proportional hazard models. In these models, all parcels share a common baseline hazard h_{0t} and their hazard is shifted proportionally, based on their characteristics. The shifter is not time-dependent. β is the vector of coefficients to be estimated.

$$h_{it} = \phi(x_{it}, \beta)\, h_{0t} \tag{8}$$

$\phi(x,\beta)$ could be any functional form. $\phi(x,\beta) = \exp(x'\beta)$ is convenient because it constrains the hazard to be positive without restricting β (the deforestation rate cannot be negative). Inference is also straightforward with this specification. We use a semi-parametric specification for the estimates in this chapter and allow the baseline hazard to be unconstrained with respect to time. The effects of $\overline{S}$, rC, and $\frac{d}{dt}C_t$ are absorbed partly in the constant term that varies over time and partly in response to the percentage of the district already cleared. Unobserved changes in R, $\bar{S}$, rC and $\frac{d}{dt}C_t$ over time are thus absorbed in the baseline hazard.

The deforestation rate for a given district is a simple estimate of the parcel-level hazard rates averaged across a district. d_{st} =1 if the land parcel is cleared between time t and t+1; g_{st} =1 if it is forested at time t; otherwise, both are zero.

$$\hat{h}_t = \frac{\sum_{s=1}^{n} d_{st}}{\sum_{s=1}^{n} g_{st}} = \text{deforestation rate}$$

Thus, an estimate of the district level hazard rate is the proportion of the forest cover at the beginning of the time interval that is cleared during the time interval considered. We use this estimate as our dependent variable.

In the proportional hazard models, we can interpret β as the marginal effect of the variable on the conditional probability of deforestation. The variable we are most interested in is the difference between the return to cleared land, net of the return to forested land, $NRit$ = $R_{it}2\bar{S}_{it}$. The basic form of the equation we estimate is:

$$\ln(\hat{h}_{it}) = \beta_0 + \beta_1 NR_{it} + \beta_2 t + \mu_{it} \qquad (11)$$

where t is a set of time dummies and the log of the percentage of the district already cleared that are used to indicate the stage of development and estimate the baseline hazard.[11]

Data

The land-use data used here is the same as in the previous chapter. (Arturo Sanchez developed it; details are given in the previous chapter.) We observe forest levels in 1979, 1986, and 1997 only. Thus, we consider deforestation in three periods, 1900 (assumed to have no clearing) to 1979, 1980 to 1986, and 1987 to 1997. The dummy variable “year dummy 1900” refers to the first period and the “year dummy 1979” refers to the second. The third is the omitted dummy.

Data Used to Construct Return Variable

In our construction of the return variable, crop prices are measured as dollars per kg, yield as kg/ha, cost as \$/ha, and transport costs as \$/ha. We need estimates for all crops (4 main export crops are used: beef, coffee, sugar and bananas), locations (436 districts in Costa Rica), and years (1900–1997). Although we are estimating deforestation from a base of zero clearing (assumed to be approximately true around 1900), we estimate annual returns only from 1950 onward, largely due to the difficulties of obtaining historical data. We do not expect 1979 forest levels to be strongly affected by pre-1950 returns in any case. For our first estimates of returns presented in this paper, we have created a fairly simple database. We have a mixture of data with varying degrees of spatial and temporal detail; for a description of data see Table 15-1.

[11] μ is not normally distributed because of the construction of the model; thus, our standard errors should be interpreted with caution.

For prices, although some production is sold domestically, we have used export prices because they are exogenous. Costa Rica is a small country that cannot affect international prices. Domestic prices will be related to export prices because we would expect farm-gate prices to be independent of the ultimate market. 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. All prices are converted to 1997 U.S. dollars.

Crop yields vary over time because of technological change. They vary across space because of differences in suitability for particular crops and in general agricultural productivity. In the previous chapter we used life zones and soils to proxy for this variability. Here, we direct estimate yield. In some areas the yield for a particular crop will be zero because it would never be grown there. Our data on yields is collected in two ways. First, for some crops we have direct data on yield per hectare. For bananas we have 1977–97 on a county level. The yield is assumed constant before 1977 for lack of data.[12] For sugar we have data at the province level for several years between 1950 and 1977 and then at the county level in 1998. We use the province-level data to extrapolate the county yields for the years before 1998. The province-level trend is assumed to apply to all counties within the province.

Our second method of estimating yield is to observe production in kilograms and area in production in hectares and calculate yield as production divided by area. This approach is used for coffee, where we have production data from 1974 to 1992 and 1996 at the county level, and area in production data at the county level from the census for 1950, 1955, 1963, 1973, and 1986. We assume coffee production is fixed pre-1974 and area in coffee is fixed post-1986, and then interpolate the coffee areas before creating the ratio. This approach is also used for the yield from pasture, where we take data on national annual beef production from 1950 to 1995 and divide by census estimates of the area in pasture to create a national yield estimate. We then adjust these yields to create county-level variation by utilizing the ratio of number of cattle to pasture in the census data. We assume this is related to productivity. In locations where yields for particular crops are undefined, we assume that they are zero.

The costs of production used are estimates of the operating costs on an annual basis; they do not include a return on the land value because land value is implicitly what we are estimating.[13] Data on production costs is 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 our data is better, though still at the national level. We have 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 data are simply held constant outside the period within which they are observed and interpolated.

We currently do not have data on transport costs. To proxy for transport costs we use the minimum linear distance from the center of the district to the closest of three key locations representing major cities and ports, San Jose, Puntarenas, and Limon. We also include this

[12] There is no obvious trend after 1977.

[13] We should also allow for higher first year costs when land is converted to its current use; these should be used to estimate the terms rC_t and $(d/dt)\ Ct$.

distance interacted with time. Thus, we allow its coefficient to change over time and control for transport costs.[14]

Thus, by interpolation and extrapolation we generate a set of four variables that are estimates of the annual return to each crop in each district in each year. Any plot of land that is deforested will only be used for one purpose. Thus we need to predict how likely each of the four crops is to be chosen. To do this, 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 accurate, they do not distinguish among crops but simply land uses (for example, permanent crops, pasture, and forest). The data used is from 1973 and 1984. We also allocate urban land and land use for crops other than the four export crops. Currently we do not allow these shares to change over time. We use the crop shares in each district as weights to create an expected annual return for each district and year. We assume that cumulative deforestation (translated into a constant annual rate) responds to the mean of returns during the periods. Thus deforestation from 1979 to 1986 depends on mean returns.

We finish with estimates of returns for three periods, 1950–1979; 1980–1986, and 1987–1997, for each district. The estimated return has a mean of $70 per hectare per year, which seems reasonable but is poorly estimated at the tails. It ranges from2$2,513 to $620. The extreme left-hand tail largely results from our current inability to observe production costs during the early years. (Clearly any results drawn from these estimates are only illustrative.) The next step is to use these return project to project a supply curve for C-Sequestration CERs.

Construction of Supply Curve

Step 1: Estimate econometric model.

This is the same approach as in the previous chapter, but all variables that relate directly to returns are replaced by the return variable. The estimating equation is:

ln (annual deforestation rate) = β_0 + β_1 *1900* dummy + β_2 1979 dummy

+β_3 cleared percentage +β_4 return

+β_5 distance to market +β_6 *(*distance to market*)* * time

Table 15-2. Regression Results Used as Basis of Carbon Supply Estimates

Dependent variable = ln (annualized district deforestation rate)

1900–1997: 3 changes

Variable	**Coefficient**	**Std. error**
Constant	-5.8[c]	0.21
Year dummy 1900	-0.43	0.68

[14] This approach does not differentiate transport costs by crop. We might expect crops to go to different locations and have different costs per kilometer per hectare because the weight and perishability of crops vary.

Year dummy 1979	2.1[c]	0.19
ln (cleared percentage)	-0.083	0.061
Land return (1997 US$)	0.00045[b]	0.00023
Distance to market (km)	-0.0034	0.0021
Distance*time	9.4 e-05[a]	3.6-05
F (6, 862)	46.17	
R-squared	0.24	
Number of obs	869	

[a] = significant at 90%; [b] at 95%; and [c] at 99%

Step 2: Calculate land-use baseline.

We apply the estimates from Step 1 to 1997 data to predict deforestation in 1997.

$$\text{Predicted deforestation} = \exp\,(\beta_0 + \beta_1\ \text{1900 dummy} + \beta_2\ \text{1979 dummy} + \beta_3\ \text{cleared percentage} + \beta_4\ \text{return} + \beta_5\ \text{distance to market} + \beta_6\ (\text{distance to market}) * \text{time})$$

We then project the right-hand-side variables for 1998.[15] We update cleared percentage and Forest using the predicted deforestation rate.

$$\text{Cleared}_{j1998} = \text{Cleared}_{j1997} + (1\text{-Cleared}_{j1997})\ \widehat{deforestation}_{j1997}$$

Returns are held at real 1997 levels. The estimates are again used to predict deforestation, now for 1998, in each district. This provides a 2-year land-use baseline in the absence of CER payments.

$$\widehat{Forest\ loss}_{jt} = \widehat{deforestation}_{jt} * Forest_{jt}$$

Table 15-3. Projected Baseline Forest Loss for Costa Rica

1997	9.48 thousand hectares
1998	9.46 thousand hectares

Step 3: Calculate carbon estimates for each district and create carbon baseline.

The Holdridge Life Zone System divides the country into 12 ecological zones and 11 transition zones (Holdridge et al. 1971). We use estimates of carbon stored in above-ground biomass per hectare in each life zone from Helmer and Brown (1998) to estimate changes in baseline carbon stocks and to assign rewards (CERs) per hectare of forest protected. We note that Helmer and Brown's method to compute total above-ground biomass (and thus carbon storage) from forest inventory data is just one among many; some Costa Rican ecologists contest these estimates and point out their shortcomings. Condit et al. (1999), for example, reviewed

[15] We also subtract 0.0001 to partly account for our correction of the problem of taking the log of zero.

alternative equations commonly used to derive biomass estimates from forest inventory data; they applied these equations to the same forest plot (in Barro Colorado Island, Panama) and obtained results that differed by as much as 50 percent. Tosi (1980) and Holdridge (1980), cited in Mora (1995), suggest an alternative approach in Costa Rica.[16] Their approach was used in MINAE (1997). More detailed discussion is given in the Chapter 14.

Table 15-4. Potential Carbon Storage and Accumulation by Life Zone

Life zone	Potential carbon stored (tC/ha)	Proportion of total area (%)
Dry Tropical (bs-T)	7–94	2.8
Humid – Tropical (bh-T)	259	20.9
Very humid – Tropical (bmh-T)	182	22.5
Humid Pre-montane (bh-P)	104	10.9
Very humid – Pre-montane (bmh-P)	153	23.5
Rainy – Pre-montane (bp-P)	159	7.3
Humid – Lower montane (bh-MB)	159	0.5
Very humid–Lower montane (bmh-MB)	210	2.2
Rainy – Lower montane (bp-MB)	162	6.8
Very humid – montane (bmh-M)	—	0.0
Rainy – montane (bp-M)	154	2.5
Rainy – Sub-alpine (bp-SA)	—	0.1

Source: Helmer and Brown (1998) and Life Zone map provided by the Tropical Science Center.

The average carbon stock in forest in each district is estimated by weighting the carbon in each life zone by the share of the district that is in that life zone.[17]

$$\text{carbon}_j = \sum_{LZ=1}^{12} \text{carbon}_{LZ}.\ \frac{\text{LZ hectares}}{\text{hectares in district}}$$

Average carbon per hectare = 166 tons (std. dev. = 52)

Range: 94–259

Carbon Baseline.

The change in carbon stock implied by the estimated deforestation path is:

$$d\text{Carbon}_t = \sum_i \widehat{forest\ loss}_{it}\ .\text{carbon}_i$$

Annual carbon lost in baseline in 1997 = 1.36 million tons

[16] Our longer-term project has collected field data and is working to develop and test the Tosi model as well as calibrating and validating the CENTURY model, a process based model.

[17] In fact rather than using hectares we use the sum of all identified lifezones because the 12 lifezones do not cover all of Costa Rica. Future work will take into account the lifezone of the specific forest parcels predicted to be lost rather than the proportions in the district as a whole.

Step 4: Create net returns—including carbon CER payments.

The carbon stock per hectare is next multiplied by a series of CER prices, p_c, to give the return to standing forest. If the price of a CER is \$10 and the real rate of return is 10 percent, the annual return to sequestration will be \$1. The net return to clearing is now:

$$\text{net return}_{it} = \text{return}_{it} - p_c.\ \text{carbon}_i = R_{it} - Sit - p_{ct}F_i$$

Step 5: Estimate carbon stock for different CER prices and years.

(i) Carbon stock with CER payments for one year.

First we use the regression estimates again to predict deforestation where return is replaced with net return. The resulting deforestation rate defines a path of forest cover and hence carbon. We calculate the difference between the change in carbon stock with a positive carbon price and the change in carbon stock in the baseline. This leads to an estimated carbon stock that depends on the CER price p_c.

$$d\text{Carbon}_t\,(p_c=0.1) = \sum_j \hat{Forest\ loss}_{jt}\,(p_c=0.1).\ \text{carbon}_j$$

Table 15-5. CER Supply (tons)

Year	**Annual payment P_c**	**Thousand tons of CER leased**
1997	\$0.50	44
1997	\$1.0	87
1997	\$1.5	128

Table 15-5 shows our illustrates our estimates of the number of tons of carbon we can expect to save from deforestation in 1997 at different levels of carbon payment. Clearly, if the payment is zero, we are in the baseline case and no CERs are supplied.

Figure 15-2. Projections of Carbon Stock: Baseline and Positive P_c

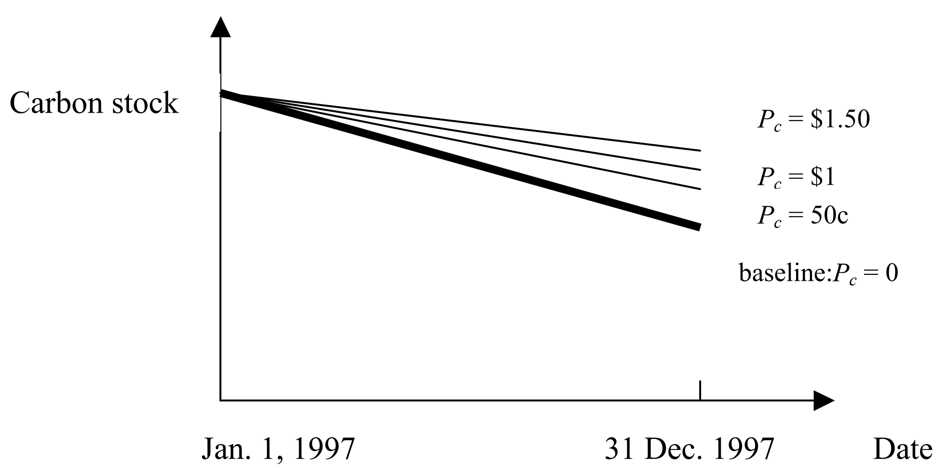
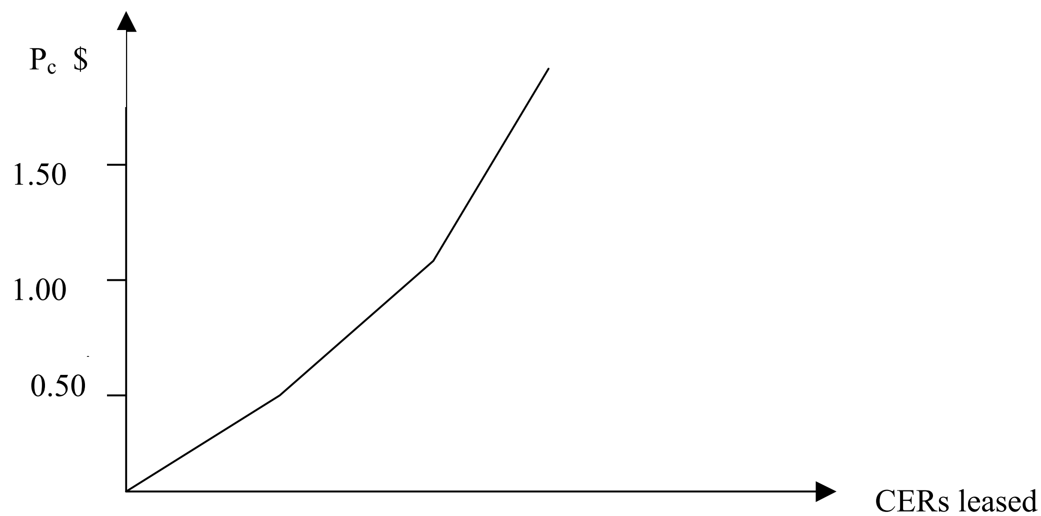


Figure 15-2 shows the projected carbon stock in the baseline and for two levels of carbon price. Higher carbon prices mean that the carbon stock falls more slowly. The relationship between carbon prices and changes in the carbon stock can also be represented in the traditional way as a one-period supply curve. This is shown in Figure 15-3.

Figure 15-3. CER Supply in 1997



(ii) Carbon payments over multiple years.

Table 15-6. 1997 and 1998 Estimated Baseline and Supply

Year	Annual payment p_c	Thousand tons of carbon lost	Thousand tons of CER leased
1997	0	1,361	0
1997	\$1.0	1,274	86.7
1998	0	1,359	0
1998	\$1.0	1,273	172.6 (86.7 from 1997 + 85.9 from 1998)

As we see in Table 15-6, even with the same payment, the number of CERs leased changes over time. In the third column of Table 15-6 we see the number of tons of carbon lost each year at different prices. Baseline loss of carbon falls slowly with time, but the amount of carbon lost with annual payments falls more slowly so that the number of additional CERs created falls with time.[18] The number of tons of loss prevented is cumulative and they will stop

[18] This is because preventing deforestation in 1997 means more good quality land is still available to deforest in 1998. It is possible that in some future years deforestation will be higher with carbon payments than it would have been if there had never been payments because of the more valuable forested land available.

accumulating when the forest reaches an equilibrium level. This equilibrium level will be higher than it would be with no carbon payments.

(iii) Temporary carbon payments.

To complete our picture of supply, we consider the possibility that carbon payments are temporary. What happens when payments stop? To look at this we rerun the estimate of carbon stock for 1998–1999 both with and without a carbon payment. Our projected right-hand side variables (e.g., forest percentages) are those generated from the estimates with a carbon payment in 1997. Our key interest is in the persistence of the effect of a carbon payment.

Table 15-7. Estimated CER Supply in 1998 with Payment of $1 in 1997 Only

	Year	**Thousands of tons**
Baseline carbon loss	1998	1,359
Carbon loss after payment stops	1998	20.7
CER supply	1998	86 (86.7 in ’97 – loss of 0.7 in ’98)

As Table 15-7 shows, when payments are stopped in 1998 after being paid for one period, the level of carbon loss in 1998 is higher than it would have been with no payment. However, the total carbon stock is still higher, so a stream of CERs continues to be created. Thus, the annual “lease” payment yields environmental returns in more than one year.

Figure 15-4 shows the dynamic effect of carbon payments on carbon stocks both when they are permanent and when they are temporary. Figure 15-5 shows the same thing, in the form of a dynamic CER supply function.

Figure 15-4. Carbon Stock and Carbon Payments

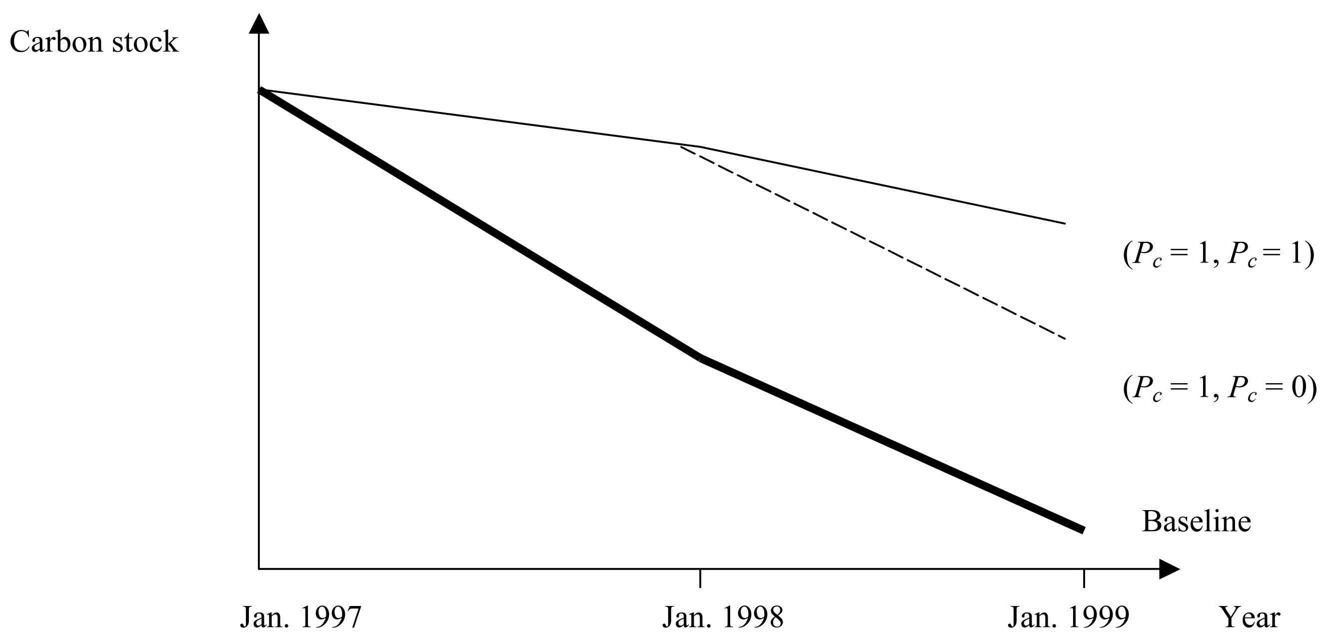
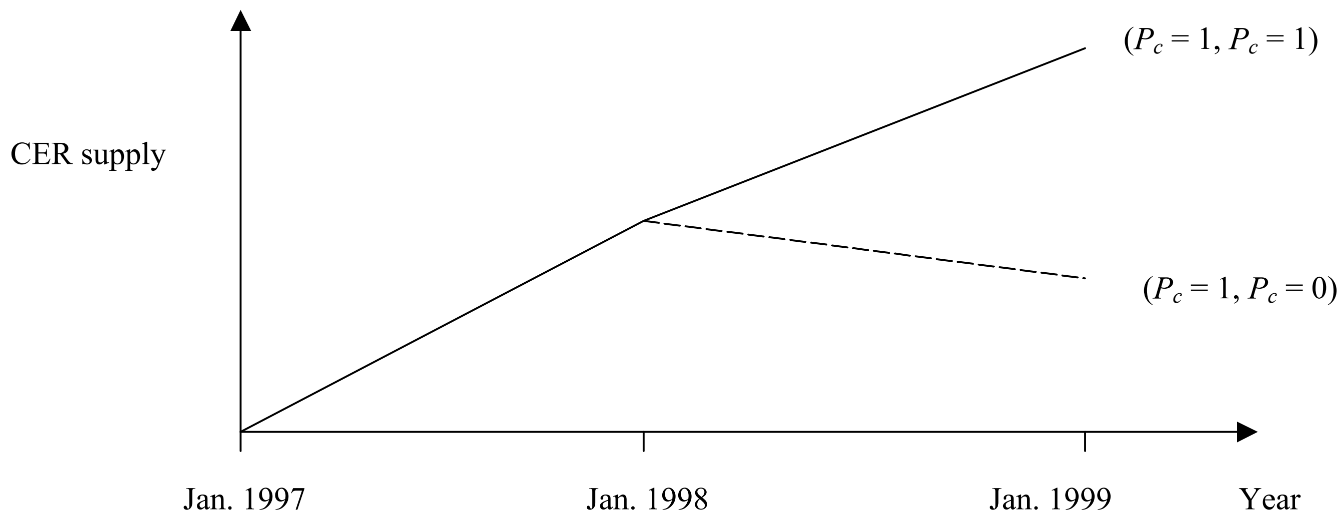


Figure 15-5. CER Supply and Carbon Payments



If the effect of a carbon sequestration project persists even when annual payments cease, the quantities of CERs given should still reflect the true sequestration above baseline. Who gets these additional CERs is a matter for negotiation among the parties involved.

Implications for C-Sequestration Supply for Other Central American Countries

Costa Rica has reached a relatively advanced stage of development. Most good agricultural land is already cleared and new output is primarily coming from intensification rather than extensification. Because deforestation is now low, the potential to decrease deforestation is also quite low.

This situation may be different in countries such as Guatemala or Nicaragua. Suppose a region had the same forest cover and was at the development level of Costa Rica in 1979. We could use our estimates to roughly predict the level of deforestation and the supply of CERs that might be expected. To illustrate the effect of being at an earlier level of development, we will show what our results would have suggested for the supply of carbon sequestration in 1979 in Costa Rica.

As Table 15-8 shows, in 1979 deforestation and hence carbon loss were much higher than they are today. Carbon losses were almost five times today's levels.

Table 15-8. Annual Carbon Lost in Baseline

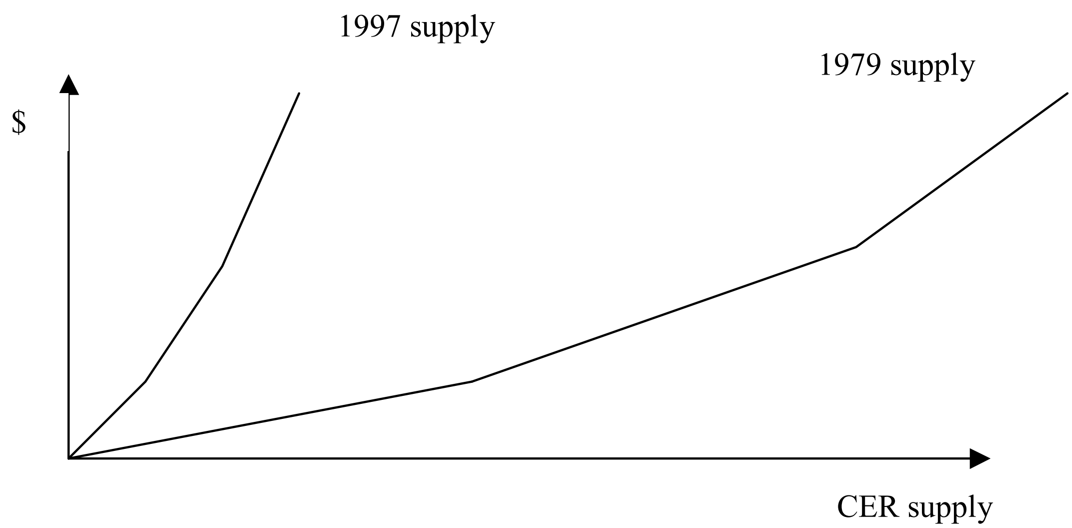
Year	Tons of carbon
1997	1.36 million tons
1979	12.2 million tons

Table 15-9 suggests that the supply of CERs would also have been an order of magnitude higher in 1979 than today.

Table 15-9. 1979 CER Supply

Year	**Annual payment**	**Tons of CERs leased in first year**
1979	.50	439 thousand
1979	$1	861 thousand
1979	$1.50	1.27 million

Figure 15-6. 1979 CER Supply Relative to 1997



Conclusion

The purpose of this paper was to illustrate a method to predict both baseline carbon losses and the supply of carbon sequestration. We have shown how thinking about deforestation as a dynamic process affects the form of supply we might expect. The actual estimates of levels of supply are for illustration only and the numbers should be taken hypothetically.

We find that the supply of sequestration CERs from prevented deforestation may be significant in Costa Rica even today, though the relatively low level of current deforestation limits it. Because Costa Rica is relatively advanced there is little deforestation to be prevented. The future sequestration potential in Costa Rica is more likely to come from reforestation, the subject of future analysis. CER supply from preventing deforestation is more likely to be significant in more heavily forested countries, or regions of countries, at a lower level of development; for example, in Guatemala or Nicaragua, where deforestation may have been retarded by civil war, rates of deforestation may be high in the future and could respond to incentives to slow the rate.

Second, we have shown how, when deforestation is considered as a dynamic process, the same level of annual payment may lead to increasing levels of CERs until the process of development is complete and the level of forest reaches a long-run equilibrium. In addition, in the short run—even if carbon payments are temporary—when they cease, CERs are likely to persist over time, although at a reduced rate. A one-time payment may retard deforestation for more than one year.

The next steps in our continuing project are to improve the quality of the empirical estimates. This will happen on a number of fronts. First, we will endeavor to improve the quality of our estimates of land returns through time, including the addition of data on transport costs. Second, we are working to extend our panel of land-cover data back to 1945. This and the inclusion of more data on the level of development will facilitate our ability to generalize our results to countries in different positions than Costa Rica. We are carrying out field work and modeling to improve estimates of carbon stocks and accumulation. Finally, we will improve the accuracy of estimates by moving from district-level data to pixel-level data.

We hope that our work to date will help people think more clearly about what is required to project land use baselines and to predict the value to different countries of being involved in projects related to carbon sequestration-based CERs. We also hope our results will help clarify some of the complex issues involved in including sequestration from land-use change in the nascent international agreements.

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.

Condit R., T. Guynup, S. Lao, R. B. Foster, S. H. Hubbell, and G. Michaels. 1999. Spatial and temporal variation in biomass of a tropical forest: Results from a large census plot in Panama. Unpublished manuscript.

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

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

FONAFIFO. 1998. *Mapa de cobertura forestal de Costa Rica*. San Jose, Costa Rica.

Helmer, E. H., and S. Brown. 1998. Gradient analysis of biomass in Costa Rica and a first estimate of country-wide emissions of greenhouse gases from biomass burning. In *Ecology of tropical development, the myth of sustainable development in Costa Rica*, edited by C. A. S. Hall. New York: Academic Press.

Huib Hengsdijk, Wageningen University, personal communication, July 1998

Holdridge, L. R., W. C. Grenke, W. H. Hatheway, T. Liang, and J. A. Tosi Jr. 1971. *Forest environments in tropical life zones.* New York: Pergamon Press.

Holdridge, L. 1967. *Life zone ecology*. Tropical Science Center, San Jose, Costa Rica.

Holdridge, L. 1980. A new look at atmospheric carbon dioxide. Paper delivered at the Symposium on the Role of Tropical Forests on the World Carbon Cycle. U.S. Department of Energy and the Institute for Tropical Forestry, March 19, Rio Piedras, Puerto Rico.

IMN (Instituto Meteorologico Nacional). 1994. *Mapa de uso de la tierra de Costa Rica*. San Jose, Costa Rica.

Kerr, Suzi C., Alex S.P. Pfaff, R. Flint Hughes, Shuguang Liu, G. Arturo Sanchez-Azofeifa, David Schimel, Joseph Tosi, and Vicente Watson. 2000. The Kyoto Protocol and payments for tropical forest: An interdisciplinary method for estimating carbon-offset supply and increasing the feasibility of a carbon market under the CDM. Manuscript submitted to *Ecological Economics.*

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

MINAE (Costa Rican Ministry of Environment and Energy) et al. 1997. National proposal for the territorial and financial consolidation of Costa Rican national parks and biological reserves. USIJI project proposal. Costa Rica.

Mora, M. E. (responsible author). 1995. USIJI project proposal. Monteverde-Gulf of Nicoya Biological Corridor, Costa Rica. Tropical Science Center, San Jose.

Plantinga, A. J., T. Mauldin, and D. J. Miller. 1998. An econometric analysis of the costs of sequestering carbon in forests. Paper presented at AERE World Congress, Venice.

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.

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

Stavins, Robert N., and Adam Jaffe. 1990. Unintended impacts of public investments on private decisions: The depletion of forested wetlands. American Economic Review 80(3):337–52.

Tosi, J. A. 1980. Life zones, land use and forest vegetation in the tropical and subtropical regions. Paper delivered at the Symposium on the Role of Tropical Forests on the World Carbon Cycle. U.S. Department of Energy and the Institute for Tropical Forestry, March 19, Rio Piedras, Puerto Rico.

Vargas, J. Rafael, and Olegario 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.

Table 15-1

Variable	Commodity	Range	Level of aggregation	Units	Source
Price	Coffee	1950–1987	National	$/kg	5
	Coffee	1988–1997	National	$/kg	6
	Bananas	1953–1987	National	$/kg	5
	Bananas	1988–1997	National	$/kg	6
	Sugar	1957–1987	National	$/kg	5
	Sugar	1988–1997	National	$/kg	6
	Beef	1959–1987	National	$/kg	5
	Beef	1988–1997	National	$/kg	6
Production	Coffee	1974–1992	County	kg	1
	Coffee	1996	County	kg	2
	Beef	1950–1979	National	kg	2a
	Beef	1980–1995	National	kg	2b
Stock	Cattle	50, 55, 63, 73, 86	County	number	14
Area in production	Coffee	50, 55, 63, 73, 86	County	ha	14
	Sugarcane	50, 55, 63, 73, 86	County	ha	14
	Pasture	50, 55, 73, 86	County	ha	14
	Bananas	63 and 73	County	ha	14
Yield	Bananas	1977–1997	County	kg/ha	3
	Sugar	1950–1973	Province	kg/ha	4
	Sugar	1998	County	kg/ha	4a
Production cost	Coffee	1979	Coffee zone	1979col/ha	7
	Coffee	1981	Coffee zone	1981col/ha	8
	Bananas	1997	National	1997col/kg	9
	Sugar	1963, 66, 72, 77, 79	National	1977col/kg	10
	Sugar	1994–1995	National	1997col/kg	11
	Beef	1974	National	1997col/kg	12
	Beef	1990	National	1990col/kg	13

Sources: 1. Instituto Del Café de Costa Rica Departmento de Estudios Agricolas y Economicos January 1995; 2. Ramos Mendez and Aguzzi Brenes G. (1997) ; 2a Consejo Nacional de Produccion, 1980–1995; 2b. Aguilar, Barboza, and Leon (1982b); 3. Data provided by HIID; 4. Mendez and Coronado (1979); 4a. Chavez-Solera et al. (1998); 5. Vargas and Saenz (1994); 6. Valor Agregado por Actividad Economica (1966 Colones) BCCR website; 7. Aguilar, Barboza and Leon (1982a); 8. de Graaf (1986); 9. Huib Hengsdijk, Wageningen University, personal communication; 10. Aguilar, Barboza, and León (1982a); 11. Chaves-Solera (1994); 12. Vigne (1974); 13. Arias and Corrales (1992); 14. Costa Rican Agricultural Census. Data provided by Arturo Sanchez.