Mitig Adapt Strateg Glob Change (2014) 19:1209–1222
DOI 10.1007/s11027-013-9469-8

ORIGINAL ARTICLE

Transaction costs for carbon sequestration projects in the tropical forest sector

**Timothy R. H. Pearson · Sandra Brown ·
Brent Sohngen · Jennifer Henman · Sara Ohrel**

Received: 19 February 2013 / Accepted: 15 April 2013 / Published online: 12 May 2013

Abstract There is general consensus that carbon (C) sequestration projects in forests are a relatively low cost option for mitigating climate change, but most studies on the subject have assumed that transaction costs are negligible. The objectives of the study were to examine transaction costs for forest C sequestration projects and to determine the significance of the costs based on economic analyses. Here we examine four case studies of active C sequestration projects being implemented in tropical countries and developed for the C market. The results from the case studies were then used with a dynamic forest and land use economic model to investigate how transaction costs affect the efficiency and cost of forest C projects globally. In the case studies transaction costs ranged from 0.38 to 27 million US dollars (\$0.09 to \$7.71/t CO_2) or 0.3 to 270 % of anticipated income depending principally on the price of C and project size. The three largest cost categories were insurance (under the voluntary market; 41–89 % of total costs), monitoring (3–42 %) and regulatory approval (8–50 %). The global analysis indicated that most existing estimates of marginal costs of C sequestration are underestimated by up to 30 % because transaction costs were not included.

Keywords Climate change · Carbon projects · Forest carbon · Mitigation · Transaction costs

1 Introduction

There are a number of analyses that suggest that C sequestration in forests is a relatively low cost option for mitigating climate change (see Nabuurs et al. 2007 for a review). However, most of the studies done to date have assumed that transaction costs, which include search

T. R. H. Pearson (✉) · S. Brown
Winrock International, 2121 Crystal Drive, Suite 500, Arlington, VA 22202, USA
e-mail: tpearson@winrock.org

B. Sohngen
Ohio State University, Colombus, OH, USA

J. Henman
Climate Adapt Ltd., London, UK

S. Ohrel
US EPA, Washington, DC, USA

costs, learning costs, legal costs, bargaining costs, and other costs incurred when two parties trade with each other, are small to negligible. If transaction costs are substantive, many forest C sequestration projects may no longer be cost-effective. While transaction costs have been widely discussed as having potentially important implications for climate change policy, and in particular, for policies related to reduction of C emissions and to C sequestration in forests, few published studies have assessed their implications on the costs of C sequestration.

The literature on transaction costs and C offsets is limited principally because the market is still developing, and costs experienced by projects 10 or even 5 years ago are not representative of costs faced today. In addition, the earliest projects faced early-actor penalties in that these projects were obliged to learn lessons and make mistakes upon which the subsequently developing market has been based. The analysis of Antinori and Sathaye (2007) illustrates this issue. The first Clean Development Mechanism (CDM) forestry project was only registered at the end of 2006 (the second did not follow until 2009). The first Climate Action Reserve (CAR) projects were registered at the end of 2007 while the Verified Carbon Standard (VCS) and the American Carbon Registry (ACR) had no forest projects until late in 2009. This early project bias is certainly reflected in the resulting costs. For example, feasibility studies in Antinori and Sathaye (2007) represent 19 % of total transaction costs while regulatory approval represented just 1 %. This is contrary to what we expect in a mature C project market.

Because there is limited evidence on the size of transaction costs in forest-based projects, few economic analyses have attempted to incorporate these costs. One exception is Cacho et al. (2005), who developed an analysis that incorporated transactions costs, but theirstudy did not actually estimate these costs. Another study by Cacho and Lipper (2007) developed a model of transaction costs and incorporated estimates directly into their sequestration analysis. However, they pointed out that their underlying transaction cost estimates actually were arbitrary and not based on quantitative estimates from the field. Given the paucity of work in this area, it is likely that most cost estimates of C sequestration projects (e.g., those reviewed in Richards and Stokes 2004 and Sohngen 2010) have underestimated the transaction costs of such projects. The extent of the underestimation will depend in part on the magnitude of the transaction cost, but it also will depend on how transaction costs are implemented in economic models. Antinori and Sathaye (2007) for example, suggested that transaction costs are relatively fixed, so that if they are spread over a larger quantity of C, they will have a small impact on any unit of C sequestration. This assumption is likely true for certain components of transaction costs, but it may not be adequate for other components. Insurance costs, for instance, likely vary in direct proportion to the value of C at risk, as opposed to the project volume of C. And, if C prices are rising, insurance costs will also rise. It is important to implement transaction costs correctly in economic models to assess their effect.

The objectives of this study were to determine the contribution of transaction costs to total costs incurred by forest C sequestration projects. This was achieved through a study of four case studies across two project categories in three geographical regions. The case study costs were then fed into a dynamic forest and land use model to demonstrate the implication of transaction costs globally..

1.1 Definition of transaction costs

Transaction costs for the purposes of this study are defined as “the resources used to define, establish, maintain and transfer property rights” (McCann et al. 2005). For C markets this can be phrased as “the financial cost to define, establish, maintain and transfer C credits.” Following the categorization proposed by Antinori and Sathaye (2007), we compiled transaction costs into six categories (Table 1). These categories include a) initial costs, which will be applied to the project only once, i.e. search costs, feasibility assessment, and negotiation; b) monitoring costs

Table 1 Categorization of transaction costs in this paper and in comparison to the original categorization by Antinori and Sathaye (2007)

Transaction cost category	Antinori and Sathaye (2007) definition	Cost category includes these elements in this paper
Search costs	• Identifying and selecting the project, project partners and consultants	• Identifying project location • Identifying project partners • Identifying project consultants
Feasibility study costs	• Full feasibility study that would include ○ a GHG baseline assessment and the determination of its additionality ○ engineering, market, baseline and environmental assessments	• Conduct feasibility study • Develop project idea note (PIN)
Negotiation costs	• Obtaining permits, • Arranging financing, and • Negotiating emission reduction purchase contracts. • Marketing and contracting for GHG credits	• Project marketing • ERPA contracts (emission reduction purchase agreements) • Contracts with individual landowners that form part of the project • Contracts with national and/or regional government as necessary
Monitoring costs	• Preparation of a monitoring plan • Continual monitoring and verification of a project's GHG savings.	• Necessary measurements for baseline determination and preparation of project registration/listing document (e.g. CDM Project Design Document (PDD)) • Measurements/monitoring for determination of emission reductions/ sequestration benefits (every 1–5 years)
Regulatory approval costs	• Validation cost incurred ex-ante to confirm that the project is eligible for claiming reductions • Ex-post certification that credits are produced and received • Registration and certification by a national and/or international regulatory body	• Development of new methodology (if necessary) • Preparation of registration/listing documents • Validation costs • Project registration fees • Verification costs • Issuance fees • Transfer fees of offsets to purchaser
Insurance costs	• Project risk insurance • Costs of insuring the emission reductions • Or self-insurance by portfolio diversification, pooling projects, or by adding a buffer "stock" of carbon	• Project liability insurance • Risk buffer/risk insurance

and regulatory approval costs, which will be applied to the project over time; and c)insurance costs, which will depend on the value at risk.

An important issue in modeling or measuring transaction costs relates to the fixed nature of many costs. For example, measuring and monitoring protocols may require some specific pieces of equipment. Obviously, the more units of C over which the equipment can be used, the lower the per unit cost of using the equipment will be. This suggests that larger projects may achieve some "economies of scale" with respect to certain transaction cost categories. Cacho and Lipper (2007), however, point out that not only is project size important, but the number of actors is important. Projects that require fewer actors to sequester a given number of tons are likely to have lower transaction costs. Their results, however, suggest that the band of costs across differing number of actors is relatively modest. They find that a 1,000 ha project with 625 actors would have transaction costs of \$7.39 per ton CO_2, while the same project size with only 200 actors would require transaction costs of \$5.34 per ton CO_2.

A related issue is that we would expect that transaction costs would fall over time as participants become more familiar with the market. Many of the costs we examined here, such as measuring and monitoring, regulatory approval, etc., may be difficult to accomplish at first. But as individuals operating in the market gain experience with projects, they will be able to accomplish many of these tasks at lower costs. Falconer et al. (2001) examined this issue, finding that administration costs fell from around 50 % of the total costs at the beginning of the program to around 15 % of the total costs by the sixth year of the program. Further, one would expect that new technologies may emerge to lower the costs of accomplishing certain tasks. For instance, new satellite technologies may emerge to greatly reduce the costs of measuring and monitoring C in forests (Asner 2009; Brown et al. 2005).

Importantly, for our analysis we focus only on the transaction costs outlined in Table 1. Other costs are included in the total cost calculation for the project but are not included as transaction costs. These other costs include opportunity costs, or the foregone income as a result of project implementation, and other project implementation costs, such as site preparation and planting costs, the salaries for forest guards or the cost of the fossil fuels used in managing the implemented activities. All of these are important costs, but they are reflected in the direct costs of implementing the project.

2 Methods

2.1 The case studies

The four case studies represent a range of projects. Two of the case studies were located in East Africa, one from South America, and one from South-East Asia. The project in South-East Asia was a REDD (Reducing Emissions from Deforestation and forest Degradation) project and was at an earlier stage of development and so less complete data were available. The projects in South America and East Africa were afforestation/reforestation (AR) projects and that at least partially explain their more advanced status—methodologies have been available for accounting for AR projects for several years while the first REDD methodology was only approved in September 2010.

One of the projects in East Africa has been developed for the Verified Carbon Standard (VCS) and is located in a highland area with a long dry season and bi-modal rainfall and an average temperature of 16 °C. The area is characterized by undulating land, with swampy valley bottoms. Prior to the project, the area was a grassland. The project is planting exotic and native tree species. The second AR project in East Africa, developed for the CDM, and is located in a lowland tropical area that was characterized as degraded shrub and grassland prior to the project. The average temperature of the area is 30 °C. The project in South America is located in the Amazon, with year round high temperatures and precipitation, but with a notable 3 month dry season. The area is characterized by undulating terraces with low gradient and impoverished acidic soils. Prior to the project activities the area had been cleared of native forest cover and was a degraded pasture. The project is planting native tree species. The project in SE Asia is a REDD project in mature tropical humid evergreen and deciduous forests with an average elevation of 800 m. The area is threatened by road building and immigration principally for plantation development and illegal timber harvest.

The projects ranged in area from 918 ha to over 300,000 ha (Table 2). The baseline for all three AR projects was degraded grasslands/shrublands whereas the baseline land cover for the REDD project wasa mature tropical humid forest. Three of the projects were using VCS standards (http://v-c-s.org/) and one the CDM standard (http://cdm.unfccc.int/), and all four were applying the Climate Community, and Biodiversity Alliance (CCBA) standards (http://www.climate-standards.org/). The duration of the projects varied widely, from 20 to 99 years, and some are renewable after one or more contract periods.

2.2 Cost estimation and analyses

Data collection and interviews were conducted in October and November 2010 and the results presented here reflect costs incurred and anticipated at that time. All three afforestation case studies offer robust cost data from the 'validation' phase of the process. This is the phase whereby the project achieves validation of its PDD by an appropriate third party against a recognized standard. In the case of afforestation/reforestation projects most often it does not make sense to proceed to the 'verification' of the C credit phase until the trees reach a certain size whereby the amount of C sequestered is worth measuring. Given the infancy of the forest C sector and its regulations, there were very few projects that had moved beyond the 'validation' phase currently. However, as part of this study through discussions about budgeting with the project developer, the costs of monitoring and verification have also been included.

To estimate transaction costs over the project lifetime (corresponding to what is stated in their respective PDDs) certain assumptions were made. Actual costs were used for all costs incurred up until October 2010. These were broken down into the three categories as described in section 1.1, and the project developers were asked to document costs per category and fill in a spreadsheet documenting costs line by line—including all direct and indirect costs. Examples of costs are staff salary, consulting fees, travel costs, and auditor costs. As far as possible project developers were asked to provide evidence for these costs through the provision of invoices and receipts. Future monitoring costs were estimated in line with the budgets developed by project developers. For all projects it was assumed that verification would occur every 5 years (as per the minimum requirement for CDM/VCS AR Projects). To calculate registry program fees, the costs associated with the APX registry were applied. For the CDM East Africa project no costs were applicable as the project falls into the 'least developed country' category, meaning that registration and issuance costs are waived under the CDM standards.

All projects using the VCS standard must contribute a number of C credits to a buffer based on an assessment of their risk of reversal (refer to the VCS standard documents at http://v-c-s.org/program-documents/info for details). Projects under the CDM are issued temporary credits that expire and can be reissued where stocks are shown to be present—this is akin to a rental. Temporary credits have issues with fungibility and have been less attractive to

Table 2 Forest sector carbon sequestration case studies. Project details and status at the time of analysis in 2010

Scope	Region	Baseline condition	Standard	Methodology[a]	Status	Duration of project (yr)	Area (ha)	Anticipated credits (Million VCUs[b] or tCERs[c])
AR	East Africa	Degraded grassland	VCS	AR AM0005	Validated and Verified	99	10,815	3.54
AR	South America	Degraded grassland	VCS	AR AM0003	Validated	30	918	0.169
AR	East Africa	Degraded grass and shrubland	CDM	AR AM0004	Validated	60	2,130	6.31
REDD	South East Asia	Lowland humid forest	VCS	VM0006	In Preparation	20	300,000	12.0

[a] Under the CDM methodologies, projects take the form of AR for afforestation reforestation, AM for approved methodology followed by a sequential number for the order in which the methodologies are approved. CDM methodologies are eligible for use by VCS projects. VCS new methodologies take the form of VM followed again by a sequential number

[b] VCUs (verified carbon units) are the offset unit issued by the VCS

[c] tCERs stand for temporary certified emission reductions and are the offset unit issued for CDM forestry projects

buyers (Brown and Pearson 2009). The solution for the voluntary market was insurance provided by the risk buffer allowing permanent and therefore fully fungible offsets.

To calculate the monetary value of the withholding amount for the risk buffer, a price of \$7.88/t CO_2 was used (weighted average price per t CO_2 provided in the 2009 Ecosystem Marketplace Forest Carbon Markets report; (Hamilton et al 2009)). Of course this price may well vary, and it is important to bear in mind that if the project is successful in maintaining the forest C stock the risk buffer will be reduced through time, and withholdings released, which can then be sold.

2.3 Integration with dynamic forest and land use model

To understand whether transaction costs will affect the efficiency of forestry C projects requires the use of larger scale modeling. To accomplish this, we used the global land use model in Sohngen and Mendelsohn (2003). The 2003 version of the model was linked to the DICE (Dynamic Integrated Climate Economy) model (Nordhaus and Boyer 2000). A more recent version of the model was developed and linked to a more recent version of the DICE model (see Sohngen 2010) and this is the version used in our analysis. We incorporated transaction cost estimates from the case studies into the economic model and assessed their implications on the efficiency of C sequestration projects.

To analyze transaction costs we assumed that they drive a wedge between the market price and the price that landowners see, as shown in Eq. (1):

$$P^L = P^M - TC \tag{1}$$

In Eq. (1) P^L is the price of C received by a landowner for tons of C sequestered, P^M is the price of C on the market, and TC is the transaction cost. The relationship between these prices, transaction costs and supply functions (or marginal cost functions) for C sequestration are shown in Fig. 1. S^0 is the marginal cost of C supply that represents the landowners' costs when they implement C projects, including the costs of planting trees, the costs of fencing areas, and the opportunity costs of land. This is the minimum amount of money landowners must receive in order to participate in the project. The market supply curve, however, is actually located at S^1. S^1represents the higher costs for actually supplying tons of C. The market supply curve accounts for transaction costs.

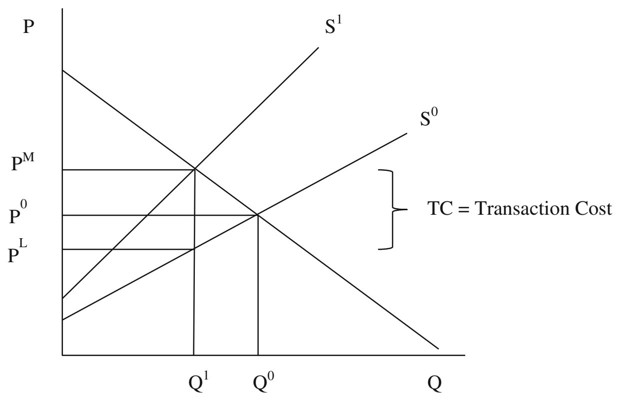

Fig. 1 Effect of transaction costs on markets. S^0 is market supply of credits without transaction costs and S^1 is the market supply with transaction costs

Most market studies do not include transaction costs, i.e., they assume TC=0, and thus will assume that landowners obtain the market price of C. In Fig. 1, this is shown as P^0. If market studies do not consider transaction costs, they will estimate C supply of Q^0. When transaction costs are included in the analysis, the market supply function will shift upwards, thereby raising all costs. In Fig. 1, we have shown that transaction costs on a per unit basis increase as more C is sequestered (i.e., as Q increases) to represent the notion that transaction costs might become larger if more value is at risk. This type of relationship between S^0 and S^1 occurs if a transaction cost is a constant proportion of the price of C (e.g., 5 % of the C price).

For this paper we assumed that transaction costs have two components, a fixed and variable part. The fixed part reflects the costs of searching for and setting up a project, measuring monitoring and verifying the project, and other components that will be the same no matter the size of the project. We also assumed that a part of the payment relates to the costs associated with insuring the tons of C in the project. Carbon tons in forest projects are at risk of loss due to a range of factors, such as forest fires. The cost of insurance is assumed to be a fixed proportion of the C price. In this case, transaction costs are given as

$$TC = A + B * P^M \qquad (2)$$

where A represents fixed costs and B variable costs.

3 Results

3.1 Comparison of transaction costs among the case studies

Total transaction costs ranged from \$26.6 million (all \$ are 2010 USD) for the REDD project in South-East Asia to \$384,000 for the CDM afforestation project in East Africa (Table 3, Fig. 2). On a per ton basis, costs ranged from \$7.71/t CO_2 (South America) to just \$0.09/t CO_2 (East Africa). On a per unit area basis the range of costs was from \$89/ha (South-East Asia) to \$1,426/ha (South America).

For the VCS projects, insurance dominated the cost structure (41 % to 89 % of total costs) due to the use of a risk buffer to address permanence. The only other categories exceeding 5 % of total transaction costs were monitoring (3–42 %) and regulatory approval costs (8–50 %). Among the regulatory approval costs, registry fees dominated for the VCS projects with large numbers of emission reductions (Fig. 3). As mentioned above, there were no fees for the CDM project due to its least developed country location. Preparation of documents, validation and verification represent costs encumbered by all projects. None of the projects, however, had methodology costs as they all used existing approved methodologies and no revisions were needed.

Over time, one expects that C prices will change to reflect increasing damages associated with rising concentrations of CO_2 in the atmosphere (Nordhaus 2008). To get a sense for the implications of transaction costs as C prices change, we estimated total transaction costs across a range of offset prices (Table 4). Insurance costs, as noted above, had the largest share of total costs, and including them ensures that transaction costs do not fall below 26 % of projected income up to a C price of \$30 per ton CO_2 for any VCS project. Transaction costs exceeded likely income for the South America project at offset prices of \$2 and \$4 per ton CO_2 (by 155 to 270 % of income). Transaction costs were low only for the CDM project that lacked both insurance and registry costs.

Table 3 Estimated and actual transaction costs for each of the four forest sector carbon sequestration project case studies

	East Africa VCS		South America		East Africa CDM		South East Asia	
	US$	%	US$	%	US$	%	US$	%
Search costs	0	0	2,256	0.2	0.	0	2,000	0.01
Feasibility studies	44,467	0.3	58,013	4.4	10,480	1.8	18,000	0.07
Negotiation costs	66,079	0.5	30,670	2.3	14,008	2.4	85,000	0.32
Monitoring costs	598,918	4.7	287,517	21.9	240,000	41.8	840,000	3.16
Regulatory approval costs	976,493	7.6	355,264	27.1	288,510	50.2	1,992,000	7.50
Methodology development	0		0		0		0	
Preparation of documentation for validation	53,064		184,859		69,131		50,000	
Project validation	55,538		61,510		75,379		42,000	
Offset verification	266,319		80,000		144,000		100,000	
Registry/program fee	601,573		28,895		0		1,800,000	
Insurance costs[a]	11,153,864	86.6	535,749	40.9	0	0	23,640,000	88.95
Summed costs								
Total cost	12,873,947		1,311,256		574,813		26,577,000	
Total validation cost	219,147		337,308		168,997		197,000	
Total verification cost	12,654,800		932,160		384,000		26,380,000	
$/ha	1,190		1,426		270		89	
$/t CO_2	3.64		7.71		0.09		2.21	

[a] Insurance costs were calculated assuming a carbon price of $7.88 t CO_2 (based on weighted average price from State of the Forest Carbon Markets 2009 Ecosystem Marketplace)

3.2 Effect of transaction costs on global C sequestration

We used Eq. 2 to estimate transaction costs in the global forest and land use model. In this analysis, A was assumed to equal $1 per ton CO_2 and B was set to 0.23, or 23 % of the price. Thus $TC = 1 + 0.23 * P^C$. This equation for TC was then implemented in the model using Eq. 1, whereby the price received by landowners is less than the price of C on the market.

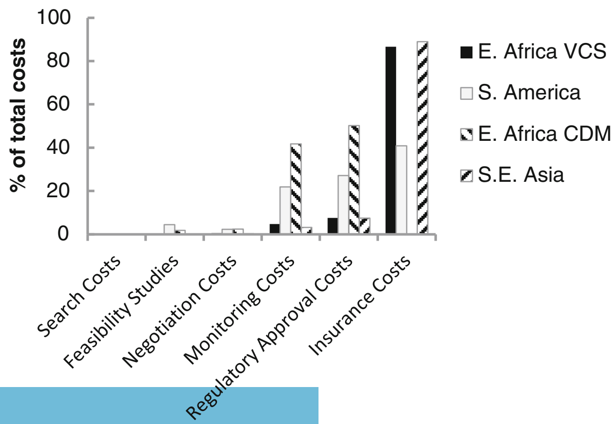

Fig. 2 Comparison across case studies of percentage of total transaction costs in each of the cost categories

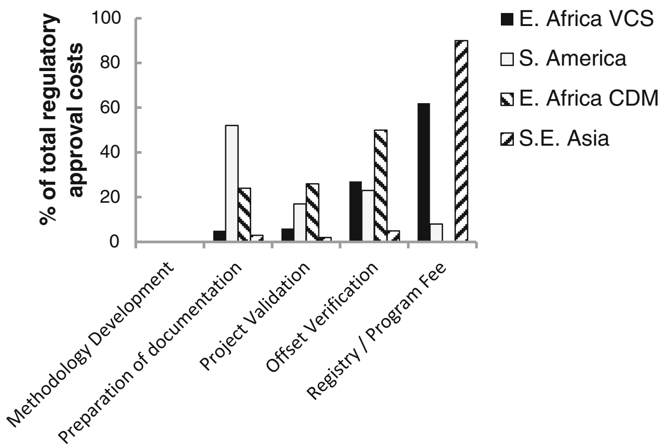

Fig. 3 Comparison across case studies of percentage of total regulatory approval costs in each of the regulatory approval cost subcategories

The base scenario, without accounting for transaction costs, generated by the model (Table 5) is consistent with most other economic analyses and indeed the earlier analysis conducted with the model used here (see Sohngen 2010). The many studies reviewed in Richards and Stokes (2004) similarly do not include transactions costs. The C prices that we used in the analysis were assumed to follow optimal C prices projected by Nordhaus (2008), they thus rise over time as C accumulates in the atmosphere.

When we reran the model with transaction costs estimated as above, landowners see lower C prices and they sequester less C (Table 5). Initially, inclusion of transaction costs reduced C sequestered by about 30 %. This makes sense given that C prices are lower and the fixed cost component of the transactions cost estimate has a larger effect. Over time as C prices rise, transaction costs have a smaller effect, mainly because the fixed portion of the transactions costs becomes a smaller and smaller proportion of the total. Regardless, even toward the end of the century, the model projects 21 % less C sequestered when transaction costs are included. These results imply that most studies of C sequestration underestimate potential C sequestration costs by up to 30 %.

4 Discussion

4.1 Case study findings

We examined four case studies across three continents with areas from less than 1,000 ha to 300,000 ha with between 170,000 and 12 million C credits anticipated. Estimated transaction costs ranged from 0.3 % to 270 % of anticipated income depending principally on the price of C credits and project size.

The highest relative transaction costs were for the VCS project in South America. This project encompassed less than 1,000 ha and therefore costs in preparing the project, in monitoring and in gaining validation and verification are not balanced by large areas in which sequestration can occur. As a result at an offset price of $8, transaction costs are estimated at 98 % of income. Even at the currently highly unfeasible price of $30 per ton the transaction costs represent almost 60 % of income. In contrast, the lowest costs were for the

Table 4 Transaction costs of four forest sector carbon sequestration carbon sequestration case studies as a percentage of estimated income at various offset price points

	Transaction cost as % of offset income at offset price of:											
	$2		$4		$8		$12		$20		$30	
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%
E. Africa VCS	$ 1.29	64 %	$ 2.09	52 %	$ 3.68	46 %	$ 5.28	44 %	$ 8.48	42 %	$ 12.48	42 %
S. America	$ 5.39	270 %	$ 6.20	155 %	$ 7.81	98 %	$ 9.42	78 %	$ 12.63	63 %	$ 16.66	56 %
E. Africa CDM	$ 0.09	5 %	$ 0.09	2 %	$ 0.09	1.1 %	$ 0.09	0.8 %	$ 0.09	0.5 %	$ 0.09	0.3 %
S.E. Asia	$ 0.74	37 %	$ 1.24	31 %	$ 2.24	28 %	$ 3.24	27 %	$ 5.24	26 %	$ 7.74	26 %

Table 5 Comparison of scenarios of market price and cumulative quantity of CO_2 sequestered without and with accounting for transaction costs in the global forest and land use model

	Base scenario		Transaction cost scenario	
	P^M (Market price) \$/t CO_2	Pg CO_2	P^L (Landowner price) \$/t CO_2	Pg CO_2 (% reduction from base)
2010	\$5.56	27.4	\$3.78	18.9 (−30 %)
2020	\$12.62	83.8	\$8.72	58.1 (−30 %)
2030	\$15.89	142.1	\$11.23	100.7 (−29 %)
2040	\$19.60	202.9	\$14.09	147.9 (−27 %)
2050	\$23.82	264.3	\$17.34	199.2 (−24 %)
2060	\$28.60	319.6	\$21.02	241.2 (−24 %)
2070	\$33.98	364.1	\$25.16	273.8 (−24 %)
2080	\$40.03	403.5	\$29.82	308.0 (−23 %)
2090	\$46.81	446.1	\$35.04	346.2 (−22 %)
2100	\$54.40	493.0	\$40.89	388.1 (−21 %)
2110	\$62.88	547.3	\$47.42	431.1 (−21 %)

Cumulative carbon gains are for the year given and illustrate the change in carbon from the baseline. The total carbon calculated above includes aboveground and belowground carbon plus carbon stored in harvested wood products

CDM project in East Africa. As a CDM project, guarantee of offset permanence comes from temporary credits rather than an insurance buffer. However, the use of temporary credits comes at a cost as such offsets must be replaced and are not fully fungible with permanent offsets in the way that offsets under a buffer system would be (Brown and Pearson 2009). As a result the CDM offsets will likely retail at a fraction of the cost of the offsets achieved under the VCS even though one is for a compliance market and the other for a voluntary market.

4.2 Impact of transaction costs on C sequestration projects at the global scale

The global scale analysis illustrates that many of the existing estimates of C sequestration costs are likely underestimated by up to 30 %. These estimates have been made under the assumption that the fixed costs of sequestration are \$1 per ton CO_2. If this study underestimates actual transaction costs then the amount of C sequestered at any given price is likely to be even lower (i.e., the underestimate is likely to be more than 30 % if actual transactions costs are higher). We do not believe, however that the fixed costs will increase substantially over time. Given that learning undoubtedly will occur and given that advances in the technology used for measuring and monitoring C will also occur, we actually expect these costs to fall.

More importantly, insurance costs represent a large share of total costs. Insurance costs may or may not decrease over time. One reason why insurance costs are currently large is that society has little experience with forest C sequestration activities, and there are strong concerns with permanence. If society becomes more comfortable with C sequestration activities after seeing their success, the rationale for maintaining insurance buffers may decline. However, it is also possible that insurance costs could remain high as C prices rise. As C prices rise, C sequestered in forests has greater value at risk. With greater value at risk, the rationale for holding insurance may continue to be important.

Lastly, we note a couple of other limitations in our approach. First, there could be important differences in transactions costs across regions that are not considered in this analysis. These differences could arise due to a range of factors including governance structures, legal status, labor rates, and other issues. Regional differences could have important implications both for regional costs and global costs. We do not have information sufficient to delineate differences by region, but recognize that it would be important to gather this information in the future. Second, we model transactions costs as exogenous in our economic model, while in reality, transactions costs should be endogenous. Market forces should drive transactions costs down over time, although we have not allowed them to change. This could be an area of future research.

5 Conclusions

We determined that most existing estimates of marginal costs of C sequestration are underestimated by up to 30 %, due to a failure to consider transaction costs. At current C prices our case studies illustrate that transaction costs represent between a third and 100 % of offset income (excluding the CDM project). Lessons clearly learned are: 1) the importance of scale, such that significant project areas are needed to ameliorate the fixed element of transaction costs; and 2) the importance of insurance costs. The dominance of insurance costs illustrates the need for further work to improve understanding on mitigating risks for land use C projects.

Acknowledgments This paper was prepared with funding from the U.S. Environmental Protection Agency. The opinions expressed in the report, however, are the authors' and do not reflect, necessarily, the views of the EPA. We express our great thanks to U.S. EPA Work Assignment Managers and to Heidi Ries of Stratus Consulting, Inc. We also acknowledge the assistance and generous provision of data from the anonymous case study projects.

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