EPTD DISCUSSION PAPER NO. 67

SMALL-SCALE FARMS IN THE WESTERN BRAZILIAN AMAZON: CAN THEY BENEFIT FROM CARBON TRADE?

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September 2000

ABSTRACT

Recently scientists have started to examine how land-uses and land-use technologies can help mitigate carbon emissions. The half million small-scale farmers inhabiting the Amazon frontier sequester large stocks of carbon in their forests and other land uses that they might be persuaded to maintain or even increase through the Clean Development Mechanism (CDM) of the Kyoto Protocol. On average, small-scale farmers in the Pedro Peixoto settlement project of Acre (Western Brazilian Amazon), had a stock of 10,067 tons of above- and below-ground carbon on their farms in 1994, 88 percent of which was stored in their forest reserves. The income and carbon mitigation effects of three types of carbon payments are analyzed in this paper: (1) above- or total-carbon stock payments paid for carbon retained in the forest or stored in all land-uses, (2) above- or total-carbon flow payments paid for carbon stored in all land-uses, and (3) above- or total-carbon net stock payments paid for carbon stored in all land-uses. The main conclusions are that carbon payments can be effective in preserving forest and carbon, but should be based on carbon stocks or net carbon stock rather than carbon flows. Payments tied to forest carbon or carbon in all land-uses provide inexpensive carbon offset potential, and payments based on total instead of above-ground carbon only slightly dilute the forest preservation effect of carbon payments. One-time carbon payments as low as R$15/t of carbon stock would preserve half of the existing forest carbon on these farms. Carbon flow payments, on the other hand, do not provide an adequate economic incentive to slow deforestation because forests are more or less in equilibrium and thus do not sequester additional carbon. If the Kyoto Protocol were amended to allow for conservation of forest carbon, a few potential CDMs could provide inexpensive carbon offsets, alleviate poverty, and preserve biodiversity. Sustainable forest management, for instance, increases both farm income and carbon and forest preservation and could provide inexpensive carbon offsets. Other projects could also provide inexpensive carbon offsets and preserve biodiversity, but would require additional income and technology transfers to compensate farmers for their lost incomes.

This paper was completed with the support of the Alternatives to Slash and Burn (ASB) Program, and draws on an extensive research program undertaken at IFPRI. This paper could not have been completed without the continuous support of the Brazilian Corporation for Agricultural Research (EMBRAPA) during the data collection and model building phases of this project. Special thanks go to Judson Valentim, Jair de Santos, and Samuel Oliveira. Our colleagues within ASB are also to be thanked for their collaboration throughout this project. Special thanks go to Cheryl Palm for reviewing this document and for her guidance on carbon issues, and to Divonzyl Cordeiro and Vania Rodrigues for the carbon measurement in Acre and Rondonia, respectively. We also thank Peter Hazell for his detailed comments on the paper.

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1. INTRODUCTION

If the Kyoto Protocol is ratified, twenty-nine industrialized countries will be required to mitigate their emissions of six key greenhouse gases, including carbon dioxide, by at least 5 percent by 2008-12. Articles 3.3 and 3.4 of the Protocol indicate that countries can either reduce their own carbon emissions (e.g., by improving energy efficiency or switching to fuels with lower carbon content) or by increasing carbon sequestration through reforestation and other vegetative investments to achieve their targeted decrease in atmospheric carbon (United Nations 1999a). Growing vegetation is a carbon sink because it removes carbon dioxide (CO_2) from the air and stores it through photosynthesis in plant biomass, both above and below ground. New carbon is sequestered until the vegetation matures, at which time the stock of carbon reaches equilibrium and ceases to grow anymore. Article 12 of the Protocol, referred to as the Clean Development Mechanism (CDM) allows electric utilities and other carbon emitters in developed countries to invest in sustainable

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development projects in developing countries that mitigate carbon at lower cost and credit this carbon to their targeted reductions. However, it is not clear whether carbon sequestered in existing forests is eligible under the Protocol (Richards 1999). If proposals to include forest carbon are accepted in 2000, then CDMs designed to promote sustainable development on small farms in settlement projects could preserve forest and biodiversity and alleviate poverty.[1] The CDM benefits developing countries because of the financial and technical support they receive and they also benefit from the resulting global reduction in greenhouse gases (Duncan et al. 1999). Developed countries have advocated the inclusion of forest carbon because, in addition to sequestering the most carbon, forests have value to national and international stakeholders because of their role in modifying local climate and for watershed protection and the maintenance of biodiversity.

Small farmers in the Western Brazilian Amazon are investment poor but have tremendous forest resources.[2] However, under prevailing economic and policy conditions, forests are perceived as impediments to these farmers. For instance, by law farmers must maintain 50 percent of their holdings as forest reserves yet, for all practical purposes, they are not allowed to undertake commercial timber extraction from that area. Thus, the only economic value the forest offers to farmers is the household and commercial value of non-

[1] Though it appears evident the Kyoto Protocol will not be ratified, the momentum in the carbon trade industry is such that something else will likely replace it.

[2] This report focuses on small-scale farmers because they comprise a large number of people and a large amount of land in the Brazilian Amazon. Other actors in the area, such as

large farm enterprises and extractivists, could also be sources of carbon sequestration but are not analyzed in this paper.

timber tree products and the on-farm use of timber. Because extraction in a forest setting (as opposed to a plantation setting) can be extremely labor intensive and markets for non-timber tree products are limited, the land on which the forest stands has more value for farmers as agricultural land than as forest. Without external interventions, farmers in the area have every incentive to deforest and plant pasture (Carpentier, Vosti, and Witcover, forthcoming), thereby emitting greenhouse gases (GHGs) and creating a poorer carbon sink. With sustainable development projects under the CDM, these small-scale farmers might retain large stocks of forest carbon in their on-farm forest reserves or sequester additional carbon by opting for higher carbon-content land-uses.

The objectives of this paper are a) to derive the types and levels of compensatory payments that would be required to induce small Western Amazonian farmers to retain their forest carbon, and b) analyze the amounts of carbon that would be sequestered under potential CDM projects and the implications for rural incomes and environmental sustainability. To achieve these objectives we use a farm-level bioeconomic model calibrated for a typical small farmer in the Pedro Peixote settlement project in the Acre region of the Western Brazilian Amazon.

2. METHOD

A bioeconomic model (FaleBEM) of a representative small-scale subsistence-oriented farmer in the forest margins of the Pedro Peixoto settlement project was available for the purposes of this study (Carpentier, Vosti, and Witcover, forthcoming). The model is briefly described below, and is then used to simulate the consequences of alternative carbon sequestration policies for land use, farm income and carbon sequestration.

THE FaleBEM MODEL

FaleBEM is a dynamic mathematical programming model that is written and solved in GAMS (Brooke, Kendrick, and Meeraus 1992). It simulates the typical farmer's responses to a wide range of policy, technology and project interventions. The model incorporates all the important biophysical and economic factors that are thought to affect farmers' decisions about land use and deforestation (see Carpentier et al., forthcoming, for a more detailed description of the model).

The model assumes that farmers maximize the discounted value of their household consumption over a 15-year time horizon. There are also minimum consumption constraints that must be met each year for food, clothes and farm implements. The model allocates farm income each year to consumption and on-farm investments. When income is invested it increases future production potential, and hence future consumption, but at the expense of current consumption. Income is generated in the model by producing products for home consumption or sale. Production choices are subject to an array of resources and technology constraints, including seasonal land, labor and cash flow constraints. In addition to on-farm production, the household can engage in extractive activities in the forest (e.g., harvesting Brazil nuts), and sell household labor off farm. It can also hire non-family labor to work on the family farm. Since the region is only a small producer of most products, all output prices are fixed in the model.

This assumption is less defensible for non-timber tree products because these products have limited marketing outlets. But the model produces such small quantities that the impact on income of any downside price effects can reasonably be ignored. The model also tracks soil fertility and soil nutrient balances, and these impact on future productivity levels within the planning period of the model. Soil fertility can be improved by adding inorganic fertilizers, by changing the cropping pattern, by putting land into fallow, or opening new areas to production (deforesting). By tracking soil nutrients in the forest, fallow, and the cultivated areas and linking them to crop nutrient demands and yields, FaleBEM effectively links deforestation decisions to production decisions on the cleared land. FaleBEM also limits certain trades in inputs and products to reflect market imperfections. For example, milk sales are constrained by quotas, and the maximum amount of hired labor that can be acquired in any given month is restricted to 15 man-days.

Although the model has a 15-year planning horizon, it is also solved recursively at five-year intervals. By updating all the constraint values on the right hand side for each solution, a series of moving 15-year farm plans are obtained that can be used to track much longer periods of time than the initial 15-year period. This is especially useful for exploring long-term changes in land use and the sustainability aspects of different farming practices. The results presented in this paper are based on a 25-year period, and were derived from five recursive runs of the model for each policy experiment.

The FaleBEM model is calibrated to a set of initial conditions that define the model's starting point in terms of the resources available (land, labor and capital), the existing land uses and the prevailing technology and prices. These conditions were determined from field data collected in 1994 in the Pedro Peixoto settlement project in Acre. The model represents a typical small but well situated farm with medium quality soils.

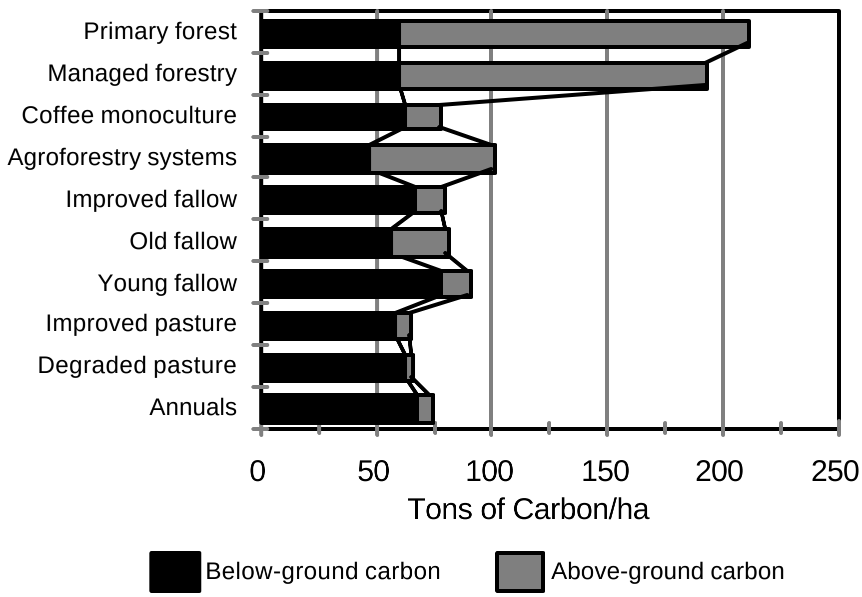
FaleBEM also keeps track of how many hectares of forest and cleared land remain on the farm in any year and the age of these different land-uses. Using this information, the on-farm carbon stock and flow are calculated each year. This provides a basis for evaluating the impacts of alternative carbon sequestration policies. For example, by introducing options for carbon payments against particular land uses, the model can evaluate the types and levels of payments that would be required to induce desired changes in land use practices, including the retention of more forest. Moreover, by adding minimum constraints on the amount of carbon that must be maintained each year, the model provides shadow prices that measure the opportunity cost to the household (in terms of the discounted consumption foregone) of allocating land from alternative uses to sequester one more ton of carbon.

CARBON MEASUREMENT ISSUES

FaleBEM tracks both the above- and below- ground carbon content associated with different land uses. The data for these purposes (Figure 1) were obtained from Braz et al. (1998), Palm et al. (1999), and Woomer et al. (1999). A few points relevant to carbon measurement are worth making. First, the appropriate measure of carbon for perennial and fallow systems is the average carbon content over the life of the system, not the maximum carbon at maturity (Palm et al. 1999). Second, variations in total carbon content across different land-uses are mostly due to differences in their above-ground carbon. Above-ground carbon varies from a low of 3 t/ha for degraded pasture to 150 t/ha for primary forest, whereas below-ground carbon varies from a low of 47 t/ha for agroforestry to 78t/ha for young fallow[3]. Unlike soils in temperate zones, tropical soils stock similar amounts of carbon below ground regardless of land use. Third, only forest management comes close to retaining the same level of total and above-ground carbon as primary forest (about 8 percent less). Even agroforestry systems sequester only half the total carbon and a third of the above-ground carbon of primary forest. Fourth, there is considerable variation across sites in carbon measurements within each type of land use that is masked by the averages in Figure 1. These variations were especially large for fallow, pasture, and agroforestry systems (Braz et al. 1998 and Palm et al. 1999). Carbon stocks are particularly impacted by the management and vintage of each land use. For instance, improved pasture with a nitrogen-fixing grass (kudzu) has double the above-ground carbon content of an improved fallow without kudzu (6 rather than 3 t/ ha). The carbon content of fallow and perennial crops (such as coffee and agroforestry) also increases with age until they reach their maximum carbon content at maturity. After maturity, the carbon content remains constant (Plantiga, et al. 1999). Finally, since primary forest has already achieved maturity, its carbon stock is more or less in equilibrium and the net carbon sequestered is negligible unless the forest is burned and the carbon is released into the atmosphere.

[3] Note that these below-ground carbon measurements are not adjusted for differences in soil type among systems. See Palm et al. (1999) for details on how below-ground carbon measurement can be standardized for soil type.

Figure 1: Below- and above-ground carbon content by land use in Acre, Brazil



Source: Braz, et al. and Palm 1999.

There are eight types of carbon payment schemes that may be relevant for farmers in Acre (Table 1). These are clustered into payments against carbon stocks, carbon flows, and net carbon stocks. Payments are further classified into those that are tied to above-ground or total carbon, and whether they are tied specifically to forest or can apply to all farm land uses, including fallow, crops, pasture and perennials.

Table 1: Type of carbon payments

Type of measurement	Carbon is sequestered in:			
	Forest		Farm (all land-uses)	
Stock	Above-ground carbon	Total carbon	Above-ground carbon	Total carbon
Flow			Above-ground carbon	Total carbon
Net stock			Above-ground carbon	Total carbon

For c*arbon stock payments,* an initial inventory is drawn up in the base year of the amount of land that is in forest or other designated uses, and then payments are made each year against the remaining stock of carbon on those lands. For example, if the farmer begins with 43 ha of forest and clears this land progressively over time, then the payments he/she receives would decrease over time in direct proportion to the rate of deforestation. Other things being equal, carbon stock payments should slow the rate of deforestation because they increase the value of the standing forest.

In contrast, *carbon flow payments* are tied to net changes from year to year in the stock of carbon held on the farm. If the farmer increases his/her stock of carbon between years, then a payment is received that is proportional to the net addition in sequestered carbon. But if the stock of carbon falls from one year to the next, then the farmer would be taxed on the basis of the net amount of carbon emitted. Because primary forest is in an equilibrium state in terms of the amount of carbon sequestered, then it does not acquire any additional value under a carbon flow payment. In fact, forest may be viewed as a liability by farmers, because if any of it is cleared (e.g., as part of a slash and burn rotation), then the large amount of carbon emitted through burning must be offset by considerable carbon sequestration on other land to avoid a tax.

Net carbon stock payments offer a middle ground between the other two extremes. In this case, payments against remaining carbon stocks are adjusted to include a tax against any carbon that has been emitted from one year to the next. If, for example, the farmer starts with one hectare of forest and clears this progressively over five years, then not only will he/she receive a decreasing stock payment over time, but he/she will be liable to a tax each year on the amount of carbon emitted through burning forest. To avoid the tax, then compensatory changes in land use would be required elsewhere on the farm to sequester a similar amount of new carbon as released by burning.

The potential for carbon payments to affect forest conservation lies in the large amount of carbon already stored in the forest. For instance, one hectare of forest in Acre contains 150 tons of above-ground carbon and 206 tons of total carbon (including soil carbon to a depth of 40 cm) (Braz et al. 1998; Palm et al. 1999). Thus, even with as small a payment as R$1 per ton of carbon stock the annual return to one hectare of standing forest for above-ground carbon is R$150, and R$206 for total carbon.[4] If payments are made for 25 years, the net present value of those returns would be R$1,473/ha for the above-ground carbon stock, and R$2,023/ha for the total carbon stock payment (based on a 9% discount rate). These returns

[4] All values are measured in December 1996 Reals (where R$1 = US$1 in 1996).

compare favorably with current forest revenues from Brazil nut extraction and forest management over 25 years, which are R$19 and R$2714 per hectare, respectively.[5]

BASELINE RESULTS

The model was first run for a 25-year period to create a baseline scenario against which all other policy experiments can be compared. The baseline scenario incorporates the current ban on timber harvesting by small-scale farmers,[6] but ignores an existing 50 percent rule that mandates that no more than half of any farm can be cleared for agricultural purposes. This policy has not been enforced in recent years and is typically ignored by farmers.[7] The representative farm starts the planning period with a land use allocation of 2.5 ha of annuals, 1.5 ha of perennials, 4 ha of fallow, 9 ha of pasture, and 43 ha of forest, giving a total farm of 60 ha

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[5] These estimates were generated by valuing labor at its market price of R$7 per day. Brazil nut extraction is labor extensive (.05 day per 18 kg) while the managed forestry is more labor intensive with an average of 12 man-days per hectare.

[6] Although technically permissible by law, the bureaucratic obstacles to obtaining official permission to sustainably harvest timber products in farmers' legal reserves have been insurmountable in practice and have made any on-farm timber extraction difficult. Such practices are therefore not permitted in the scenarios presented here. Recent changes in certification requirements may, in the future, reduce these costs. Once these new costs are known, they could easily be incorporated into the model.

[7] The Brazilian Forest Code number 4.771 obliges landowners to retain 50 percent of their holdings as forest reserves, and technically deforestation permits are required for all forest felling. This law was modified in 1997 by presidential decree to stipulate that in states lacking approved zoning plans, farms must retain 80 percent of their land in forest. Small-scale farms (those below 250 hectares) were eventually exempted from this decree. In practice, many pass the 50 percent (or 80 percent) line, and fines are rarely assessed on smallholders. That said, some empirical evidence suggests that the law and the enforcement rhetoric associated with it do discourage deforestation.

and stocks of 10,067 tons of total carbon and 6500 tons of above ground carbon. Eighty-nine percent of the total carbon is retained in the forest, and most of it is above ground.

Figure 2 depicts the pattern of land use (including forest, and therefore implicitly deforestation) generated by the model over the 25-year time span for this typical small-scale farm in Acre.

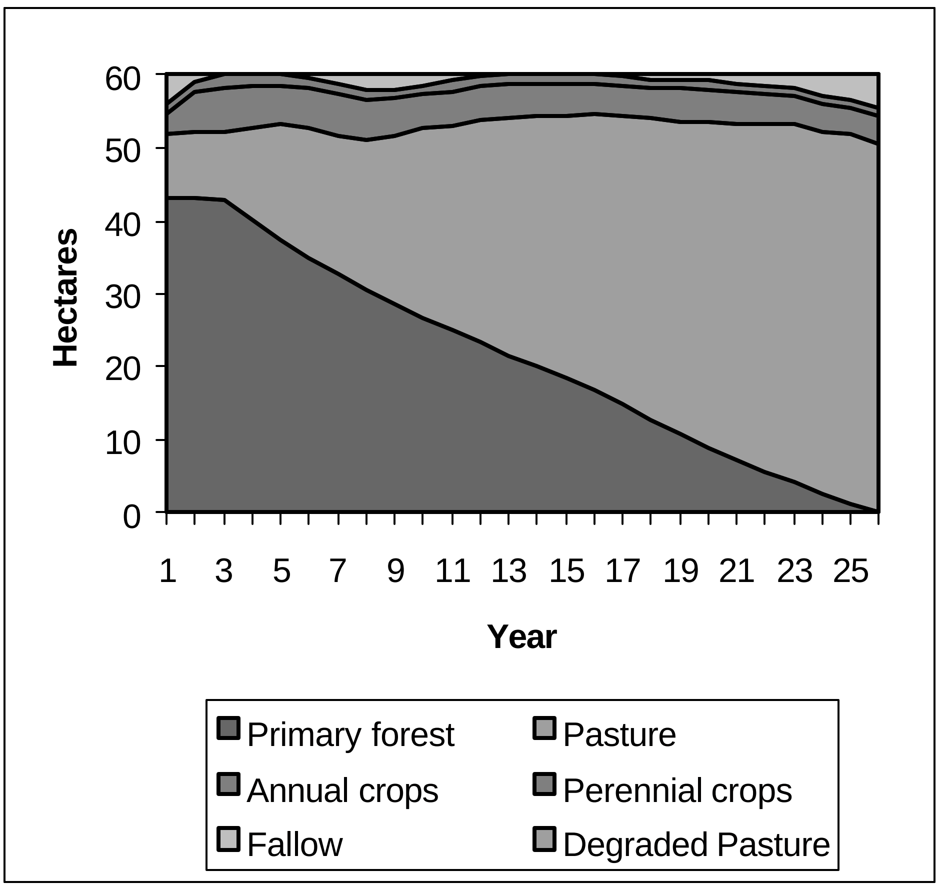


Figure 2: Land use in the baseline simulation

Several baseline results deserve mention. First, the amount of forest retained declines monotonically over time, and finally disappears altogether by year 25. This is despite the small but positive revenue provided by the extraction of Brazil nuts (an activity currently undertaken on about half the farms in the project). Second, in terms of area, pasture for cattle production is the dominant land use activity, and it eventually occupies about 85 percent of the farm. Third, annual crop production occupies only about 8 percent of the farm throughout the 25-year time period. Fourth, perennial crops, which for convenience include manioc production though this is not strictly a perennial, take up only about one hectare of land (less than 2 percent of the farm) throughout the 25-year period. Finally, young fallow up to four years old, weaves in and out of the baseline solution, before becoming significant as the forest disappears completely.[8] Farm income stabilizes after year 13 at approximately R$9,000 per year. The present day value of consumption over the 25-year period is R$50,688 (Table 2).

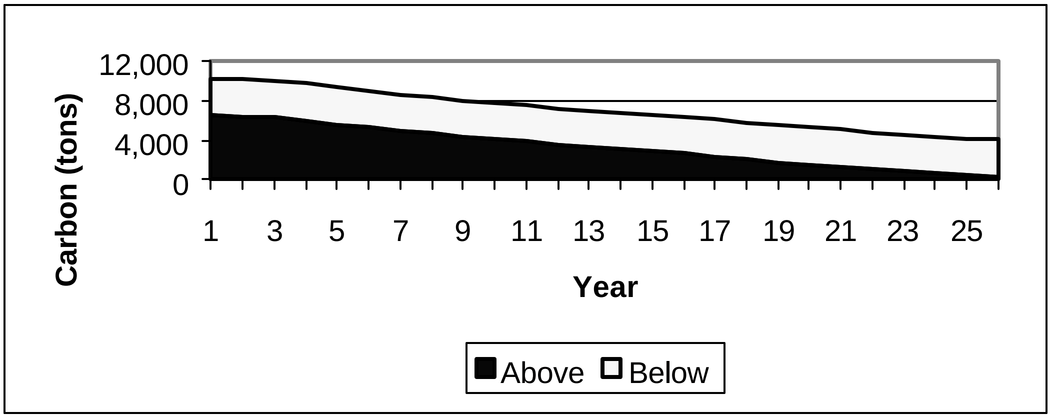
The baseline scenario also shows a steady decline in total and above-ground carbon stocks (Figure 3). Starting from an initial stock of 10,067 tons of total carbon and 6500 tons of above-ground carbon, these decline to 4,021 and 265 tons, respectively, by year 25 as the forest is burnt.

[8] When the baseline scenario is extended to 35 years, the area in fallow continues to increase at approximately 0.1 hectare every year, to reach 5.5 hectares in year 35.

Table 2: Simulation results for alternative carbon stock payment schemes

Scenario	Present day value of consumption (R$)	Forest in year 25 (ha)	Total carbon in year 25 (tons)	Above-ground carbon in year 25 (tons)
Baseline	50,688	0	4021	265
Annual payment for total carbon, forest:				
R$0.1/t				
R$0.5/t	59,331	4	4473	
R$1.0/t	83,768	16	6319	
R$1.5/t	117,165	25	7571	
R$2.0/t	154,431	27	8825	
	196,804	42	9869	
Annual payment for total carbon, all land uses:				
R$0.1/t	61,210	3	4390	
R$0.5/t	91,961	16	6413	
R$1.0/t	132,226	24	7409	
R$1.5/t	174,205	27	7787	
R$2.0/t	215,521	43	10179	
Annual payment for above-ground carbon, forest:				
R$0.1/t	57,217	2		521
R$0.5/t	75,014	10		1738
R$1.0/t	97,518	21		3330
R$1.5/t	121,995	27		4159
R$2.0/t	148,819	34		5070
Annual payment for above-ground carbon, all land uses:				
R$0.1	57,326	1		424
R$0.5	75,567	10		1759
R$1.0	98,489	22		3472
R$1.5	123,667	25		3913
R$2.0	150,291	33		4977

Figure 3: Above- and below-ground carbon stocks in the baseline simulation



POLICY EXPERIMENTS

The model is useful for analyzing the impact of alternative carbon sequestration polices, including carbon payments, land use regulations and forest management policies. Carbon stock and carbon flow payments are simulated at five levels of carbon payments (R$0.1, 0.5, 1.0, 1.5 and 2.0 per ton of carbon). The carbon payment scenarios assume that farmers would receive carbon-offset payments, though this may not necessarily happen under a CDM. In addition to direct carbon payments, the Brazilian government could use other incentive schemes to induce farmers to maintain more carbon on their farms. Two such options are simulated with the model: land-use taxes and price subsidies. The taxes are collected on all low carbon-content land uses (essentially, land that is not in forest or woody perennials). The subsidies are price support schemes designed to induce farmers to maintain land-uses with high carbon content.[9]

[9] Note that coffee is a relatively low carbon content land use though it has three times more above-ground carbon than annuals.

Finally, the government could impose more rigid rules on carbon sequestration, and regulate the amount of forest or carbon that is retained, or it could change the rules governing forest management. One example is the existing 50 percent rule, and though this law already requires that farmers leave at least 50 percent of their holdings in forest, it is rarely enforced. The model is used to simulate what would happen if this rule were enforced, and to evaluate the impact of some alternative regulatory systems. The model is also used to simulate the consequences of allowing farmers to practice low-impact forest management in the forest areas they choose to preserve.

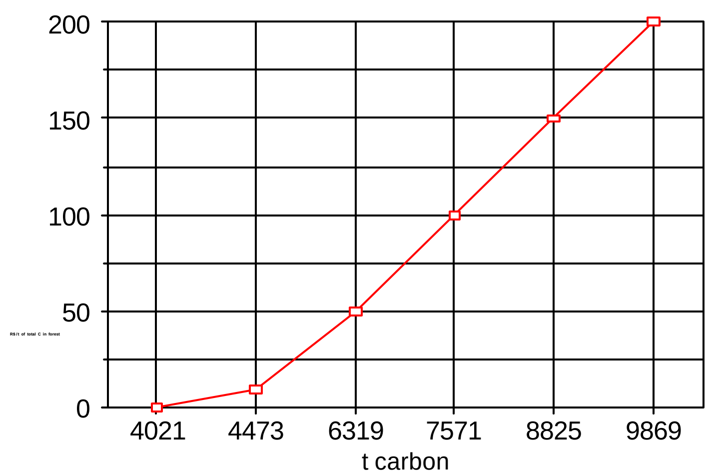
Carbon payment policies, including taxes and subsidies, and direct regulations are only practical if farmers can be held accountable to measurable carbon performance standards. Aggregate whole farm measures are generally best because they allow farmers to retain carbon or forest in the most cost effective ways from their perspective. Two measures are reported in the model scenarios: the total area of retained forest and the amount of carbon sequestered (above and below ground).

3. CARBON STOCK PAYMENT SCENARIOS

ANNUAL PAYMENTS FOR TOTAL FOREST CARBON STOCK

Under this scenario, farmers receive an annual payment for each ton of total carbon that they retain in their forest. The payment was varied from R$0.10/t to R$2.00/t of carbon per year to capture the relationship between the level of carbon payment and the total carbon retained on the farm at year 25 (Table 2). An annual payment of R$0.10/t of forest would preserve 4 ha of forest and 4,473 tons of carbon at year 25 compared with no forest and 4021 tons of carbon in the baseline. The preserved amount of forest and total carbon increase to 16 ha and 6,319 tons if the payment is quintupled to R$0.50/t, and to 42 ha and 9869 tones if the payment is increased to R$2/t of forest carbon. The relationship between the rate of payment and the preserved forest area and carbon tonnage is linear for payment rates between R$0.5 and R$2.0/t (Figure 4). Over this range, each additional cent payment preserves another 0.173 ha of forest and 23.7 tons of carbon at year 25.

Figure 4: Total carbon in year 25, by level of payment for total carbon stock in the forest



ANNUAL PAYMENTS FOR TOTAL CARBON STOCK ON FARM

Under this scenario, farmers are paid annually for each ton of total carbon they retain in all land-uses on their farms, and not just in their forest. The payment was again varied from R$0.10/t to R$2.00/t. The resulting impact on on-farm carbon stocks by year 25 is shown in Table 2. This payment scheme leads to similar amounts of total carbon stocks in year 25 as in the previous scheme in which payments are tied to the forest area. For example, a payment of R$1.0/t leads to 7409 tons of carbon at year 25, compared to 7571 under the forest carbon payment scheme. The amount of forest saved is also about the same as with the forest payment scheme.

The relationship between the payment rate and the forest area and carbon stock at year 25 is again linear for payments between R$0.5 and R$2.0/t; each additional cent preserves another 0.18 ha of forest and 25.1 tons of carbon.

ANNUAL PAYMENTS FOR ABOVE-GROUND FOREST CARBON STOCK

Under this scenario, farmers are paid annually for the above-ground carbon stored in their forest. This scheme retains less forest than the previous carbon payment schemes, but does lead to significant amounts of above-ground carbon (Table 2).

ANNUAL PAYMENTS FOR ABOVE-GROUND CARBON STOCK ON FARM

Under this scenario, carbon payments are made for every ton of carbon retained above ground on the farm, regardless of land use. The results are very similar to the previous scheme in which above-ground carbon payments are restricted to forest land (Table 2), but with slightly smaller amounts of forest and total carbon stocked at year 25 for payments greater than R$1.0/t.

COMPARISON OF CARBON STOCK PAYMENT SCHEMES

Table 3 summarizes the results for alternative carbon stock payment schemes for one level of carbon payment—R$1.0/t of carbon. All four schemes have similar implications for the area of forest and the tons of carbon preserved by year 25. They all preserve at least 20 ha of forest, about half of the original forest area. Moreover, the two total carbon payment schemes preserve more than 75% of the original total carbon on the farm, while the two above-ground carbon payment schemes preserve more than 50% of the original above-ground carbon.

However, there are important differences in the present day value of consumption associated with the different payment schemes. Total carbon payments of R$1.0/t per year nearly triple the present day value of consumption over the baseline value of R$50,688, while above-ground carbon payments nearly double the value of consumption. These results have important implications for the amount of payment that needs to be transferred to induce farmers to retain the amounts of forest and carbon stocks indicated in Table 3. For each carbon payment scheme, the difference between the present day value of consumption and the baseline value of R$50,688 is a direct measure of the present day value of the transfers that would be required over the 25 year period. For example, to preserve 7,571 tons of total carbon through forest carbon payments, it would take annual transfers equivalent to a lump sum payment today of R$66,477. This is equivalent to a lump sum payment today of R$19/t for every ton of carbon saved by year 25. This cost increases to R$81,538 (or R$24/t) if the payments are made against carbon in all land uses, even though the amount of carbon and forest preserved is slightly smaller. The above-ground payments are more cost-effective, costing only R$15 per ton of carbon saved. They are also a cheaper way to preserve forest, costing about R$2,200/ha of forest by year 25 compared to R$2659 and R$3397/ha for the two total carbon payment schemes.

Table 3: Comparison of carbon stock payment schemes with rate of R$1.0/t/year

	Baseline	Annual payment for total carbon; forest	Annual payment for total carbon; all land uses	Annual payment for above-ground carbon; forest	Annual payment for above-ground carbon; all land users
Present day value of consumption (R$)	50,688	117,165	132,226	97,518	98,489
Forest in year 25 (ha)	0	25	24	21	22
Total carbon in year 25 (t)	4021	7571	7409	--	--
Above-ground carbon in year 25 (t)	265	--	--	3330	3472
Present day value of transfers over 25 years (R$)	--	66,477	81,538	46,830	47,801
R$/t of total carbon	--	19	24	--	--
R$/t of above-ground carbon	--	--	--	15	15
R$/ha of forest	--	2659	3397	2230	2173

4. CARBON FLOW PAYMENT SCHEMES

ANNUAL PAYMENTS FOR NET ABOVE-GROUND CARBON STOCK; ALL LAND USES

In this scenario, annual carbon stock payments are based on the stock of carbon remaining at the end of each year in all land uses, but adjusted down by a tax on carbon emitted from any forest burnt during the year. The results are shown in Table 4. This type of payment yields marginally more carbon and forest area at year 25 than the previous above-ground carbon stock payment scheme for payments greater than R$1.0/t. For example, with a payment of R$2.0/t, 36 ha of forest and 5358 tons of above-ground carbon remain in year 25 compared to 33 ha forest and 4977 tons above-ground carbon with the above-ground carbon scheme (all land uses) in Table 2. The difference is due to the tax on carbon emissions from clearing forest.

ANNUAL PAYMENTS FOR ABOVE-GROUND AND TOTAL CARBON FLOWS; ALL LAND USES

Under these scenarios farmers receive annual per ton payments for carbon flows from one year to the next computed as carbon in year t + 1 minus carbon in year t. Higher payments (and taxes) are needed to induce significant land use changes with these schemes. For instance, a payment of R$1.0/t for above-ground carbon only preserves 6 ha of forest at year 25 compared with more than 20 ha with most of the carbon stock payment schemes in Table 3. To achieve a stock of 5,000 tons of above-ground carbon at year 25, a flow payment of

R$9.0/t is required on above-ground carbon (Table 4), while a R$1/t payment is adequate to induce a similar result with the carbon stock payment scheme (Table 2).

Table 4: Simulation results for carbon flow and net carbon stock payment schemes

Scenario	Present day value of consumption (R$)	Forest in year 25 (ha)	Total carbon in year 25 (tons)	Above-ground carbon in year 25 (tons)
Baseline	50,688	0	4021	265
Net above-ground carbon stock, all land uses:				
R$0.1/t				
R$0.5/t	57,065	2		495
R$1.0/t	74,507	12		1927
R$1.5/t	96,800	23		3468
R$2.0/t	121,466	30		4472
	148,979	36		5358
Total carbon flow payments, all land uses:				
R$1.0/t	47,437	7	4827	
R$3.0/t	40,086	21	6678	
R$5.0/t	34,114	26	7367	
R$7.0/t	25,198	35	8808	
R$9.0/t	22,814	43	9974	
Above-ground carbon flow payments, all land uses:				
R$1.0/t	46,056	6		1086
R$3.0/t	38,184	17		2692
R$5.0/t	31,750	24		3698
R$7.0/t	26,771	29		4460
R$9.0/t	21,778	36		5385

The above-ground carbon flow payment scheme leads to less forest and fallow than the total carbon flow payment scheme. This difference increases as the level of payment increases. For example, a carbon flow payment of R$9/t maintains 36 ha of forest when tied to above-ground carbon, and 43 ha of forest when tied to total carbon. Both carbon flow payment schemes induce a larger area of fallow than their carbon stock payment counterparts. However, although the use of cleared land changes to increase carbon sequestration, it is not enough to offset the emissions from deforestation. Therefore farmers have to pay a carbon tax every year instead of receiving payments as with the carbon stock payment schemes. A R$1/t payment or tax on above-ground carbon flow reduces the present day value of consumption to R$46,056, a 5 percent reduction from the baseline, while a R$9/t annual payment reduces the present day value of consumption to R$21,778, a 57 percent reduction from the baseline. Consumption is slightly lower under the above-ground carbon flow payment scheme. The carbon flow payment scheme essentially acts as a tax that farmers have to pay to deforest, and it is more profitable for them to alter their land uses on cleared land, slow deforestation, and pay the tax than to halt deforestation completely.

COMPARISON OF CARBON FLOW PAYMENT SCHEMES

Table 5 compares the three carbon flow schemes for the same payment rate of R$1.0/t of carbon. The net above ground carbon stock scheme saves considerably more forest and carbon, but at much higher unit costs (R$4611/ha of forest and R$14/t of carbon). The present day value of the transfers over 25 years is also high at R$46,112. The carbon flow schemes are much less effective at protecting forest and carbon at the same payment rate of R$1/t, but the costs per unit saved are much lower. Moreover, because farmers are taxed when they deforest, the present day value of the transfers is negative; farmers are actually made worse off on average. It takes much higher payment and tax rates to induce any significant changes in land use with the carbon flow payment schemes, and this leads to significant losses in the present day value of consumption (Table 4).

Table 5: Comparison of carbon flow and net carbon stock payment schemes (R$1.0/t)

	Baseline	Net above-ground carbon stock	Above-ground carbon flow	Total carbon flow
Present day value of consumption (R$)	50,688	96,800	46,056	47,437
Forest at year 25 (ha)	0	23	6	7
Total carbon in year 25 (t)	4021	--	--	4827
Above-ground carbon in year 25 (t)	265	3468	1086	--
Present day value of transfers over 25 years (R$)	--	46,112	-4,632	-3251
R$/t of total carbon	--	--	--	-4
R$/t of above-ground carbon	--	14	-6	--
R$/ha forest	--	4611	-201	-452

5. ALTERNATIVE POLICIES FOR CONSERVING CARBON

Carbon payment schemes are one instrument for encouraging farmers to sequester carbon. But other policies may also be effective and it is useful to evaluate some of these alternatives to see how they perform against carbon payments.

LAND TAXATION

Land taxes on low-carbon land uses could be one way to encourage greater carbon sequestration. We consider two types of land taxes. The first is a tax on all cleared land, while the second is a tax on all cleared land that is planted to non-perennials.

A tax on all cleared land of R$32/ha would reduce the net present value of farm consumption to R$38,007 and yet preserve only 5 ha of forest and 4,679 tons of total carbon in year 25 (Table 6).[10] A similar tax on all cleared land planted to non-perennials reduces the net present value of consumption to R$41,419 while saving only 3 ha of forest and 4442 tons of carbon (Table 6). A tax on land-uses does not appear to be very effective, and would induce considerable loss in small farm welfare for only modest gains in carbon sequestration.

[10] Increasing the tax beyond R$32 per hectare makes it impossible for farmers to pay the tax and feed their families. Imposing a tax on cleared land planted to non-perennials also yields an infeasible solution for payments above R$32 per hectare because farmers do not have enough labor or money to plant nonperennials.

Table 6: Alternative policy scenarios for retaining carbon

	Baseline	50% rule	Min. carbon 4000t	Min. carbon 6000t	Min. carbon 8000t	Min. carbon 10,000t	Forest manage ment	Tax (R$32/ha) on all cleared land	Tax (R$32/ha) on non-perennial land
Present day value of consumption (R$)	50,688	44,201	50,414	50,299	43,461	15,913	54,333	38,007	41,419
Forest in year 25 (ha)	0	30	2	13	28	43	9	5	3
Total carbon in year 25 (t)	4,021	8,199	4000	6000	8000	10,000	5,137	4,679	4,442
Above-ground carbon in year 25 (t)	265	4500							
Present day value of transfers over 25 years (R$)	--	-6487	-274	-389	-7227	-34,775	3645	-12,681	-9269
R$/t of total carbon	--	-1.6	-13.0	-0.2	-1.8	-5.8	3.3	-19.3	-22.0
R$/t of above ground carbon	--	-1.5	--	--	--	--	3.1	--	--
R$/ha forest	--	-216	-137	-30	-258	-809	428	-2536	-3090

INPUT SUBSIDIES

Instead of directly paying farmers for carbon sequestration, policymakers could use market incentives to favor land-uses with high carbon content. Carpentier, Vosti, and Witcover (forthcoming) have demonstrated that when labor-intensive land-uses such as coffee are adopted, more forest is preserved and less pasture is seeded. Coffee was not a profitable crop to grow in Acre in 1994 because the coffee price was low and inputs were expensive. Seedling, fertilizer and pesticide subsidies might switch the balance in favor of coffee production. Four scenarios for subsidizing inputs were considered:

- free coffee seedlings
- free coffee seedlings and a 50 percent fertilizer subsidy
- free coffee seedlings and free pesticides
- free coffee seedlings and free fertilizer.

Free coffee seedlings do not induce farmers to plant more coffee even when a 50 percent subsidy is offered on fertilizer. Moreover, the forest disappears within 25 years and only low levels of total carbon are sequestered (Table 7). More carbon-saving land uses are adopted when free seedlings and free fertilizer are offered. Under this scenario, 8 ha of forest and 2.7 ha of coffee remain after 25 years. The scenario maintains 5,014 tons of carbon in year 25, approximately 1,000 more tons than in the baseline. The present day value of the transfers are worth R$32,018. The free coffee seedling and free pesticide scenario only retains 186 tons of carbon more than the baseline after 25 years but at a cost of R$5032 in the present day value of the transfers.

Table 7: Results for alternative coffee input subsidy schemes

	Present day value of consumption (R$)	Forest area at year 25 (ha)	Total carbon at year 25 (t)	Present day value of transfers over 25 years (R$)
Baseline	50,688	0	4021	--
Free seedlings	51,121	1	4182	433
Free seedlings plus 50% fertilizer subsidy	54,389	1	4242	3,701
Free seedlings and pesticides	55,720	2	4207	5,032
Free seedlings and fertilizer	82,706	8	5014	32,018

THE 50 PERCENT RULE

The baseline scenario did not incorporate the federal law prohibiting deforestation beyond 50 percent for small farms. Once this restriction is introduced into the model, virtually all the land that can be deforested is dedicated to pasture and livestock production activities. Annual crop production and fallow decline over time. Farmers adhering to the 50 percent rule can expect the present day value of their consumption to fall to R$44,200, a 13 percent decline from the baseline (Table 6). The shadow price on the 50 percent forest restriction increases from 0 in the first six years (until the 30 ha upper bound is reached) to R$200/ha by the 25th year. Implementation of the 50 percent rule would double the total carbon stock compared to the baseline solution.

PERFORMANCE STANDARDS ON CARBON

In these scenarios, the farmer is required to meet specified carbon performance standards that are specified as minimum constraints on the amount of total carbon stock that must be maintained at all times. Four standards are simulated, corresponding to total carbon constraints of 4,000, 6,000, 8,000, and 10,000 tons. The highest level is approximately the same as the initial stock of 10,067 tons of total carbon available at the beginning of the planning horizon.

Only small amounts of forest are preserved at year 25 with the 4,000 and 6,000 minimum ton constraints (2 and 13 ha, respectively), but these increase to 28 and 43 ha of forest when the minimum is increased to 8,000 and 10,000 tons of total carbon, respectively (Table 6). As the standard gets stricter, more and more forest and fallow are maintained on the farm. The present day value of consumption is barely affected until the carbon constraint is raised to 8000 tons, at which time there is a loss of R$7,227. This loss increases to R$34,775 when the carbon constraint is increased to 10,000 tons, a 69 percent reduction from the baseline value. The corresponding unit costs to the farmer are R$5.8 and R$809 for each ton of carbon and hectare of forest saved, respectively. These are the amounts of money that the farmer would need to be given today to induce him/her to preserve 10,000 tons of carbon and 43 hectares of forest.

FOREST MANAGEMENT OPTION

Sustainable forest management on private holdings is currently being evaluated in Brazil by the Brazilian Corporation for Agricultural Research (EMBRAPA) to increase the value of the standing forest. Data for the simulation were based on on-farm trials conducted by EMBRAPA in which the forest is harvested on a rotational basis every 10 years using low-intensity extraction methods, including improved felling techniques and use of oxen instead of tractors to drag wood, and extraction rates of 10 cubic meters/ha/year compared to 30-40 cubic meters/ha/year traditionally extracted by loggers (Borges de Araujo and de Oliveira 1996; Neves d'Oliveira, Borges de Araujo, and de Oliveira 1996).

When introduced into the model, the sustainable forest management option leads to the retention of 9 ha of forest at year 25 compared to zero in the baseline scenario (Table 6). The area of fallow is also reduced to zero, and there is a slight reduction in the area in pasture, though this continues to be the predominant land-use. The present day value of consumption increases by 7.2 percent to R$54,333, and the total carbon stock at year 25 increases by 28 percent to 5,137 tons. Thus, farmers practicing forest management in their private forest reserve would gain additional income and increase their above-ground and total carbon stocks. As the price of timber increases (as it has done in recent years), forest management may become even more attractive (Carpentier, Vosti, and Witcover, forthcoming).

COMPARISON OF ALTERNATIVE CDM POLICIES

The only policies that preserve as much carbon and forest as the carbon stock payment schemes are the 50% rule and the 8,000 tons carbon performance standard. These schemes also achieve significant preservation at low cost to the government because they rely on regulation and compulsion rather than on payments to farmers to change land-use incentives.

However, they have high costs to the farmer in terms of the present day value of consumption they must forego.

Subsidies on coffee inputs and taxes on low carbon land uses are not effective in preserving forest and carbon, but they are costly either to the government in terms of subsidies or to the farmer in terms of taxes. Allowing farmers to undertake sustainable forestry practices and low-intensity extraction increases farm income and the present day value of consumption, but has only modest impacts on the amount of forest and carbon preserved.

6. CONCLUSIONS

This paper has evaluated the possibilities for using carbon payments as a way to sequester more carbon on small farms in the forest margins of the Brazil's Western Amazon region. Alternative carbon payment schemes were evaluated with the aid of a model of a typical small farmer in a settlement project in the state of Acre. The model was also used to evaluate some alternative policies that the government might pursue to achieve the same objectives as carbon payments.

The main conclusions are that carbon payments can be effective in conserving forest and sequestering carbon, but the payments should be tied to carbon stocks or net carbon stocks rather than carbon flows. An annual payment of R$1/t for each ton of carbon stored in the forest (both above and below ground) could save about half the existing area of forest on the representative farm, and about 75 percent of the existing total carbon. This payment scheme is equivalent to a lump sum transfer today of R$66,477 per farm, or 19/t of carbon remaining at year 25. If the payment is tied to carbon in all land uses rather than just forest, the results are much the same but the cost increases to the equivalent of a lump sum transfer today of R$81,538 per farm, or R$24/t of carbon remaining at year 25.

The cost of carbon payments can be reduced considerably by tying the payments to above-ground rather than total carbon. With this approach it does not matter whether the payment is tied to forest or all land uses, and it leads to preservation of about half of the existing stock of forest and above-ground carbon at year 25. The cost is equivalent to a lump sum transfer today of about R$47,000 per farm, or R$15/t of above-ground carbon remaining at year 25.

The opportunity cost of carbon offset on small farms in Acre, Brazil, is consistent with previous estimates for tropical forest carbon and low compared to previous estimates for other parts of the world and other industries. For instance, Richards (1999) reports carbon offset costs of between $2 and $10 per ton of tropical forest carbon. In Costa Rica, 200,000 tons of carbon was sold in 1996 at an average cost of $10 per ton (Richards 1999). Plantiga, Mauldin, and Miller (1999) find that costs to enroll 25% of Maine, South Carolina, and Wisconsin's agricultural land in an afforestation project would costs an average of $60, $45, and $48/t of carbon, respectively. The current price paid for carbon offsets is $10-12 per ton of carbon (Stuart and Moura-Costa 1998). Duncan et al. (1999) report a predicted abatement cost per ton of carbon of $0 to 2 and $2 to 3 for chemical co-generation of energy and plantations, and biomass electricity, respectively.

In general, developing countries such as Brazil are not in favor of including forest carbon in carbon-offset projects. Brazil's position is that forest carbon projects do not embody any technology transfer benefits, unlike most other carbon-offset projects under the CD. The results of this study show that agricultural carbon payments that do not include forest carbon do not benefit small-scale Western Amazonian farmers, or save much forest. If the Kyoto Protocol were amended to allow for conservation of forest carbon, then CDMs could provide inexpensive carbon offsets, alleviate poverty, and preserve biodiversity.

Of the alternative policies to carbon payments analyzed in this paper, the only ones that preserve as much carbon and forest as the carbon stock payment schemes are the 50% rule and the 8,000 tons carbon performance standard. These schemes also achieve significant preservation at low cost to the government because they rely on regulation and compulsion rather than on payments to farmers to change land-use incentives. However, they have high costs to the farmer in terms of the present day value of consumption they must forego, and would seriously reduce the welfare of an already marginal group.

Subsidies on coffee inputs and taxes on low carbon land uses are not effective in preserving forest and carbon, but they are costly either to the government in terms of subsidies or to the farmer in terms of taxes.

Allowing farmers to undertake sustainable forestry practices with low-intensity timber extraction increases farm income and the present day value of consumption, but has disappointing impacts on the amount of forest and carbon preserved. This result is less encouraging than Duncan et al. (1999), who found that sustainable forestry could provide low-cost carbon offsets and a supply of up to 1 billion tons of carbon on both private and public forests in the Amazon.

In order to implement a carbon stock payment scheme, important measurement issues would have to be resolved. Rapid developments are being made with Geographic Positioning Systems (GPS) and Dual Camera Videography that will help reduce the costs of measuring and enforcing carbon offset projects. For instance, Southgate (1998) found that the cost of land-use assessment in the Amazon based on satellite imagery and ground-truthing was less than $0.20 per hectare. New technologies are quickly being developed to reduce these costs, such as a patent recently filed by ECCI, an Illinois corporation, to certify emissions reductions. New methodologies are also being developed to facilitate and standardize below-ground carbon measurements (Palm et al. 1999).

Transaction costs might also be reduced through emerging companies that offer services as clearing-houses between buyers and sellers of carbon (Environmental Correct Concepts, Inc. (ECCI)), and by institutions such as the Consultative Group on International Agricultural Research and Winrock International that are providing training in carbon measurement. More work is needed, however, on the institutions needed to minimize the costs of such a project, especially if small farmers are to take advantage of this new opportunity. If developed countries want to ensure that carbon trade will help alleviate poverty, in addition to slowing climate change, they must insist that CDM projects are designed to include small farmers. To make this possible, research on ways to reduce the transaction costs of trading with thousands of small farmers will be needed. If no cost-effective mechanism to aggregate these small farmers can be found, then small farmers will be excluded from the technology transfer and other benefits that might accrue from carbon trade. To be successful, CDMs will most likely have to provide value-added technology to "occupy" labor and reduce incentives to deforest and cultivate land in ways that violate the agreed-upon carbon stock or to deforest land outside the CDM project.

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