Spring 5-9-2010

Carbon Finance & Cattle Externalities in the Brazilian Amazon: Pricing Reforestation in terms of Restoration Ecology

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Carbon Finance & Cattle Externalities in the Brazilian Amazon: Pricing Reforestation in terms of Restoration Ecology

Undergraduate Thesis presented to the University of Connecticut Honors Program
April 30, 2010

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Source: Treehugger

Abstract

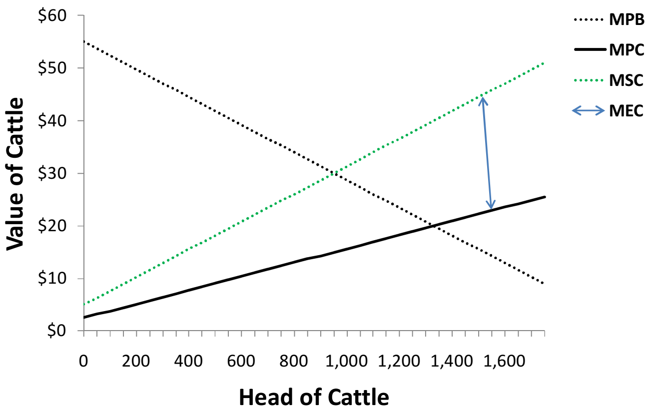
This paper evaluates land-use conflict between cattle pasture and tropical rainforest in the Brazilian Amazon and attempts to reconcile negative production externalities within the framework of carbon finance. Specifically, it analyzes the price per metric ton of CO_2e that would make reforestation projects, in terms of restoration ecology, a viable land-use alternative. Regional information on opportunity, implementation, and transaction costs is used to develop a partial equilibrium cost-benefit analysis, in which carbon sequestration is the only benefit. Financing is employed through Kyoto's Clean Development Mechanism and long-term certified emission reductions (lCERs) are the carbon financial instrument modeled. Results indicate that carbon revenue alone cannot provide the incentives necessary to induce the reforestation of high diversity rainforest. In order to cover the costs of several land-use changes analyzed, current prices would need to grow from \$4/tCO_2e to approximately \$7.5/tCO_2e.

1. Introduction

Cattle ranching in the Brazilian Amazon is the largest driver of deforestation in the world and is responsible for approximately one in every eight hectares converted globally (Greenpeace International, 2009). As a result, Brazil is among the highest greenhouse gas emitters and is responsible for 8-14 percent of global emissions from land-use change (Olsen and Bishop, 2009). Yearly conversions averaged 17,500 km^2 between 1989 and 2006 (Walker et al., 2008) and according to recent estimates, cumulative forest loss now exceeds 16% of the original 4 million km^2 of closed moist forest that once existed (Alves, 2007)[1]. Cattle comprise the largest obstacle to reclaiming tropical forests and the immense ecological value they possess (Fig. 1).

[1] Walker et al. (2008) note that seventy seven percent of cleared lands were pasture in the 1995 agricultural census, and 9.9%, "abandoned". These may have once been pastures, in which case the authors believe it possible that almost 90% of historical deforestation in the Amazon is accounted for by ranching.

Fig. 1. Illustrative negative production externality resulting in market failure.



Marginal private benefit is the utility received from consuming one more head of cattle. The **marginal private cost** represents the cost to cattle ranchers of raising one more head of cattle. The **marginal social cost** is the full cost of cattle production including the loss of carbon value from deforestation. The **marginal external cost** is equal to this lost "intrinsic" value of carbon not currently priced into market transactions.

Animal grazing density in the Amazon is between 0.5 and 0.8 animal units per hectare and profits are generally less than $50 per hectare (Walker et al., 2008).

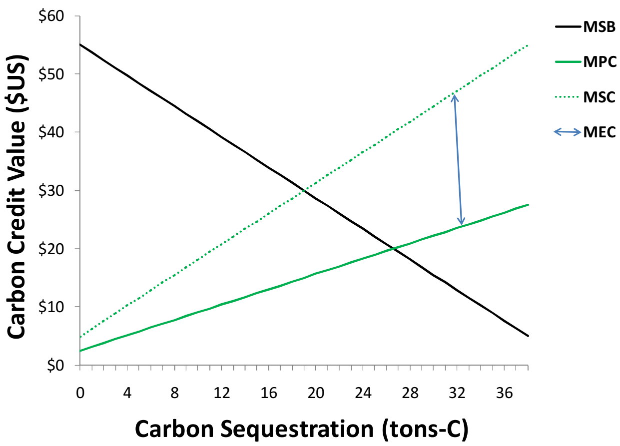
The Amazon is the largest remaining tropical rainforest in the world and ranks among the highest biodiversity hotspots. It provides multiple ecosystem services including the regulation of rain fall, flood and water yield regulation, control of soil erosion, and carbon storage and sequestration. The continued delivery of these services remains essential to our economic prosperity and other aspects of our welfare (eftec, 2005) [2]. In terms of an indicative value per hectare of forest, the benefit of carbon storage in forests is estimated between US$650 to US$3,500 per hectare in net present value terms (IIED, 1999). A review of existing literature places the value per ton of carbon at US$34 (Clarkson and Deyes, 2002) [3]. In 2005, statistics from the United Nations Food and Agriculture Organization estimated Brazilian forest alone to have 104,638 megatons of stored forest carbon valued at over $2 trillion (Butler, 2005) [4]. The service of carbon sequestration is distinctive in that it is global in nature and is therefore a public good. As land conversion continues the value of this service becomes severely diminished exacerbating the effects of climate change[5]. Paying for this carbon sequestration service is possible in the framework of carbon trading under the Kyoto Protocol's Clean Development Mechanism (CDM).

2. Background

In 1992, the United Nations Framework Convention on Climate Change laid the foundation for the Kyoto Protocol. The treaty introduced an international market for emissions trading aimed at reducing the level of carbon emitted from economic activities and was heavily influenced by the United States' Acid Rain and NO_x programs, both successful pioneer efforts in market-oriented pollution schemes. In theory, market-based approaches achieve more cost-efficient reductions than traditional command-and-control regulation (U.S. EPA, 2009). At the end of 2008, the global carbon market had a trading volume of 4,811 MtCO2e valued at $126.3 billion (Capoor and Ambrosi, 2009). This value is expected to reach $170 billion by the end of 2010 (Lomax, 2010). This includes allowance and project-based transactions in both the voluntary and compliance markets. CDM certified emission reductions fall under the latter, in which Annex 1 countries are allowed to invest in developing nations to claim carbon reductions that simultaneously encourage sustainable development (TFS Green, 2010) (Fig. 2.).

[2] Daly (1990) defines ecosystem services as the range of conditions and processes through which natural ecosystems, and the species that they contain, help sustain and fulfill human life.
[3] This value is currently used by the UK Government in assessing the social cost of carbon emissions (eftec, 2005)
[4] Total forest carbon includes carbon stored in above- and below-ground biomass, dead wood, leaf litter, and soils of forests. The value of carbon is calculated assuming a rate of $20 per ton.
[5] According to a study done in 2004 at the University of Brasilia Amazon deforestation is pumping 200 million metric tons of gas into the atmosphere every year (BBC, 2004).

Fig. 2. Illustrative market solution highlighting reforestation potential in terms of carbon finance[6]



Marginal Social Benefit (MSB) represents the WTP of Annex 1 investors for forestry sector carbon emission reductions. Carbon sequestration costs faced by landowners and coordinating agencies represent the **Marginal Private Cost (MPC)** curve**. Marginal Social Cost (MSC)** represents the total cost to society per unit increase in forest area including lost value from ranching. **Marginal External Cost (MEC)** is the income forgone from cattle production when a land change takes place. This must be compensated before a land conversion will voluntarily occur in the market.

1 metric ton of carbon sequestered is equal to 3.67 carbon dioxide equivalents (tCO_2e).

Afforestation and Reforestation projects (ARPs) were introduced in 2003 and are currently the only land uses eligible under the protocol (Capoor and Ambrosi, 2009)[7]. Afforestation is defined as newly created forest on land that has been free of forest for more than 50 years and reforestation as newly created forest on land that has been free of forest cover on December 31, 1989 (Tüv-Süd, 2008). Two types of credits are issued: temporary certified emission reductions (tCERs) and long-term certified emission reductions (lCERs). These can be distinguished by the length of their crediting periods which are renewable 5 year terms for tCERs and twice renewable 20 year (max 60) or single 30 year issuances for lCERs. At expiration, these credits must be replaced by similar credits or supplemented by other reductions (Olschewski and Benítez, 2005). Pricing has not yet occurred via normal market channels but the World Bank's BioCarbon Fund, which provides carbon finance for projects that sequester or conserve greenhouse gases in forest, agro- and other ecosystems, quotes around US$4 per ton of carbon dioxide equivalent (tCO_2e) (Pearson et al., 2005; Streck, 2006). For reference, the 2008 average price of a permanent certified emission reduction was US$16.78 (Capoor and Ambrosi, 2009).

$4 per tCO_2e will be used as the initial price of carbon in the analysis and a 20 year reforestation lCER will be modeled. Reforestation options have been developed for several restoration techniques and will be priced to determine the cost and assess the feasibility of this specific land-use change.

3. Methodology

In order to favor comparability among CDM project types, all assumptions related to the methodology should be made explicit and the following information included (Richard and Stokes, 2004):

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[6] De Jong et al. (2000) estimated the potential of carbon sequestration through agroforestry and forest management in Chiapas as function of the incentives, finding a potential of 1 to 38 Mton-C for incentives within $5–15/ton-C in a study area of 600,000 ha. ARP feasibility frontiers showing the carbon sequestration potential as a function of carbon price were derided highlighting the effect of economies of scale.

[7] ARPs are being developed in both the compliance and voluntary markets (Torres et al., 2010). However, the extent of these projects is small accounting for less than 1% of volumes transacted in 2008 indicating that land use, land-use change, and forestry assets are marginal despite the potential for huge implementation (Capoor and Ambrosi, 2009). Trabucco et al. (2008) estimate available area for ARPs at 790 MHa in non-Annex I countries. Natural Vegetation might be able to sequester 25-30% of expected emissions in 1990-2100 (Beerling and Woodward, 2001).

(1) A description of the practices to be implemented.
(2) A definition of the sequestration pathway on the long term.
(3) Identification of a baseline without the project.
(4) A discussion on the geographical scope.
(5) A description of costs stressing the importance of opportunity costs.

3. 1 Restoration Techniques

Restoration ecology is the process of assisting the recovery of ecosystems and is chosen over commercial plantations in this study for its potential in providing multiple ecosystem services at a future point in time[8]. Information on techniques to be implemented is gathered from literature on reforestation projects conducted over the last 30 years in the Atlantic Rain Forest[9]. Rodrigues et al., (2009) found that the reconstruction of permanent forest with high diversity is feasible but depends on landscape characteristics and the strategies applied. Generally, a common approach employed is to plant many native species from different functional groups to re-establish forest composition, structure and dynamics. Three main principles of restoration are to (Gandolfi et al., 2007):

i. reconstruct species-rich functional communities capable of evolving;
ii. stimulate any potential for self-recovery still present in the area (resilience) whenever this is possible; and
iii. plan restoration actions in a landscape perspective.

In reality, choosing the best restoration strategy for a particular area is not straightforward and a number of alternatives are available to the restorationist depending on the situation. This is due because of differing degrees of historical disturbances, degrees of resilience, reference information, surrounding landscape and socio-economic background (White and Walker, 1997; Holl et al., 2000; Ashton et al., 2001; Maginnis and Jackson, 2007). A list of techniques and cost information is presented in Table 1.

Table 1 – Reforestation options

	Restoration Technique	Average Cost (US$/ha)	Fixed	Period 1	Period 2
	Commercial Eucalyptus	700	420	140	140
1	Direct Seed Sowing (Low)	760	456	152	152
2	Direct Seed Sowing (High)	1,450	870	290	290
3	Topsoil Transposition	2,180	1,308	436	436
4	Nucleation Techniques	2,200	1,320	440	440
5	Planting Seedlings (Low)	3,000	1,800	600	600
6	Planting Seedlings (High)	4,500	2,700	900	900
7	Hydroseeding	20,000	12,000	4,000	4,000
	1 US$ =1.65 R$ 23/6/2008		**60%**	**20%**	**20%**

Source: Rodrigues et al., 2009; Engel and Parrotta, 2001

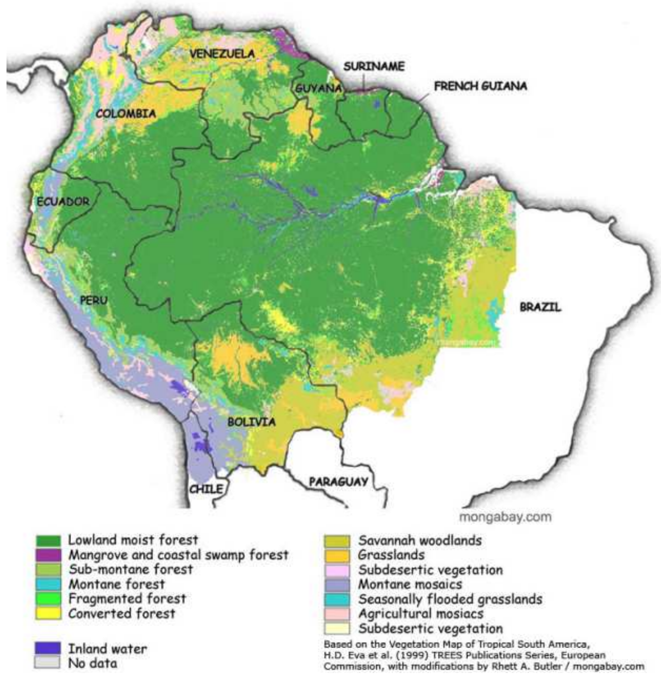
Because of scarce data on the costs of these techniques and the periods in which they are incurred it is assumed that 60% of the average cost per hectare is incurred in the establishment phase and 20% in each of the first two years. This is based on a study by Engel and Parrotta (2001) in which planting costs were evaluated for the lowest cost restoration technique: direct seed sowing. The authors found that after 2.5

[8] The decision between plantations and secondary forest succession represents a trade-off in patterns of biomass accumulation. Plantations often select species that sequester carbon faster than secondary forests under the same edaphic and climatic conditions (Lugo, 1992). There is also a significant loss of value when timber extraction is excluded from the project.
[9] Intense forest degradation started more than 500 years ago in Brazil (Dean, 1995). Only about ca. 12% of the original Atlantic Rainforest Biome Remain (Rodrigues et al., 2009).

years of planting, natural regeneration of woody perennial species was observed at all sites in both the direct-seeded and unplanted control plots (treatments). These costs all lie relatively early on in the project so the effect of discounting will be smaller. Engel and Parrotta (2001) also suggest that cheaper methods of plantation establishment on grass-dominated and degraded tropical landscape entail more risk than alternative but more expensive techniques regarding forest recovery and resilience.

3.2 Carbon Sequestration Data

The carbon sequestration rate is based on literature reviewing secondary forests growing on abandoned agricultural lands and pastures. Silver et al. (2000) discuss the potential of secondary forests to serve as carbon sinks for atmospheric carbon dioxide in above-ground biomass and soils. Data on moist tropical forest suggests that significant amounts of carbon can accumulate in plants and soil over relatively short (~20 year) time periods (Brown & Lugo, 1992). The overall rate of above-ground biomass accumulation in the first 20 years was 6.17 Tons-C/ha-year[10]. Soil Carbon accumulated at a rate of 1.30 Tons-C/ha/year over a similar period (Silver et al., 2000). The lCER instrument was partly chosen due to uncertainty surrounding carbon sequestration in forests over long periods of time[11]. The baseline selected for this study is zero based on findings that pasture soil is actually a net carbon source in the decades following deforestation[12]. Consequently, the effective carbon sequestration rate used here is 7.5 Tons-C/ha-year, or an annual reduction of 27.5 tCO_2e per hectare.



Source: Mongabay.com

3.3 Geographic Scope

Amazonian states lying on the "arc of deforestation" were chosen as representative areas in this study for economic and ecological reasons. From a land use perspective, locations are at the margin where a land trade-off between pasture and forest is assumed to exist. From a restoration perspective, areas here are more recently deforested and are in closer proximity to primary tropical rain forest. Thus, specific sites selected should be areas with a relatively high self recovery potential. This is the probability that a degraded ecosystem has to reestablish its natural ecological forms and processes (Padovezil & Lima, 2009). Choosing optimal locations will reduce restoration costs based on a dichotomous key for selecting project sites developed by Gandolfi et al. (2007).

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[10] All sites were completely cleared and the majority of them were also burned prior to forest regrowth.

[11] The longer the time frame of a reforestation initiative the more uncertain the degree of carbon stored. It is believed that increased carbon storage can be achieved relatively quickly but is likely to be a finite process eventually reaching a maximum sequestration potential. The time period is not well known but such a limit may be reached in the first 50-100 years following forest establishment (Silver et al., 2000).

[12] "Whether pasture soils are a net sink or a net source of carbon depends on their management, but an approximation of the fraction of pastures under 'typical' and 'ideal' management practices indicates that pasture soils in Brazilian Amazonia are a net carbon source, with the upper 8 m releasing an average of 12.0 t Crha in land maintained as pasture in the equilibrium landscape that is established in the decades following deforestation" (Fearnside and Barbosa, 1997).

The Amazon exhibited significant growth in cattle from 25 million head in 1990 to over 74 million in 2005 (Fig. 3.). The states of Pará, Mato Grosso, and Rondônia saw their herds increase by 292%, 294%, and 560%, respectively over this period (Walker et al., 2008). Table 2 details the local cattle economies of five selected municipalities. Information was collected from 8 panel studies conducted with 43 producers in 2002.

Source: Wikimedia Commons

Table 2 – Profitability and land characteristics in selected municipalities.

	Municipality/State	Net Income (US$/ha/year)	Land Value (US$/ha)	IRR	Size of Properties (ha)	Date of Panel Study	FX Rates R$/US$
	Tupã/SP	29	1457	3.8	300	4/26/2002	2.27
1	Alta Floresta/MT	56	485	14.5	1200	5/21/2002	2.47
2	Ji-Paraná/RO	53	499	11.5	1700	5/15/2002	2.50
3	Santana do Araguaia/PA	38	799	14.7	3200	5/15/2002	2.50
4	Redenção/PA	28	550	9.1	4800	3/25/2002	2.36
5	Paragominas/PA	44	530	11.0	12000	3/22/2002	2.36

MT is Mato Grosso; RO is Rondônia; PA is Para; SP is São Paulo

Source: Barros (2002); Smeraldi and May (2008)

Amazonian ranchers can earn higher returns on investment than their Brazilian competitors due to productivity and land cost advantages (Walker et al., 2008).

CDM ARPs can either be small or large scale. Small scale projects are limited to annual sequestration amounts of 16,000 kilotons CO_2e or less (Tüv-Süd, 2008). At a sequestration rate of 27.5 tCO_2e per hectare a year, land size would be limited to approximately 580 hectares. As observed above, many existing ranches are larger than this. Engel and Parrotta (2001) believe the costs of many restoration techniques are too high to actively engage small landholders. For these reasons, a large scale ARP is selected targeting more corporate style ranches[13]. Torres et al. (2010) analyzed several sequestration options and generated cost curves for ARPs recognizing the effect of economies of scale. Fig. 4 shows this effect in which average sequestration costs decrease toward variable cost until marginal costs become constant. According to their study, this point is reached with land sizes greater than 3,000 hectares. Information will be used from the state of Pará (options 3, 4, and 5) to capture these effects[14].

[13] Choosing corporate ranchers as representative economic agents is advantageous because of the likelihood a legal land title is in possession. Additionally, they may be more adept at handling the transaction process.
[14] In the state of Pará, more than 51 percent of agricultural lands are in holdings that exceed 1,000 hectares, and nearly half that land is controlled by enterprises that are larger than 10,000 hectares, many of them ranches (Simmons, 2004).

Fig. 3. Cattle expansion in the Amazon 1990-2005

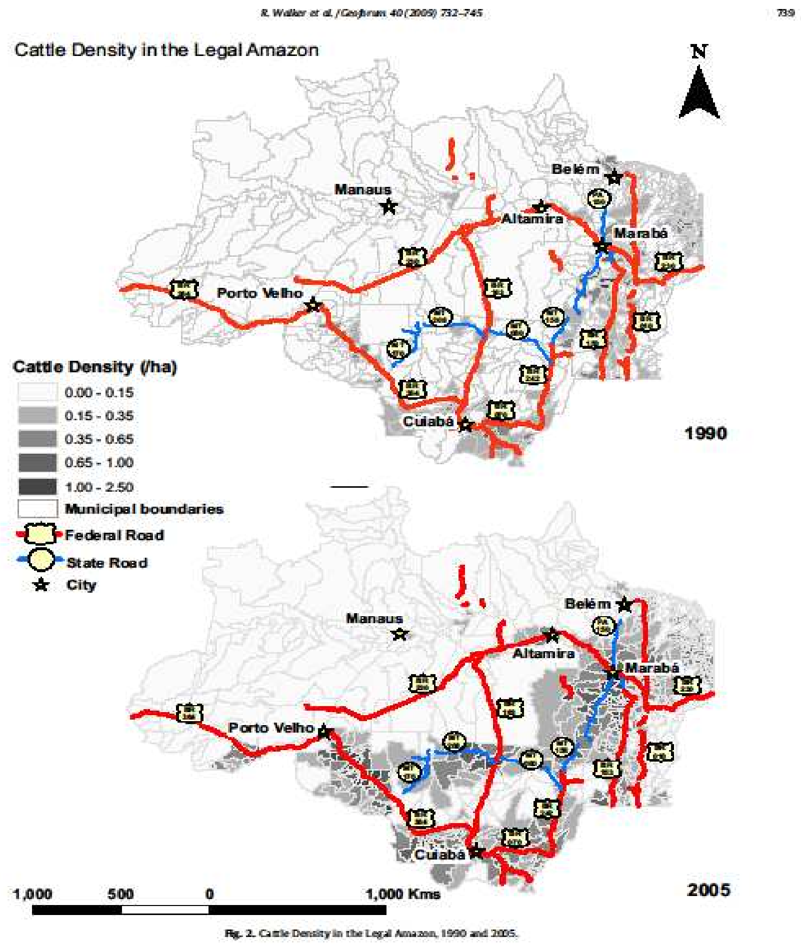
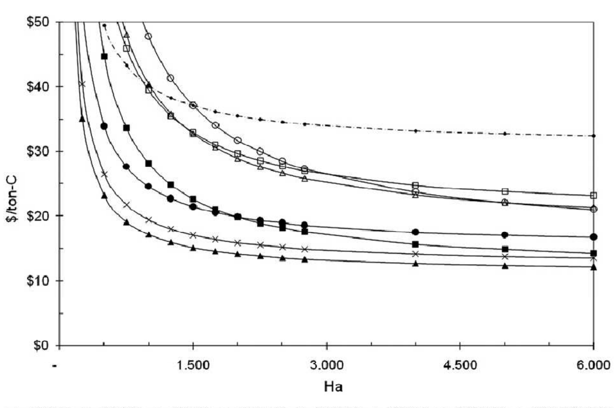


Fig. 4. Sequestration cost curves for ARPs considering initial transaction and implementation costs.



Sequestration Options		Ton-C/ha
1	Reforestation Tropical	150
2	Improved fallow tropical (high)	128
3	Improved fallow tropical (low)	96
4	Living fence tropical	54
5	Improved fallow sub tropical	46
6	Improved coffee (under shade)	39
7	Living fence, sub-tropical	28

Source: Torres et. al. (2010)

3.4 Costing Carbon Analytically

Costs are calculated using a partial market equilibrium in which the prices of inputs are assumed constant in order to derive a cost function. Cost curves may be generated from this function to show the variations in total sequestration cost ($), average cost ($/ton-C, $/ton-C/year) or marginal costs ($/ton-C) as function of the project area (ha) or sequestration potential in a region (ton-C) (Torres et al., 2010). Due to the importance of initial costs in a project's success or failure, average costs will be used throughout the analysis. Carbon prices will also be quoted in dollars per ton of carbon dioxide equivalent ($/tCO2e) to aid institutional investors in the comparison of competing abatement options in the carbon market (Olsen and Bishop, 2009). Costs can be grouped into three categories: Implementation, Transaction, and Opportunity. The first two have both fixed and variable components:

i. Implementation activities consist of all cash outlays required to establish forest growth from site preparation to planting and maintenance. Table 1 contains this information with fixed costs occurring in period zero and variable costs in periods one and two only.
ii. Transaction costs include feasibility studies, project design documents, validation, and registration. According to Bauer et al. (2005), CDM transaction costs range from $43,000 to $210,000. The lower limit represents small scale projects and the upper large scale. Similarly, there are CDM variable costs that range from $3,000 to $15,000 per year for verification and certification. The upper limits are used for the fixed and variable transaction costs.
iii. Opportunity costs are those necessary to compensate ranchers for the lost income they would have earned if they did not decide to reforest. Richard and Stokes (2004) concluded that these may be the most important factor in costing and are often the most difficult to assess. Table 2 contains opportunity costs per hectare along with representative land sizes.

Cost-benefit analysis is then employed to evaluate the several restoration techniques in table 1 against opportunity costs and land size characteristics for the Pará state municipalities in table 2. Two equations are adapted from Torres et al. (2010) that calculate (1) the average net present value of a project and (2) the average sequestration cost of one tCO_2e.

Eq. 1.

$$ANPV = \frac{1}{T} \times \sum_{t=0}^{T} \rho^{t}\{p_{c,t} \times CS_{t}\} - \frac{1}{T} \times \sum_{t=0}^{T} \rho^{t} \left\{\frac{(I_{F,t} + T_{F,t})}{S} + I_{V,t} + T_{V,t} + OP_{t}\right\}$$

ANPV	Average net present value ($/ha-year)
t	time (years)
T	duration of the project (years)
ρ	discounting factor, $\rho = (1 + \delta)^{-1}$
$I_{F,t}$	Implementation Fixed Cost in year t ($/project)
$I_{V,t}$	Implementation Variable Cost in year t ($/ha)
$T_{V,t}$	Transaction Variable Cost in year t ($/ha)
OP	Opportunity Cost in year t ($/ha)
S	Project Area (ha/project)
$P_{C,t}$	Carbon price paid at time t ($/$tCO_2e$)
CS_t	Carbon sequestered from t – 1 to t, (tCO_2e/ha)
S	Area implementing carbon sequestration practices (ha)

Equation 1 assesses the performance of an ARP by finding the difference between average discounted revenues and average discounted costs over the life of the project. More significantly, it allows a price of carbon to be solved for when setting ANPV equal to zero and size constant. This price is the threshold at which a landowner would supposedly be indifferent between reforestation and cattle ranching. Equation 2 solves for the average sequestration cost per tCO2e. All costs are yearly averages per hectare.

Eq. 2.

$$p_c = \frac{1}{CS}\left[\frac{(I_F + T_F)}{S} + I_V + T_V + OP\right]$$

p_c Average Sequestration Cost ($/tCO$_2$e)
CS Carbon sequestered (tCO2e/ha-year)

Equation 1 is useful to an ARP investor because it gives the relative cost of reducing carbon compared to other reduction opportunities. It also indicates to a landowner the level of profitability a new land use might provide. Equation 2 is useful for project designers choosing between different sequestration options.

4. Analysis

The basic parameters to the model are assembled in the box below. A 20 year crediting period is used in which verification and issuance of credits occurs every 5th year at a price of $4/tCO2e. Accordingly, payments occur at the end of years 5, 10, 15, and 20. The financial model developed is in Appendix A.

PROJECT PARAMETERS

Financing			**Carbon Assumptions**		
Mechanism	ICER	Kyoto CDM ARP	*Sequestration Rate*	7.50	Tons-C/ha/year
Length of Project	20.0	Years	*Conversion Factor*	3.67	44/12
Price of Carbon	4.00	$/tCO2e	*Baseline*	0.00	Tons-C/ha/year
			Carbon Sequestered	27.5	tCO2e/ha/year

Municipality/State	**Property Sizes (ha)**	**Local Opportunity Cost**	**Annual Sequestration (tCO2e)**	**Total Potential (tCO2e)**
Santana do Araguaia/Pará	3200	7.00%	88,080	1,761,600
Redenção/Pará	4800	1.50%	132,120	2,642,400
Paragominas/Pará	12000	3.00%	330,300	6,606,000

Note that each municipality has different opportunity costs. These are adjusted from the IRR column in Table 2 using an inflation rate between 7-8%. From 1995 to 2009, the median increase of the Brazilian general price index (IGP) was ca. 8% and the average slightly higher at ca. 9.5%[15]. These are set at three different levels to see the effect of different marginal opportunities on an ARP's ANPV. Since fixed costs are based on an average per hectare value, there is a small amount of variability correlated with this factor as size increases. Project parameters along with implementation, transaction, and opportunity costs are inputted into a financial model built from equation 1 and equation 2. We are interested in whether or not a project is profitable at the current market price. If it is not, the price of carbon that it would take to induce a land conversion is calculated using Excel's Solver.

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[15] http://vsites.unb.br/face/eco/cepes/pdfs/Mollo%20&%20ASF%202006%20NPE%20%28Neoliberalism%20in%20Brazil%29.pdf, http://www.pwc.com/pt_BR/br/estudos-pesquisas/assets/highlights-brazil-09.pdf

Conducting an initial cost-benefit analysis for Santana do Araguaia/PA highlights the inputs for modeling Eq. 1. Average discounted benefits are calculated using the top four line items and average discounted costs the bottom six. All costs refer to the direct seed sowing (low) option. Total fixed implementation costs occur in year zero and are calculated by multiplying project size by average establishment cost per hectare. Variable implementation costs occur in years one and two and remain in average units; all other variable costs not in \$/ha-year then need to be converted. Opportunity costs are already in this format which leaves the transaction costs. Dividing \$15,000 by 3200 hectares gives us a transaction variable of \$5/ha-year. Working out the summations and discounting back to the present will give you the average net present value per hectare. A positive ANPV means a project should be undertaken, while a negative one rejected. At a price of \$4/tCO2e the ANPV results in a loss of \$11.80/ha-year indicating that the carbon income cannot offset enough of the costs to make the restoration technique viable. Solving for the price at time zero that sets ANPV equal to zero gives us \$4.93/tCO_2e. Prices at or above this point could in theory result in a land-use change.

COST-BENEFIT ANALYSIS		
duration of the project (years)	20	T
discounting factor, $\rho = (1 + \delta)$-1	7%	ρ
Carbon sequestered from t – 1 to t, (tCO2e/ha)	27.5	CSt
Carbon price paid at time t (\$/tCO2e)	4.00	Pc
Average Discounted Sequestration Benefit (\$/ha/year)		
Area implementing carbon sequestration practices (ha)	3,200	S
Implementation Fixed Cost in year t (\$/project)	1,459,200	IF
Transaction Fixed Cost in year t (\$/project)	210,000	TF
Implementation Variable Cost in year t (\$/ha)	152	IV
Transaction Variable Cost in year t (\$/ha)	5	TV
Opportunity Cost in year t (\$/ha)	38	OP
Average Discounted Sequestration Cost (\$/ha-year)		

Equation 2 sums the average fixed and variable costs over the life of the project and multiplies them by one over the sequestration rate (CS) to get an average price per tCO_2e reduced. The average sequestration cost in Santana do Araguaia under option 1 is \$3.1 per tCO2e.

5. Results and Discussion

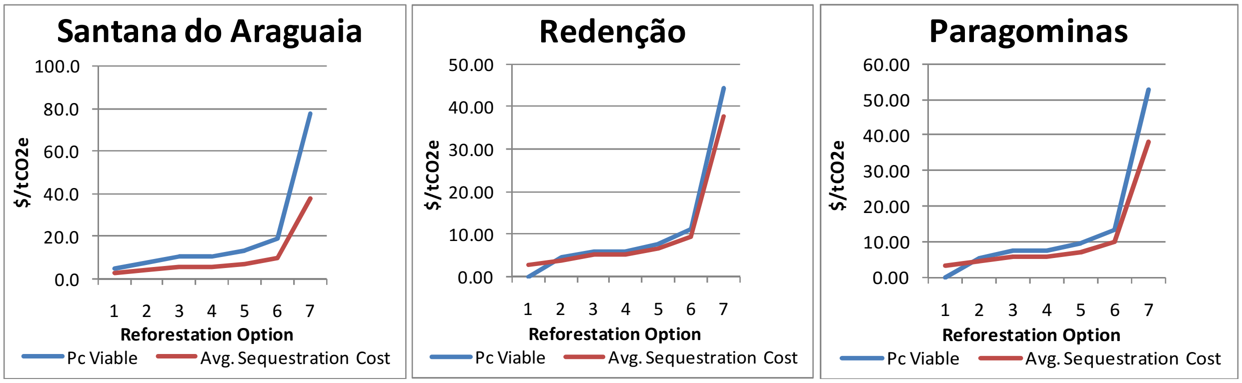
Carrying out the same analysis for all three municipalities and the seven restoration techniques yields similar results with the majority of reforestation options unprofitable. In Santana do Araguaia, where opportunity costs are relatively high, even the default eucalyptus plantation is unprofitable.

Santana do Araguaia/PA

	Restoration Technique	ANPV (\$/ha/year)	Pc Viable t = 0 (\$/tCO2e)	Avg. Sequestration Cost (\$/tCO2e)	5 Year Pc Viable Growth Rate (Annual)
	Commercial Eucalyptus	(8.9)	4.7	2.9	3.28%
1	Direct Seed Sowing (Low)	(11.8)	4.9	3.1	4.27%
2	Direct Seed Sowing (High)	(44.9)	7.5	4.3	13.54%
3	Topsoil Transposition	(80.0)	10.3	5.6	20.87%
4	Nucleation Techniques	(81.0)	10.4	5.7	21.05%
5	Planting Seedlings (Low)	(119.5)	13.4	7.1	27.42%
6	Planting Seedlings (High)	(191.6)	19.1	9.9	36.75%
7	Hydroseeding	(936.8)	78.0	38.0	81.12%

Model Inputs: (3200 ha, ρ 7%, Op 38 \$/ha)

Fig. 5. Viable prices of carbon at time zero versus average sequestration costs



The same patterns are seen in the municipalities of Redenção and Paragominas except that, due to lower opportunity cost rates (1.5% and 3.0%, respectively), some cheaper options do become viable. It can also be observed that options 1 through 4 become profitable at prices around $7.50/tCO$_2$e.

Redenção/PA

	Restoration Technique	ANPV ($/ha/year)	Pc Viable t = 0 ($/tCO2e)	Avg. Sequestration Cost ($/tCO2e)	5 Year Pc Viable Growth Rate (Annual)
	Commercial Eucalyptus	28.0	-	2.5	-
1	Direct Seed Sowing (Low)	25.1	-	2.6	-
2	Direct Seed Sowing (High)	(9.1)	4.4	3.8	1.92%
3	Topsoil Transposition	(45.3)	6.0	5.2	8.37%
4	Nucleation Techniques	(46.3)	6.0	5.2	8.52%
5	Planting Seedlings (Low)	(85.9)	7.8	6.7	14.15%
6	Planting Seedlings (High)	(160.3)	11.0	9.4	22.42%
7	Hydroseeding	(928.4)	44.5	37.6	61.92%

Model Inputs: (4800 ha, ρ 1.5%, Op 28 $/ha)

Paragominas/PA

	Restoration Technique	ANPV ($/ha/year)	Pc Viable t = 0 ($/tCO2e)	Avg. Sequestration Cost ($/tCO2e)	5 Year Pc Viable Growth Rate (Annual)
	Commercial Eucalyptus	8.1	-	3.0	-
1	Direct Seed Sowing (Low)	5.2	-	3.1	-
2	Direct Seed Sowing (High)	(28.7)	5.5	4.3	6.54%
3	Topsoil Transposition	(64.6)	7.4	5.6	12.95%
4	Nucleation Techniques	(65.6)	7.4	5.7	13.10%
5	Planting Seedlings (Low)	(104.9)	9.4	7.1	18.75%
6	Planting Seedlings (High)	(178.6)	13.3	9.9	27.10%
7	Hydroseeding	(940.2)	52.8	38.0	67.54%

Model Inputs: (12,000 ha, ρ 3%, Op 44 $/ha)

But what does a price of $7.50/tCO$_2$e mean in the context of successful ARPs? To put this number in perspective remember that the first issuance of credits, and also the first positive cash flow, occurs in year 5. Therefore, what annual growth rate of Pc is needed during this period to make these ARPs viable? Or, how much does the price of carbon have to grow during a single Kyoto commitment period to get projects moving today? Doing out the math, using $4/tCO$_2$e as the present value and $7.50/tCO$_2$e as the future

value, gives an annual growth rate of 13.4% a year. Information on viable growth rates are listed in the far right columns. Almost every single viable growth rate seems highly unlikely given the large uncertainty faced by the fate of the carbon market, especially concerning the future role that the CDM mechanism will play in a global mitigation strategy for carbon emissions. Nonetheless, the results are useful in showing that carbon alone will not initiate land conversion for the purposes of high diversity forest restoration.

6. Conclusion

The current price of lCERs is not high enough to make ARPs profitable and will not be able to fix negative production externalities caused by cattle ranching in the Brazilian Amazon. Land conversion from pasture to high diversity forest will need either higher carbon prices or additional markets for other ecosystem services. But, a lack of incentive is only one insight revealed by the analysis. The data also bring about the following conclusions:

i. Average sequestration costs increase uniformly across all areas and for all sequestration options. Different opportunity costs seem to have a small impact on the success or failure of these projects whereas the size of implementation costs and the periods in which they occur is considerable. Previous studies have found opportunity costs to be one of the more important cost variables in ARPs but this may not be the case for reforestation efforts conducted within the framework of restoration ecology.

ii. Variations in the difference between average costs and the viable price of carbon shown in (Fig. 5.) draw attention to an important part of modeling carbon credits: the time periods in which revenues are received matters and can make or break an ARP close to profitability. The more expensive the technique, the less risk assumed in terms of permanence but the bigger the discrepancy. Theoretically, average sequestration cost should be very close to the viable price of carbon but the divergence highlights that a large amount of costs are incurred in the early years while benefits not received until years later are deeply discounted. Forward contracts may solve this problem by enabling developers to sell a forward stream of credits that have yet to be generated by the project but this is a risky approach and may reduce the prices received for reductions. High risk project lCERs would be significantly discounted by the market (Olschewski and Benítez, 2005).

iii. Results show that only the cheapest restoration techniques may be viable and that these may not even be possible in all areas. This implies even more uncertainty for project developers because the cheapest techniques are also the ones that entail the most risk. Thus, at very low prices of carbon, ARPs might not even be considered in a government's portfolio of carbon reductions and would not be implemented. On the other hand, different opportunity costs indicate that reforestation projects may have a better chance of succeeding in places where the profitability of ranching is low and the real opportunity cost rate of other land uses small.

Forests are a distinctive type of land use in that they can simultaneously provide private and social benefits. They are a public good in one sense, providing valuable global and regional ecosystem services, and a private good in another, offering ecosystem goods such as lumber, biomass for energy, and numerous non-wood forest products, albeit, with various levels of trade-offs between the two. Bottom line: the current land use conflict is a textbook market failure in which the value lost to the public significantly outweighs the value gained in the private market. Unfortunately, this is a problem that will not be fixed until the public's demand for services such as climate regulation exceeds that of the private demand for cattle. In the short-to-medium term, viable growth rates for carbon prices are unrealistic to

warrant such a change. Regardless, carbon is just one piece of the puzzle and the analysis conducted here hints toward the inclusion of other ecological services as a logical next step.

lCERs were chosen due to their temporary and flexible nature. From an investor's perspective obligated to reduce emissions, these are only a break in liability (Dutschke and Schlamadinger, 2003). They must be replaced at expiration. In 20 years, a landowner may choose to harvest the forest and revert back to ranching or other agricultural activities. Conversely, a landowner may have the option in 20 years to sell more than just carbon on the market. The Amazon rainforest naturally provides valuable water[16] and soil services which, depending on the development of other ecosystem services markets, could get factored into a future ARP revenue stream. This could give a landowner or carbon investor valuable use options in years 20, 40, or 60.

In the short-term, securing ecosystem services will be significantly cheaper using an avoided emissions scheme such as the United Nations Reduced Emissions from Deforestation and Degradation (REDD) program. Yet in the future, as population increases and resource scarcity becomes more acute, restoring these services that have been lost over hundreds of years will be a worthwhile investment. Reducing the externalities driven by cattle production in the Brazilian Amazon will take time but the solutions exist within the emerging areas of carbon finance and environmental markets. In the end, the tradeoff will not just be pasture for forest, or beef for lumber, but instead for air, water, and soil; nothing less than the foundations of human civilization and economic prosperity.

[16] "Ecologist Philip Fearnside, who has spent his career studying the Amazon, observes that the agriculturally prominent south-central part of Brazil depends on water that is recycled inland via the Amazon rainforest. If the Amazon is converted into cattle pasture, he notes, there will be less rainfall to support agriculture." "As the trees disappear, rainfall runoff increases and the land is deprived of the water from evapotranspiration." (Brown, 2006).

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Appendix A. Carbon Financial Model (Santana do Araguaia/PA, Direct Seed Sowing-Low)

Eq. 1.

Cost-Benefit Analysis

	time (years)		t	
	duration of the project (years)	20	T	
	discounting factor, $\rho = (1 + \delta)$-1	7%	ρ	
	Carbon sequestered from t – 1 to t, (tCO_2e/ha)	27.5	CSt	
	Carbon price paid at time t ($/tCO2e)	4.00	Pc	
			PV Revenue=	**1013**
	Average Discounted Sequestration Benefit ($/ha/year)		**1/T=**	**50.7**
	Area implementing carbon sequestration practices (ha)	3,200	S	
456	Implementation Fixed Cost in year t ($/project)	1,459,200	IF	
	Transaction Fixed Cost in year t ($/project)	210,000	TF	
152	Implementation Variable Cost in year t ($/ha)	152	IV	
	Transaction Variable Cost in year t ($/ha)	5	TV	
	Opportunity Cost in year t ($/ha)	38	OP	
			PV Cost=	**1249**
	Average Discounted Sequestration Cost ($/ha-year)		**1/T=**	**62.4**
			PV Project=	**-235.47**
			ANPV ($/ha-year)=	**($11.77)**
Eq. 2.			**Avg. Sequestration Cost=**	**3.05**

FC	**26**	**1,669,200**
IV	**15**	**972,800**
TV	**5**	**300,000**
OP	**38**	**2,432,000**
1/CS	**3.64%**	

Period

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	28	55	83	110	138	165	193	220	248	275	303	330	358	385	413	440	468	495	523	550
					550					550					550					550
					392					**280**					**199**					**142**
1,459,200																				
210,000																				
	152	152																		
	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
522	**182**	**170**	**35**	**33**	**30**	**28**	**27**	**25**	**23**	**22**	**20**	**19**	**18**	**17**	**15**	**14**	**14**	**13**	**12**	**11**
-522	-182	-170	-35	-33	362	-28	-27	-25	-23	258	-20	-19	-18	-17	184	-14	-14	-13	-12	131