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WHAT MAKES CARBON WORK? A SENSITIVITY ANALYSIS OF FACTORS AFFECTING FOREST OFFSET VIABILITY

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Early implementation experience and a handful of empirical analyses in the literature indicate that the supply of forest carbon offsets may be constrained by, among other factors, transaction costs, access to markets, and carbon accounting rules and regulations. To more fully explore this issue, we use a forest growth and carbon accounting model to assess the relative influence of several key accounting, financial, and market variables on forest carbon offset project viability. We find that project performance, indicated by sequestration rate and project profitability, varies widely across the three project/forest type combinations evaluated here. The effects of carbon price and project length vary in both magnitude and direction from project to project. Project accounting considerations, including baseline establishment method and deductions for "leakage" and other factors, tend to figure prominently in each project, but vary in their absolute effect. These initial results suggest that choice of accounting protocol is a critical decision facing landowners considering forest offset projects. Results also suggest that a one-size-fits-all accounting approach may fail to maximize either landowner participation or the representation of forest types or management systems.

KEYWORDS: carbon, forest offset, project accounting

INTRODUCTION

Forest offset projects have long been seen as a potential source of greenhouse gas (GHG) mitigation (Sedjo 1989). In the Southeastern United States, forest management has been identified as having particularly strong potential – 28.8 to 93.9 million metric tons of carbon dioxide equivalent (tCO_2e) per year, depending on the price of carbon (U.S. Environmental Protection Agency 2005). Against the backdrop of this potential lies a series of questions. How will the net benefit of a forest management offset project be evaluated? How can it be ensured that the project provides GHG mitigation above and beyond what would have happened anyway ("additionality")? How should we establish the reference point against which future carbon storage or sequestration will be measured ("baseline")? How do we account for changes in off-site emissions or storage that occur as a result of the project activity ("leakage")? How can we monitor the project over time and ensure that resulting carbon credits are made available for sale in a cost-effective manner?

Over the years, these issues have, to varying extents, been confronted in the literature. This is especially true with regard to the complexities of offset policy design (e.g., Richards and Andersson, 2001; Trexler et al. 2006) and the economic implications of program implementation (e.g., Murray et al. 2004; Murray et al. 2007). Research has also investigated landowner perceptions (van Kooten et al. 2002; Fletcher et al. 2009) and hypothetical management responses to the imposition of a carbon price (van Kooten et al. 1995; Huang and Kronrad 2006; Gutrich and Howarth 2007). Despite years of attention, published research detailing practical experience with forest offset project implementation in the United States remains somewhat scarce.

On the ground, significant policy and market uncertainty has tempered optimism over the future market prospects for domestic forest carbon offsets. For example, the Chicago Climate Exchange (CCX), the nation's first voluntary but legally-binding GHG reduction program, attracted a great deal of attention throughout the middle of the last decade but was recently shuttered amid flat-lining credit prices at the close of its second commitment period. In Congress, comprehensive climate legislative passed the U.S. House of Representatives in the summer of 2009 (H.R. 2454, the American Clean Energy and Security Act), but failed to pass the Senate. Multiple other bills were introduced over the course of the last five years, but have likewise failed to gain passage (e.g., S. 2191, the Lieberman–Warner Climate Security Act of 2008; S. 1733, the Clean Energy Jobs and American Power Act of 2009; the American Power Act of 2010).

Although there is at present no federal climate policy to drive demand for forest carbon offsets, opportunities do continue to exist for sellers of forest and other offset credits. Implementation of a cap-and-trade program in California, slated to begin in 2013, could itself generate demand for over 200 million tCO_2e in offset credits by 2020 (Shillinglaw et al. 2010). Over-the-counter (OTC) transactions present another opportunity for sellers. Total voluntary offset market value has fallen from a historic high of $755 million in 2008 to $424 million in 2010, but global volume has grown from an estimated 11 million tCO_2e in 2002 to over 131 million tCO_2e in 2010 (Peters-Stanley et al. 2011).

The implementation history and continued presence of the voluntary market makes it a logical focus for analysis. The present voluntary offset market in the United States is characterized by a variety of rules and accounting systems, or protocols, through which landowners may undertake forest offset projects. Previous research shows that choice of offset accounting protocol can strongly influence the amount of carbon offsets that a landowner may generate for sale (Pearson et al. 2008; Galik et al. 2009b). Even the choice of baseline accounting technique, the approach used to estimate a comparison point against which future gains are weighed, can increase the per-ton cost of offset project implementation dramatically, far exceeding the influence of measurement and monitoring costs (Galik et al. 2009a).

With few on-the-ground projects from which to draw empirical evidence and a relative scarcity of published literature on the matter, a lingering question is the relative effect of the other myriad factors beyond carbon measurement and accounting that can affect the viability of forest offset projects. What follows is a first attempt to evaluate the various project and financial considerations that can affect the viability of forest offset projects in the Southeastern United States. We incrementally examine the effect of sixteen separate project parameters on project sequestration and profitability. The results from the analysis are then used to highlight potential areas of opportunity or concern for policymakers designing the terms of offset programs and for landowners contemplating offset program participation.

METHODS

Here we conduct a univariate sensitivity analysis across a wide variety of project, accounting, and financial parameters for two different forest offset project types in two Southeastern forest types. We evaluate (1) a rotation extension project in high management intensity, high productivity loblolly-shortleaf (*Pinus taeda-P. echinata*) pine stands; (2) a rotation extension project in longleaf-slash (*P. palustris-P. elliottii*) pine stands; and (3) an improved productivity project in loblolly-shortleaf pine stands. Carbon sequestered in the hypothetical projects, as well as simple metrics of project financial performance, are then estimated using a custom spreadsheet model.

Model Overview

The forest offsets model developed here is used to estimate annual sequestration in live tree, standing deadwood, down deadwood, understory, forest floor, and wood products pools. Annual sequestration in each pool is estimated using U.S. Forest Service Forest Inventory and Analysis (FIA)-derived ecosystem-level equations (Foley et al., 2009, citing Smith and Heath, 2002; Smith et al., 2006). The user selects one of 46 forest types, a project type, the business as usual (BAU) rotation length, the new project rotation length, project length, and number of stands. The model then calculates the change in gross forest carbon across up to 10 stands for the life of the project. Finally, the model applies a user-defined project baseline, deductions for leakage and uncertainty, and buffer set-asides to generate estimates of net creditable carbon, or that portion of stored carbon a landowner may register or sell.[1]

Further description of the model and its various applications can be found in Galik et al., (2009a), Galik et al. (2009b), and Foley et al. (2009), but a brief overview of components most relevant to the present analysis is included here. We assume an even-age management regime, whereby a stand is cut upon reaching the set rotation age. No intermediate thinnings are conducted. Although thinning can be an important tool in even-aged systems, the present version of the model does not adequately capture changes in stand structure and growth that may occur after thinning.

[1] Note that net creditable carbon can vary for the same project depending on the accounting framework used (Pearson et al., 2009; Galik et al., 2009b; Foley et al., 2009).

When a harvest does occur in the model, carbon in the live tree pool goes to zero, and a portion of carbon formerly in that pool is transferred to wood product, down dead wood, and forest floor pools. Storage in the latter two pools is determined by the age of the stand at time of harvest, again using the FIA-derived ecosystem-level equations referenced above. Conversion factors provided by Smith et al. (2006) are used to estimate the volume of merchantable timber produced by the stand and the amount of carbon contained in harvested wood products. That portion of wood-product carbon remaining either in use or disposed in landfills 100 years from harvest is credited to the project's sequestration total in the year of harvest (see, e.g., Miner, 2006). Amounts of softwood and hardwood pulp and saw timber are multiplied by user-defined timber prices to generate estimates of timber income for a given harvest year.

Two project types are assessed, extended rotation and improved productivity. For extended rotation, the model tracks the change in carbon across 10 regulated stands under both BAU and extended rotation scenarios. To regulate harvests post-extension, the model extends the first rotation by half the difference in ages between the BAU and project rotation lengths (e.g., 5 years for a 10 year extension) before beginning the set rotation length the following rotation. In this fashion, harvests are spaced equally across the stands in both BAU and project rotation lengths.

For improved productivity projects, the model transitions 10 regulated stands of a given forest type to their high management intensity, high productivity counterpart upon harvest of each stand. Three such forest type pairs are included in this analysis: South Central loblolly-shortleaf pine; Southeast loblolly-shortleaf pine; and Southeast longleaf-slash pine. Improved forest types are representative of those stands achieving more than 5.9 m^3 ha^{-1} yr^{-1} in growth (as compared to an average annual growth of 3.2 m^3 ha^{-1} yr^{-1} in their standard productivity counterparts). The specific management interventions used to generate this increase in productivity are implicitly captured in the FIA-derived ecosystem level equations that drive the model. In reality, it is possible that some combination of site preparation, fertilization, or use of improved seedlings would generate the observed increase in sequestration. We do not focus on the methods generating these increases in productivity, only the resulting increase in yield. That is not to diminish the importance of the timing of silvicultural interventions or the cost of their implementation, which can affect the rate and magnitude of credits generated and the ultimate financial feasibility of the project itself. Furthermore, activities such as fertilization can themselves generate significant GHGs in the course of their production and use, which some protocols require project developers to debit against observed gains in sequestration. We do not track the emissions associated with these activities.

Having estimated total project carbon storage for both the BAU and project scenario, the model then calculates net creditable carbon, expressed here in units of tCO_2e. The first step is to estimate the project baseline, or the reference level of storage against which net project sequestration will be assessed. Here, we assess three separate baseline approaches: base year, single project performance standard, and FIA mean. Base year equals the total stored across the 10 stands in year 1 of the project. A single project performance standard is the level of sequestration that would have been stored if the BAU rotation and management intensity had been continued. Here, this equals the level of storage recorded under the BAU rotation length in the case of extended rotation projects, and the continuation of BAU rotation length, productivity, and management intensity in the case of improved productivity projects. FIA mean baselines are the sum of FIA mean values for live tree, standing dead; down dead, and wood products pools, as dervived from COLE-lite 1605(b) report queries for each forest type (http://www.ncasi2.org/cgi-bin/RCOLE/coleLite.pl; last accessed July 8, 2009). Note that base year and FIA mean generate a single number that is then applied to each year of the project, whereas the single project performance standard tracks carbon stored under BAU conditions and therefore varies year to year.

If a project records an increase in carbon storage from one year to another, it is allocated the inter-year difference for the portion that is above the baseline. Deductions for leakage (emissions induced offsite due as a result of the project; See, e.g., Murray et al., 2004), buffer set-asides (a pool of credits held in reserve to project against unexpected loss; See Murray and Olander, 2008), or measurement error are then applied. Sequestration estimates, calculated within the model in units of metric tons carbon, are then multiplied by 3.667 to convert to units of tCO_2e and then by the carbon price for that year (minus any fees for credit issuance or trading) to generate estimates of carbon revenue. The process is similar for years where sequestration is lower than the previous year (i.e., a year-over-year loss), a key difference being that projects in those situations must buy back the difference at the prevailing carbon price for that year.

Total project revenue for a given year is equal to the sum of net revenue from carbon and timber for that year, minus any project management expenses. These expenses include fees associated with project measurement, monitoring, and verification, as well as those costs associated with site preparation, planting, and harvest. Values for these expenses are taken to be the average of high and low costs for each project size as listed in Table 1 of Galik et al. (2009a). For the purposes of this analysis, improved productivity projects are also assessed additional planting costs of \$555.75 ha^{-1} to account for fertilizer and herbicide application and the use of improved seedlings (derived from Brown and Kadyszewski, 2005, assuming a cost of \$306 per treatment application, rounded up to account for cost of seedlings; total cost reflects the average between a low-cost estimate of performing one treatment and the high-cost estimate of performing two).

Sensitivity Analysis

The specific parameters evaluated in the sensitivity analysis are found in Table 1Table . “Base case” scenario values were derived from current pricing data, existing protocol requirements, and early project-related literature. They represent a best guess as to the average values likely encountered by a project being implemented today. High and low values for each parameter were selected on the basis of either historical trends or, when available, future projections. These values represent the range likely to be encountered in the course of offset project implementation.

Note that ranges need not be symmetric within each parameter, nor need they be consistent across parameters. Some parameters are subject to greater variability than others, therefore requiring a larger range. Base case values for some parameters may also fall closer to one end of the range than the other (e.g., hardwood pulpwood prices, trading at historical highs as of October 2010; TimberMart-South, 2010). This is preferable to an artificial normalization of each parameter, as the results are more likely to reflect the actual range of conditions encountered by project developers on the ground. Further, it is impossible to normalize the entire set of parameters to a common range, as some are in units of years, some in dollars, and some in percentages.

Apart from commodity prices and a variety of project financial particulars (e.g., discount rate, project registration fees), Table 1 also includes a number of parameters pertaining to project implementation and accounting. “Baseline rotation” indicates the BAU rotation age, and “rotation extension” indicates the number of years added to the BAU rotation in an extended rotation offsets project. “Project length” is the duration of the project and the length of time for which project performance is assessed in this analysis.

"Baseline method" describes how the project's reference point is calculated, while "carbon pools" describes which components of the forest ecosystem are included in the calculation of both project baseline and project sequestration.

Also included are accounting adjustments intended to ensure the environmental integrity of the offset project or to facilitate the sale of generated credits. As used in Table 1, "Leakage", "Uncertainty", and "Buffer" are deductions, assessed as a percentage of additional sequestration in any given year. "Aggregation" refers to the costs required to group individual project carbon credits into larger assemblages so as to facilitate the eventual purchase by a buyer. These fees are assessed as a percentage of net creditable carbon generated by the project, and range from an average of 11% for 100 ha projects, to 10% for 1,000 ha projects, and 9% for 10,000 ha projects.

Beginning with the first parameter listed in Table 1, we hold all other parameters at their base case value and incrementally calculate the NPV of the hypothetical project, the NPV of the BAU, non-project alternative, the difference between the two, and the average annual amount of creditable carbon yielded by the hypothetical project ($tCO_2e\ ha^{-1}\ year^{-1}$) for each value of the selected parameter. When assessing project size, results are normalized to a 1,000 hectare project to allow for comparison. We then repeat the process for all subsequent parameters. Performance metrics under each parameter and value combination are then aggregated and sorted to identify those components having the greatest relative influence on project value and sequestration.

To calculate project and BAU scenario NPV, we first estimate annual net project benefits (NB) for a given year *t*:

Net Benefits (NB_t) =

$$((NCC_t \text{ x } PC_t) + \sum_{S=1}^{4} (H_{St} \text{ x } P_S)) - ((NCC_t \text{ x } FC) + (NCC_t \text{ x } CA) + FI_t + CP + CM + CH_t + CQ)$$

Where:
NCC_t = net amount of creditable carbon generated in year t in units of tCO_2e (project scenario only)
PC_t = carbon price in year t (project scenario only)
H_{St} = amount of timber harvested of species and product type S produced in year t
S = timber species and product type (1=softwood pulpwood, 2=softwood sawtimber, 3=hardwood pulpwood, 4=hardwood sawtimber)
P_S = timber price for timber type S
FC = per-tCO_2e registration or trading fee (project scenario only)
FI_t = project initiation and maintenance fees in year t (project scenario only)
CP = total stand site preparation and planting costs
CM = total stand maintenance costs
CH_t = total harvest preparation costs in year t
CA = aggregation fees (project scenario only)
CQ = total quantification costs, including costs to sample, monitor, and verify the project (project scenario only)

The NPV of both the BAU and project scenario can be then calculated as:

$$Net\ Present\ Value\ (NB_0,\ldots,NB_L) = \sum_{t=0}^{L} \frac{NB_t}{(1+r)^t}$$

L is the project length and *r* is the real discount rate.

RESULTS

The results of the sensitivity analysis can be seen in Figures 1-3. The data are reported in what is traditionally referred to as a tornado graph, in which variables are ranked by their strength of effect on the value of the target metric. The metrics explored in this analysis include (1) the NPV of the project, including both timber and carbon revenue; (2) the difference between project NPV and the NPV of the non-project, BAU alternative; and (3) the average annual amount of creditable carbon generated by the project. As described below, relative effect of individual project parameters can vary significantly between hypothetical offset projects.

Discount rate and timber price were the two most important parameters affecting project NPV (Figure 1). The choice of discount rate led to a difference between low and high NPVs of $1.13 million, $1.56 million, and $538,999 for improved productivity loblolly, extended rotation loblolly, and extended rotation longleaf projects, respectively. Projects evaluated using lower discount rates had higher NPVs. Timber prices were the most important parameter affecting NPV for extended rotation projects, yielding net differences of $688,212, $1.75 million, and $688,227 for improved productivity loblolly, extended rotation loblolly, and extended rotation longleaf projects, respectively.

Carbon price was much less important in the extended rotation projects (ranking 13th for the longleaf project and last for the loblolly project) but slightly more influential for the improved productivity project (ranking 8th). It could of course be argued that the smaller range assumed for carbon price as compared to timber price would predetermine the observed results, but we are confident that it does not. When using a larger +/- 50% range for the carbon price, values do change, but parameter order is largely preserved (for example, the difference between the NPVs of the BAU and project scenarios changes from $1,897 to $3,795 in the longleaf extended rotation project; from $21,607 to $43,214 in loblolly extended rotation).

Deductions for leakage and buffers had more influence on project NPV in the two loblolly projects than the longleaf project, which was itself more affected by the method used to calculate the baseline. In general, the baseline calculation method affected NPV more for the two extended rotation projects than for the improved productivity project. Changing the baseline method from FIA mean to either of the other two methods increased NPV for the improved productivity project, while the results were mixed for the extended rotation projects (base year increased NPV and the single project performance standard dramatically reduced it). Production at the assumed baseline rotation age is close to maximum sustainable yield, meaning that any extension is likely to result in decreased wood product yield (and by extension, wood product sequestration). This effect is directly captured in the single project performance standard, but not in the other baseline estimation techniques. Alternatively, a base year approach uses only the net sequestration of the stand in the first year as a comparison point, allowing all gains above it to be credited to the project. The FIA mean approach uses regional storage as the comparison point, yielding a baseline that is higher and therefore more stringent than base year.

The relative effect of project length on NPV likewise varied by project type. Furthermore, no uniform relationship between project length and NPV was apparent. For the improved productivity project, the highest NPV was obtained in the base case scenario; projects either shorter or longer than 50 years resulted in a lower NPV. For both of the extended rotation projects, 100-year and 50-year projects resulted in the highest and next highest NPV. Project size had a much more uniform relationship with project NPV; for all three projects an increase in project size increased NPV. In addition, transaction costs, including registration and trading fees, had a negligible effect on project NPV for all three projects.

The difference between project NPV and the NPV of the non-project, BAU alternative was also examined in an effort to isolate the effects of changes in management (Figure 2). Figures 2b and 2c show that both extended rotation projects typically generated less income than their BAU alternative; only one extended rotation scenario generated a net-positive NPV (a loblolly stand starting with a baseline rotation age of 35 years). By contrast, the base case for the improved productivity project increased NPV by nearly $200,000 as compared with BAU. Indeed the only cases in which the improved productivity project had a lower NPV as compared to BAU were for small (100 ha) or short (25 yr) projects, or projects with discount rates greater than 8%. Accounting-related parameters follow a similar pattern for the difference between NPV and BAU as they do for overall NPV; leakage and buffer deductions and baseline method tend to be more important, while transaction costs tend to be less important.

The amount of creditable carbon generated by each project was also estimated (Figure 3). In the base case, both extended rotation projects generated slightly negative amounts of sequestration, due in part to lower relative levels of storage in stands immediately following harvest. The improved productivity project, however, sequestered an annual average of 5.32 tCO_2e ha^{-1} in the base case. Similar to the NPV and difference between NPV and BAU scenarios, deductions for leakage and buffer were among the most important parameters affecting how much creditable carbon was yielded by each project. Choice of baseline accounting method, specifically a single project performance standard, was also a strong driver of negative sequestration in both of the extended rotation projects. As described above, this is in part attributable to the net reduction in wood product sequestration recorded in the project as compared to the baseline.

DISCUSSION

The results of this analysis lend insight into project parameters with the potential to most strongly influence the NPV and the amount of creditable carbon generated by three Southeastern U.S. forest offset projects. In extended rotation projects, timber prices and the discount rate had the most effect on NPV, while carbon price had little effect. This stems from the simple fact that these projects, as considered here, derived most of their income from the sale of timber, rather than from the sale of carbon credits.

For both loblolly and longleaf pine extended rotation projects, the base case project yielded negative levels of sequestration, due primarily to leakage and buffer deductions and carbon repayment obligations occasionally incurred following harvest activity. With lower net timber production and no net revenue from the sale of carbon credits, the NPV for these projects was lower than it would have been under continued BAU management. Indeed, only one of the scenarios evaluated here resulted in an extended rotation project with a project NPV higher than the non-project, BAU alternative. Most yielded negative amounts of creditable carbon. By contrast, base case scenario for the loblolly improved productivity project had a higher NPV than it would have under BAU by nearly $200,000 and sequestered over 5.3

$tCO_2e\ ha^{-1}\ yr^{-1}$. Of the 46 iterations evaluated for the improved productivity project, only nine resulted in lower NPV than under BAU management, and only one yielded negative creditable carbon.

When comparing against the non-project, BAU alternative, each project evaluated here shows evidence of tradeoffs between stand growth, carbon sequestration, and timber production. For the extended rotation projects evaluated here, the small amounts of creditable carbon generated in the early years are moderated by applied discounts (e.g., leakage, uncertainty, buffer) and eventually surpassed by foregone timber production. For improved productivity, shorter projects are faced with the increased costs of implementing the higher productivity management regime, but are not long enough to reap the full rewards of improved growth. Projects longer than 50 years likewise express lower absolute and relative NPV as the stand reaches a new equilibrium and project discounts continue to moderate the sequestration benefits that do accrue.

Multiple project configurations are evaluated here, but we acknowledge that some may be unlikely to be implemented. For example, previous research finds that optimal rotation extensions can actually decrease with an increase in carbon price for high productivity sites, especially with a low discount rate (Huang and Kronrad, 2006). This is due in part to earlier mortality in higher productivity sites, and is borne out in our findings, seen in the poor relative performance of the high productivity loblolly-shortleaf extended rotation project (Figure 2b).

Notwithstanding these results, however, research has shown that carbon prices tend to extend optimal rotation ages. van Kooten et al. (1995) found an unambiguous positive trend in rotation extension with increases in carbon price, even at discount rates of 5% and timber prices of \$50 per m^3 of timber, although in these particular cases the effect tended to be relatively small. Furthermore, Huang and Kronrad (2006) demonstrate that shortened rotations are optimal in projects with low discount rates on high productivity sites, but also find many scenarios in which higher carbon prices led to rotation extensions, especially on lower productivity sites.

Even projects with favorable NPV or creditable carbon as modeled here could be unattractive to landowners or project developers for other reasons. For example, both of the extended rotation projects had their highest NPVs under 100-year contracts. Longer commitments are generally thought to deter participation, but the literature remains somewhat unresolved on this particular issue, especially for the length of contracts considered here (e.g., van Kooten et al., 2002; Fletcher et al., 2009).

The forest/project type combinations evaluated here are likewise a mere subset of the hundreds of possible scenarios that could have been considered. They are presented as an indication of the type of effects that could be expected, but we acknowledge that there are other combinations of project variables or additional values of project variables that could result in higher or lower creditable carbon or economic returns. For example, we do not evaluate the effects of increasing sawtimber or pulpwood prices over time, nor do we estimate the effects of shifting labor costs. While we have no doubt that these factors may influence the absolute feasibility of a project, their impact on the relative feasibility of a project is greatly minimized as they would likely be encountered in both the project and BAU scenarios.

Furthermore, the model provides insight into single project scenarios given a set of user-defined project attributes. At present, it does not optimize project management in light of changing parameters or conditions. It does not, for example, capture shifts in project management (e.g., shortening or lengthening of rotation) made in response to changes in carbon or timber prices. Therefore, the results presented here should not be interpreted as an absolute prediction of what would be expected for a particular project on the ground.

CONCLUSION

Our analysis generates important insight into forest offset project implementation. The findings represent an important first step in determining and assessing the factors most important to offset project viability. They are particularly useful for identifying the project variables on which to focus when establishing forest carbon protocols or when analyzing the project feasibility. Collectively, our review of three hypothetical projects suggests that project accounting may have more influence on the performance of a project relative to a BAU scenario than carbon or timber price. Individual project attributes, such as the size of the project, the length of accounting period, and the rotation length, are likewise strong determinants of relative project performance. In situations where several different accounting approaches exist, as is the case in the present voluntary market, landowner choice of protocol is therefore critically important. Policymakers must also be mindful of the effect of accounting on project performance when designing offset programs for future compliance markets, as a one-size-fits-all approach may not work if the ultimate objective is to maximize either landowner participation or the representation of forest types or management systems.

LITERATURE CITED

Brown, S., and J. Kadyszewski. 2005. Carbon Supply for the Pilot Region: Arkansas, Louisiana, and Mississippi. Report Submitted to the Electric Power Research Institute. Winrock International. 71 p.

Fletcher, L.S., D. Kittredge Jr., and T. Stevens. 2009. Forest landowners’ willingness to sell carbon credits: a pilot study. *Northern Journal of Applied Forestry* 26(1): 35–37.

Foley, T., D. deB. Richter, and C.S. Galik. 2009. Extending rotation age for carbon sequestration: a cross-protocol comparison of North American forest offsets. *Forest Ecology and Management* 259(2): 201–209.

Forest2Market. (2009). North Carolina Timber Report. 1st Quarter, 2009.Volume 5(1). 3 p.

Galik, C.S., J.S. Baker, and J.L. Grinnell. 2009a. Transaction costs and forest management carbon offset potential. Climate Change Policy Partnership, Duke University. 16 p.

Galik, C.S., M.L. Mobley, and D.deB. Richter. 2009b. A virtual ‘field test’ of forest management carbon offset protocols: the influence of accounting. *Mitigation and Adaptation Strategies for Global Change* 14(7): 677–690.

Gutrich, J., and R.B. Howarth. 2007. Carbon sequestration and the optimal management of New Hampshire timber stands. *Ecological Economics* 62(3-4): 441–450.

Huang, C.-H., and G.D. Kronrad. 2006. The effect of carbon revenues on the rotation and profitability of loblolly pine plantations in East Texas. *Southern Journal of Applied Forestry* 30(1): 21–29.

Miner, R. 2006. The 100-year method for forecasting carbon sequestration in forest products in use. *Mitigation and Adaptation Strategies for Global Change:* doi: 10.1007/s11027-006-4496-3.

Murray, B.C., B.A. McCarl, and H.-C. Lee. 2004. Estimating leakage from forest carbon sequestration programs. *Land Economics* 80(1): 109–124.

Murray, B.C. and L.P. Olander. 2008. Addressing impermanence risk and liability in agriculture, land use change, and forest carbon projects. Nicholas Institute For Environmental Policy Solutions, Duke University. 16 p.

Murray, B.C., B. Sohngen, and M.T. Ross 2007. Economic consequences of consideration of permanence, leakage and additionality for soil carbon sequestration projects. *Climatic Change* 80(1-2): 127–143.

Pearson, T., S. Brown, and K. Andrasko. 2008. Comparison of registry methodologies for reporting carbon benefits for afforestation projects in the United States. *Environmental Science and Policy* 11(6): 490–504.

Peters-Stanley, M., K. Hamilton, T. Marcello, and M. Sjardin. (2011). Back to the Future: State of the Voluntary Carbon Markets 2011. Ecosystem Marketplace & Bloomberg New Energy Finance. 93 p.

Richards, K.R., and K. Andersson. 2001. The leaky sink: persistent obstacles to a forest carbon sequestration program based on individual projects. *Climate Policy* 1(1): 41–54.

Sedjo, R. 1989. Forests: a tool to moderate global warming? *Environment* 31(1): 14–20.

Shillinglaw, B., M.K. Hanlon, and M. Meizlish. 2010. The California Carbon Market: Implications for Forest Carbon Offset Investment. Market Outlook: December 2010. New Forests. 4 p.

Smith, J.E., and L.S. Heath. 2002. A model of forest floor carbon mass for United States forest types. U.S. Department of Agriculture, Forest Service Northeastern Research Station. RP-NE-722. 37 p.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. U.S. Department of Agriculture, Forest Service Northeastern Research Station. GTR-NE-343. 216 p.

TimberMart-South. 2011. South-wide Average Prices. Available online at http://www.timbermart-south.com/prices.html; last accessed January 7, 2011.

TimberMart-South. 2010. *Southern Timber Market Trends, October 2010*. Available online at http://www.afoa.org/PDF/CI1010a.pdf; last accessed January 7, 2011.

Trexler, M.C., D.J. Broekhoff, and L.H. Kosloff. 2006. A statistically-driven approach to offset-based GHG additionality determinations: what can we learn? *Sustainable Development Law and Policy* 6(2): 30–40.

U.S. Environmental Protection Agency. 2005. Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture. Office of Atmospheric Programs. EPA 430-R-05-006. 154 p.

U.S. Environmental Protection Agency. 2009. EPA Analysis of the American Clean Energy and Security Act of 2009 in the 111th Congress, Data Annex. Office of Atmospheric Programs.

van Kooten, G.C., C.S. Binkley, and G. Delcourt. 1995. Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American Journal of Agricultural Economics* 77(2): 365–374.

van Kooten, G.C., S.L. Shaikh, and P. Suchánek. 2002. Mitigating climate change by planting trees: the transaction costs trap. *Land Economics* 78(4): 559–572.

Table 1. Parameters and values considered in the sensitivity analysis.

Parameter	Base Assumption	Additional Values Considered
Timber Price[A]	Approximate current stumpage price (\$ green ton^{-1}) for pine and hardwood pulpwood and sawlogs. Pine pulp: \$8 Pine saw: \$30 Hardwood pulp: \$7 Hardwood saw: \$20	Pine pulp: \$6, \$11 Pine saw: \$15, \$40 Hardwood pulp: \$2, \$7 Hardwood saw: \$10, \$25
Carbon Price[B]	EPA projected carbon prices under H.R. 2454, the American Clean Energy Security Act of 2009.	-25%, +25%
Discount Rate	6%	4%, 5%, 7%, 8%, 9%, 10%
Baseline Rotation	25 years (high productivity/mgmt loblolly-shortleaf); 45 years (loblolly-shortleaf and longleaf-slash);	-10 years, +10 years
Rotation Extension	10 years (all forest types)	5, 15, 20 years
Project Length	50 years	25, 75, 100 years
Project Size	1,000 hectares (ha)	100, 10,000 ha
Baseline Method	FIA Mean	Base Year, Single Project Performance Standard
Carbon Pools	Live Tree; Standing Dead; Down Dead, Wood Products (in use and landfill)	± Standing Dead; ± Down Dead; ±Wood Products; ± Forest Floor; ± Understory
Leakage	20%	0%, 40%, 60%
Buffer	20%	0%, 40%, 60%
Uncertainty	10%	0%, 20%
Aggregation	No	Yes
Quantification Method	In-Field Sampling	Modeling/Look-Up Tables
Project Registration Fees[C]	\$500 Initiation; \$500 Annual Maintenance	Initiation: \$0, \$1,000 Annual Maintenance: \$0
Credit Trading/Issuance Fees[C]	\$0.10	\$0.05, \$0.20

[A] Base value and range approximated from reported timber prices, 1990 to present (e.g., TimberMart-South, 2010, 2011; Forest2Market, 2009).

[B] See U.S. Environmental Protection Agency (2009), Scenario 2. Assumes a starting price of \$7/tCO_2e in 2011, with data linearly interpolated for all missing years between 2011 and 2050. Prices are held constant at a maximum base-case value of \$70.40 post-2050.

[C] Fees represent a compilation of current charges by the American Carbon Registry (http://www.americancarbonregistry.org/membership/member-benefits-and-fees; last accessed August 22, 2010) and the Climate Action Reserve (http://www.climateactionreserve.org/how/program/program-fees/; last accessed August 22, 2010).

Figure 1. Relative effect of project, accounting, and financial variables on the net present value (NPV) of three hypothetical forest offset projects. Projects evaluated include a) improved productivity of loblolly-shortleaf pine stands, b) extended rotation in high management intensity, high productivity loblolly-shortleaf pine stands, and c) extended rotation in longleaf-slash pine stands. Grey bars represent values below the base case scenario, while black bars represent values above.

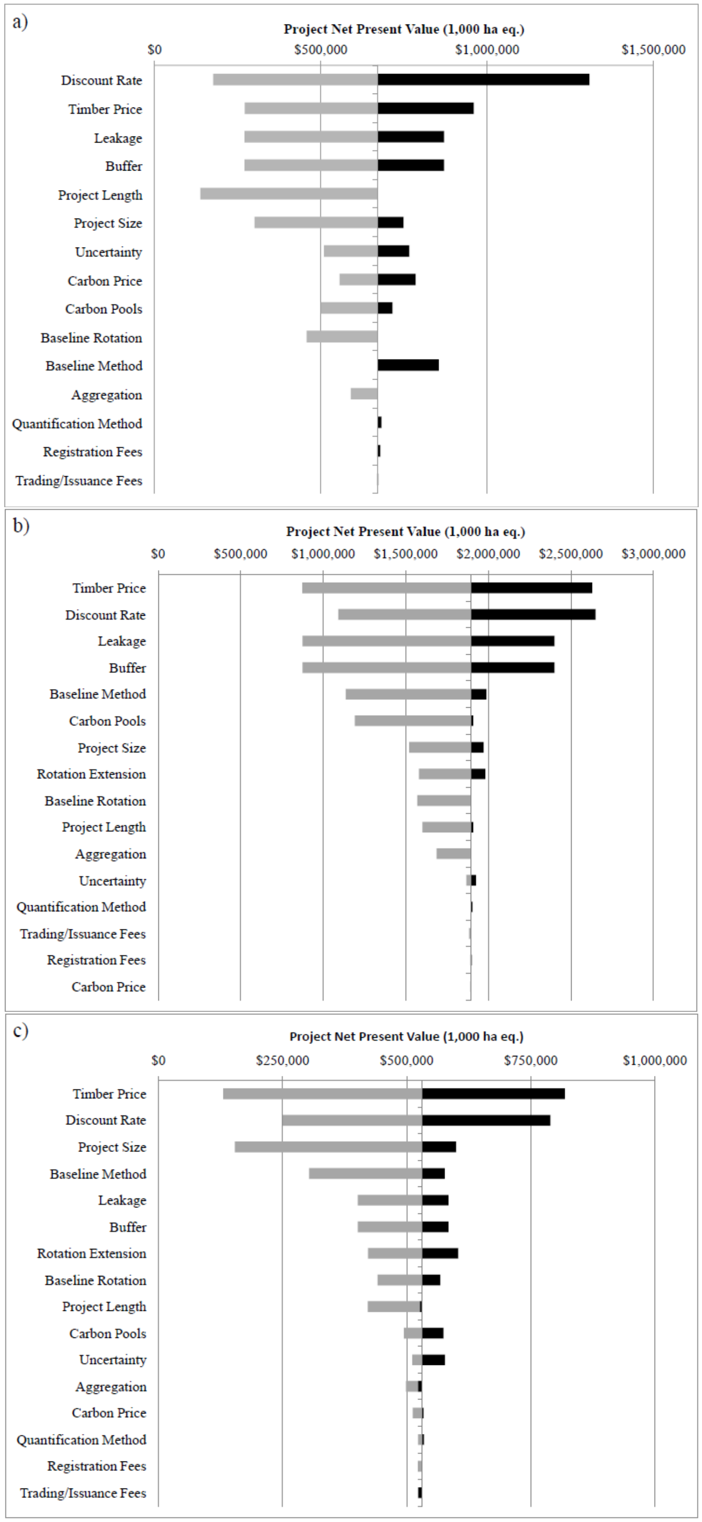
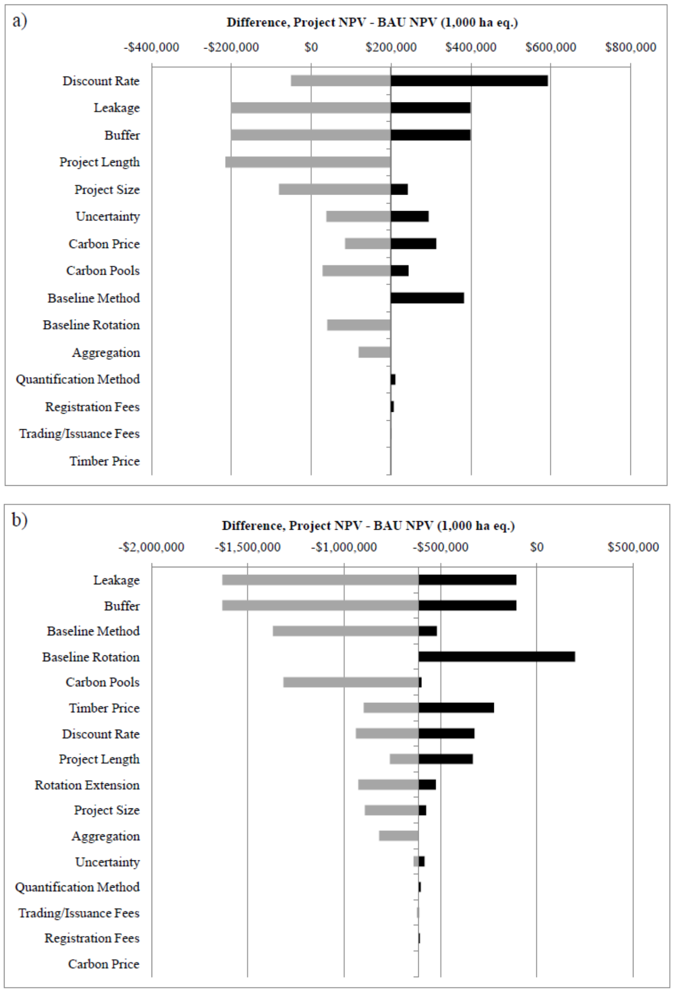
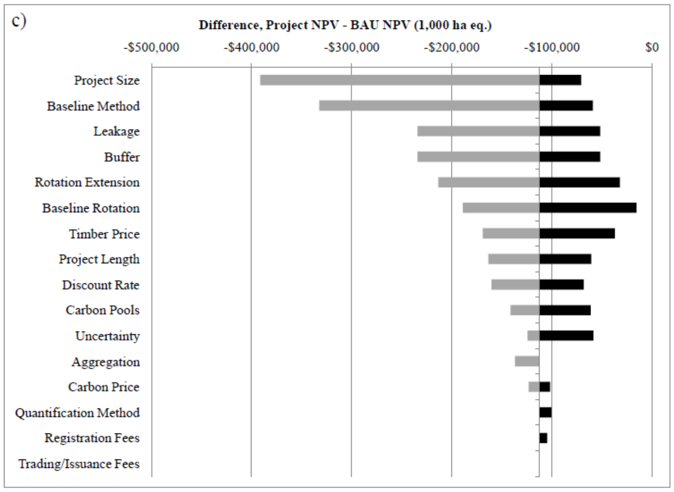

a)
Project Net Present Value (1,000 ha eq.)
$0
$500,000
$1,000,000
$1,500,000
Discount Rate
Timber Price
Leakage
Buffer
Project Length
Project Size
Uncertainty
Carbon Price
Carbon Pools
Baseline Rotation
Baseline Method
Aggregation
Quantification Method
Registration Fees
Trading/Issuance Fees
b)
Project Net Present Value (1,000 ha eq.)
$0
$500,000
$1,000,000
$1,500,000
$2,000,000
$2,500,000
$3,000,000
Timber Price
Discount Rate
Leakage
Buffer
Baseline Method
Carbon Pools
Project Size
Rotation Extension
Baseline Rotation
Project Length
Aggregation
Uncertainty
Quantification Method
Trading/Issuance Fees
Registration Fees
Carbon Price
c)
Project Net Present Value (1,000 ha eq.)
$0
$250,000
$500,000
$750,000
$1,000,000
Timber Price
Discount Rate
Project Size
Baseline Method
Leakage
Buffer
Rotation Extension
Baseline Rotation
Project Length
Carbon Pools
Uncertainty
Aggregation
Carbon Price
Quantification Method
Registration Fees
Trading/Issuance Fees

Figure 2. Relative performance of three hypothetical forest offset projects against their BAU, non-project alternative. Relative performance is defined as the difference between offset project net present value (NPV) and that of the BAU, non-project alternative. Projects evaluated include a) improved productivity of loblolly-shortleaf pine stands, b) extended rotation in high management intensity, high productivity loblolly-shortleaf pine stands, and c) extended rotation in longleaf-slash pine stands. Grey bars represent values below the base case scenario, while black bars represent values above.





c)
Difference, Project NPV - BAU NPV (1,000 ha eq.)
-$500,000
-$400,000
-$300,000
-$200,000
-$100,000
$0
Project Size
Baseline Method
Leakage
Buffer
Rotation Extension
Baseline Rotation
Timber Price
Project Length
Discount Rate
Carbon Pools
Uncertainty
Aggregation
Carbon Price
Quantification Method
Registration Fees
Trading/Issuance Fees

Figure 3. Average annual carbon generated (tCO_2e ha^{-1} yr^{-1}) for three hypothetical forest offset projects. Projects evaluated include a) improved productivity of loblolly-shortleaf pine stands, b) extended rotation in high management intensity, high productivity loblolly-shortleaf pine stands, and c) extended rotation in longleaf-slash pine stands. Grey bars represent values below the base case scenario, while black bars represent values above.