JOURNAL OF FOREST BUSINESS RESEARCH

Peer-reviewed Forest Business Note **Journal of Forest Business Research 2(1), 85-93, 2023**

Carbon additionality: an illustration by southern pine plantations

Bin Mei,[a,*]

a: Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA.
[*]Corresponding author: E-mail: bmei@uga.edu

ABSTRACT

Forests not only produce fiber but also sequester atmospheric carbon, which offers a nature-based solution to global warming. To internalize the externality of forest carbon, additionality must be defined and quantified. This study applies the discounted cash flow approach to price forest carbon additionality. A carbon credit is derived from the annual marginal forest growth, while a carbon release penalty is triggered by a harvest based on biomass removal. The business-as-usual is defined by the Faustmann rotation, in which the profit from timber production from perpetual rotations is maximized. Accordingly, additionality is defined by the net present value of the extra carbon sequestration beyond the baseline on a perpetual basis. It is discovered that a higher planting density on a better quality site combined with no thinning provides a more cost-effective means for a southern pine plantation to sequester additional carbon. It is also found that a shorter carbon contract is more cost-effective in achieving additionality despite a lower total carbon benefit.

Keywords

carbon trading, climate change, forest-based climate solution, public good, timberland investment

Citation

Mei B. 2023. Carbon additionality: an illustration by southern pine plantations. J.For.Bus.Res. 2(1): 85-93

Received: 16 February 2023
Accepted: 16 March 2023
Published: 22 March 2023

INTRODUCTION

In addition to producing timber products, forests function as a natural carbon sink that can help reduce the concentration of atmospheric carbon and thus mitigate global climate change. As a public good, the positive externality of forest carbon need to be quantified so that its benefit and cost can be better understood by the whole society and carbon trades can be guided. For forest carbon, a crucial concept is additionality, or additional carbon sequestration beyond a landowner's business-as-usual practice. Despite its theoretical soundness, how to define additionality in practice remains a challenge (e.g., Mason and Plantinga 2013; Tahvonen and Rautiainen 2017).

In this study, the discounted cash flow method is used to examine forest carbon additionality. A carbon credit is derived from the annual marginal growth of a southern pine plantation, while a carbon release penalty is triggered by a harvest based on biomass removal. The business-as-usual is defined by the Faustmann rotation, in which the profit from timber production from an infinite number of rotations is maximized. Accordingly, additionality is defined by the net present value of the extra carbon sequestered beyond the baseline on a perpetual basis. A number of scenarios are analyzed to investigate the impact of the forest management practice, the site quality, and the contract length on carbon additionality. Results from this study can shed some light on the unprecedentedly active carbon trading in the voluntary market in recent years.

MATERIAL AND METHODS

The evaluation is based on loblolly pine plantations in the lower coastal plain of Georgia, USA (Figure 1).

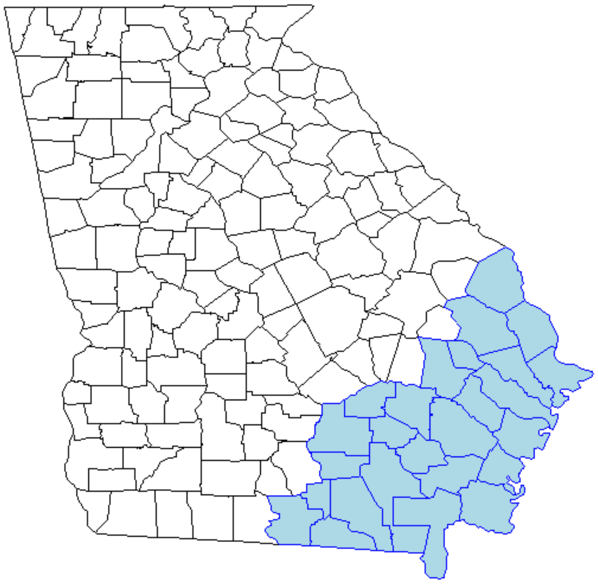

Figure 1. Lower coastal plain region in Georgia, USA.

For the accounting of aboveground forest carbon, it is assumed that an annual carbon credit is generated as trees grow and a carbon release penalty is incurred at the harvest. Annual carbon credits are linked to marginal sequestration from the biological growth of the forest. Specifically, a carbon credit (C_t) is calculated as

$$C_t = P \cdot Q(t) \tag{1}$$

where P is carbon price in dollars per ton and $Q(t)$ is marginal sequestration in tons per acre (1 acre = 0.404686 hectare) over a year. Here, a carbon price of \$20 per ton, or \$5.45 per ton of CO_2 equivalent, is used as observed from the voluntary market (Donofrio et al. 2021).

To convert forest yield data in green tons per acre to tons of carbon per acre, Equation 2 is used

$$Q(t) = \Delta G(t) \cdot BEF \cdot (1 - MC) \cdot \rho \tag{2}$$

where $G(t)$ is the forest yield function at age t, $\Delta G(t)$ is the marginal yield over a year, BEF is the biomass expansion factor,[1] MC is the moisture content, and ρ is the carbon content. For loblolly

---

[1] The ratio of forest biomass to timber biomass.

pine, *BEF* = 1.20 *MC* = 0.54, and ρ = 0.47 (PMRC 2023; Zhao et al. 2016). Carbon release is assumed to be 65% of total carbon stored in the forest biomass removed at the time of a harvest (Mei 2023; Sun et al. 2022). Therefore, the cash flows associated with forest carbon within one harvest cycle can be illustrated in Figure 2.

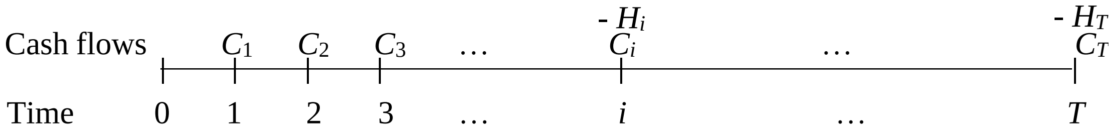

Figure 2. A timeline with cash flows associated with forest carbon within a harvest cycle. Note: Ct is carbon credit at time t, Ht is carbon release penalty at time t, i is the time for a thinning, and T is the time for the final harvest.

The corresponding net future value of forest carbon (N_c) is calculated as

$$N_c = \sum_{t=1}^{T} (C_t - H_t)(1+r)^{(T-t)} \tag{3}$$

where C_t is the carbon credit at time *t*, H_t is the carbon release penalty from a thinning or a harvest at time *t*, and *r* is the discount rate. Thus, the perpetual carbon value (PCV) for a given rotation *T* can be calculated as

$$PCV(T) = \frac{N_c}{(1+r)^T - 1} \tag{4}$$

The baseline, or the business as usual, is defined as the one that maximizes the land expectation value (LEV) according to the Faustmann model (Faustmann 1995)

$$LEV(t) = \frac{S \cdot G(t) - E \cdot (1+r)^t}{(1+r)^t - 1} \tag{5}$$

where *S* is stumpage price, *G*(*t*) is the forest yield function at age *t*, *E* is the site establishment cost (including site preparation, seedlings, and planting costs), and *r* is the discount rate. Once the optimal rotation T^* is identified, we consider a *N*-year contract that is beyond the optimal rotation age so that the social benefit from additional carbon sequestration is the increase in the PCV, $\Delta PCV = PCV(T^* + N) - PCV(T^*)$, and the cost to a landowner to enroll in such a contract is the reduction in the LEV, $\Delta LEV = LEV(T^*) - LEV(T^* + N)$.

Based on past research or available data sources, the following values for the key variables are used to find the optimal rotation for the baseline: stumpage prices of $10 per green ton for pulpwood, $20 per green ton for chip-n-saw, and $30 per green ton for sawtimber, representing the averages in the last 30 years (TMS 2023)[2]; forest growth and yield data from the online simulator of Plantation Management Research Cooperative at the University of Georgia (PMRC 2023); a site establishment cost of $250 per acre (Chhetri et al. 2019; Li 2018); and a real discount rate of 5% (Buongiorno and Zhou 2020; Li 2018; Mei 2023). To study the impact of different forest management practices, land quality, and contract length on the valuation of forest carbon additionality, three initial planting densities (500, 680, and 850), a thinning at age 15, two site indices (75 and 90) with a base age of 25, and two contract length (3 and 6 years beyond the Faustmann rotation) are incorporated into the analysis.

RESULTS AND DISCUSSION

Table 1 presents the analysis for a loblolly pine plantation in the lower coastal plain of Georgia with an initial planting density of 500 trees per acre, a site index of 75, and no thinning.

Table 1. Illustration of carbon additionality by a loblolly pine plantation.

1	2	3	4	5	6	7	8	9	10	11
Age	PW	CNS	ST	Total yield	Carbon weight	Carbon credit	LEV	N_c	Carbon release	PCV
5	0.0	0.0	0.0	0.0	0.0	0.0				
6	0.7	0.0	0.0	0.7	0.2	3.4		3.4	2.2	3.5
7	3.1	0.0	0.0	3.1	0.6	12.8		16.4	10.5	14.4
8	7.2	0.0	0.0	7.2	1.1	21.1		38.3	24.2	29.4
9	12.3	0.0	0.0	12.4	1.3	26.8		67.0	41.7	46.0
10	18.1	0.4	0.0	18.5	1.6	31.9		102.3	62.4	63.4
11	24.2	1.7	0.0	25.8	1.9	38.0		145.4	87.1	82.1
12	30.4	3.9	0.0	34.4	2.2	44.4		197.1	116.0	101.9
13	36.7	7.2	0.1	44.0	2.5	50.1	49.2	257.1	148.6	122.5
14	42.9	11.4	0.4	54.6	2.7	55.0	175.9	324.9	184.3	143.5
15	49.0	16.1	0.9	66.0	3.0	59.1	296.3	400.2	222.7	164.5

---

[2] TimberMart-South's delineation of timber products by the diameter at breast height: pulpwood, 6 inches and up; chip-n-saw, 8 to 11 inches; and sawtimber, 12 inches and up.

16	55.0	21.2	1.8	78.1	3.1	62.5	409.2	482.7	263.3	185.5
17	60.8	26.6	3.2	90.7	3.3	65.3	514.1	572.1	305.7	206.2
18	66.4	32.2	5.1	103.7	3.4	67.6	610.1	668.3	349.7	226.5
19	71.9	37.8	7.4	117.0	3.5	69.4	696.8	771.1	394.8	246.5
20	77.2	43.4	10.1	130.7	3.5	70.6	773.8	880.3	440.7	265.9
21	82.3	49.0	13.2	144.4	3.6	71.5	840.8	995.8	487.1	284.8
22	87.2	54.5	16.7	158.3	3.6	71.8	898.1	1117.4	533.8	303.1
23	91.9	59.9	20.4	172.1	3.6	71.9	946.0	1245.1	580.5	320.8
24	96.4	65.1	24.3	185.9	3.6	71.6	984.7	1379.0	627.1	337.9
25	100.8	70.3	28.5	199.6	3.5	71.0	1014.9	1518.9	673.2	354.4
26	105.0	75.3	32.8	213.1	3.5	70.1	1037.1	1664.9	718.8	370.2
27	109.1	80.2	37.1	226.4	3.5	69.1	1052.0	1817.3	763.7	385.4
28	113.0	84.9	41.6	239.5	3.4	67.9	1060.2	1976.0	807.8	400.1
29	116.8	89.5	46.1	252.3	3.3	66.5	1062.5	2141.4	851.1	414.1
30	120.4	93.9	50.6	264.9	3.3	65.1	1059.4	2313.6	893.4	427.5
31	123.9	98.2	55.1	277.1	3.2	63.6	1051.6	2492.8	934.7	440.4
32	127.2	102.3	59.6	289.1	3.1	62.0	1039.6	2679.4	975.0	452.7
33	130.4	106.3	64.0	300.7	3.0	60.4	1023.9	2873.8	1014.2	464.5
34	133.6	110.1	68.3	312.0	2.9	58.7	1005.2	3076.2	1052.4	475.8
35	136.6	113.8	72.6	323.0	2.9	57.1	983.7	3287.1	1089.5	486.6

Note: The loblolly pine plantation is located in the lower coastal plain of Georgia and has an initial planting density of 500 trees per acre, a site index of 75, and no thinning. PW, CNS and ST for pulpwood, chip-n-saw and sawtimber yield in green tons per acre; LEV for land expectation value in dollars per acre; Nc for net future value of carbon credits per acre up till the current age; and PCV for perpetual carbon value in dollars per acre for a given rotation. Total yield is the sum of yield across the three timber products. Carbon weight is in tons. Carbon release is in dollars per acre.

Columns 2-4 are timber yield in green tons per acre for pulpwood, chip-n-saw, and sawtimber, respectively. Column 5 is the total yield, or the sum of the yield across the three timber products. Column 6 is carbon weight in tons per acre converted from the forest marginal growth according to Equation 2. Column 7 is the calculated carbon credit with a carbon price $20 per ton.

Column 8 is the LEV calculated for a given rotation. It turns out that, at age 29, the LEV is maximized at $1,062.5 per acre, and the corresponding PCV is $414.1 per acre. For a 3-year carbon contract beyond the optimal timber rotation at age 29, the PCV on a 32-year rotation basis rises to $452.7 per acre, or a $38.6 increase, whereas the associated LEV reduces to $1,039.6 per acre, or a $23.0 decrease.[3] Therefore, the social benefit or the positive externality from additional carbon sequestration from the 3-year contract is measured to be $38.6 per acre, while the cost to the

---

[3] The reduction in LEV is rounded up to 23.0. All calculations come with 2-digit decimal places in Excel.

landowner is $23.0 per acre. To encourage landowners to enroll into the 3-year carbon contract, a minimum payment of $23.0 per acre to the landowner is needed and the corresponding benefit-cost ratio is 38.6/23.0 = 1.68.

Under the same framework, results for other scenarios are summarized in Table 2.

Table 2. Analyses of forest carbon additionality for selected scenarios.

		No thinning			Thinning at age 15		
Planting density	Site index	Additionality	Cost	B/C ratio	Additionality	Cost	B/C ratio
3-year contract							
500	75	38.6	23.0	1.68	49.2	35.7	1.38
500	90	65.9	51.8	1.27	70.0	100.5	0.70
680	75	38.1	21.7	1.76	47.2	30.5	1.55
680	90	64.9	55.0	1.18	71.9	77.6	0.93
850	75	37.1	24.7	1.50	44.8	28.5	1.57
850	90	66.4	36.4	1.82	72.9	51.1	1.43
6-year contract							
500	75	72.5	78.8	0.92	90.5	137.0	0.66
500	90	122.6	169.2	0.72	128.1	293.6	0.44
680	90	120.6	175.4	0.69	131.7	253.3	0.52
850	90	123.2	145.8	0.85	133.5	205.4	0.65

Note: Planting density in trees per acre. Site index with a base age of 25. Additionality for social benefit from additional carbon sequestration. Cost for reduction in land expectation value due to delayed harvest for carbon. B/C ratio for benefit-cost ratio. For a planting density of 680 or 850 on a tract with a site index 75, the optimal timber rotation exceeds 30 years. As the PMRC online simulator projects forest growth and yield only up to 35 years, the 6-year additionality cannot be calculated and thus the correspond results are not reported in this table.

Cases without a thinning for a 3-year carbon contract beyond the Faustmann rotation are discussed first. For a higher site index, both the carbon additionality and the opportunity cost increase regardless of the planting density. However, there is no clear trend for the benefit-cost ratio. The high planting density (850 trees per acre) on a higher quality site (site index 90) provides the highest benefit-cost ratio of 1.82.

In general, the social benefit from additional carbon sequestration and the opportunity cost for landowners to supply forest carbon both increase with the site index, all else equal. At the low or medium planting density, a higher site index leads to a lower benefit-cost ratio, while at the high planting density, the trend reverses. The main reason is that a higher planting density with a higher site index results in a less proportion of sawtimber products in the total yield. Hence, the reduction in LEV is less significant compared to the increase in PCV.

When a thinning at age 15 is considered for a 3-year carbon contract beyond the Faustmann rotation, both the carbon additionality and the opportunity cost increase, but the benefit-cost ratio tends to fall compare with the no-thinning case except for the case of a planting density of 850 trees per acre on a tract with a site index 75. Hence, thinning is less cost-effective in achieving carbon additionality, albeit it enhances the financial returns to landowners.

For a 6-year carbon contract, both the carbon additionality and the opportunity cost become larger; however, the benefit-cost ratio declines substantially. Thus, a longer carbon contract is less cost-effective, although it can bring more benefit to the society from additional carbon sequestration.

The results of the sensitivity analysis on timber prices and the discount rate are discussed qualitatively as follows. Higher timber prices make the opportunity cost of forest carbon higher, thus reducing the benefit-cost ratio, while a higher discount rate makes social carbon benefit higher due to the time value of money effect, thus increasing the benefit-cost ratio.

CONCLUSIONS

Using forests to sequester atmospheric carbon is an important approach to combat global warming. To internalize this externality of forest carbon, additionality ought to be quantified. Here, the discounted cash flow approach is applied to price forest carbon additionality. Overall, it is found that a higher planting density on a better quality site combined with no thinning provides a more cost-effective means for a southern pine plantation to sequester additional carbon. There is also evidence that a shorter carbon contract is more efficient in achieving additionality, in terms of the benefit-cost ratio, despite a lower total carbon benefit.

CONFLICT OF INTERESTS

The author declares no conflict of interest.

REFERENCES CITED

Buongiorno J, Zhou M. 2020. Consequences of discount rate selection for financial and ecological expectation and risk in forest management. J. For. Econ. 35(1):1-17.

Donofrio S, Maguire P, Myers K, Daley C, Lin K. 2021. State of the Voluntary Carbon Markets 2021. Forest Trends & Ecosystem Marketplace. 40.

Faustmann M. 1995. Calculation of the value of which forest land and immature stands possess for forestry (Originally published in German Journal of Forest Research in 1849). J. For. Econ. 1(1):7-44.

Chhetri SG, Gordon J, Munn I, Henderson J. 2019. Comparison of the timber management expenses of non-industrial private forest landowners in Mississippi, United States: Results from 1995–1997 and 2015. Environments 6(9):107.

Li Y. 2018. A comparative overview of current-use valuation of forests for property-tax purposes in the US South. J. For. 117(1):46-54.

Mason CF, Plantinga AJ. 2013. The additionality problem with offsets: Optimal contracts for carbon sequestration in forests. J. Environ. Econ. Manag. 66(1):1-14.

Mei B. 2023. Carbon offset as another driver of timberland investment returns in the United States. Journal of Forest Business Research 2(1):1-19. Available at: https://forest-journal.com/index.php/JFBR/article/view/carbon-offset-timberland-returns-usa

PMRC. 2023. Plantation Management Research Cooperative: https://https://pmrc.uga.edu/simulator. Last accessed February 24, 2023.

Sun C, Mei B, Li Y. 2022. Optimal contract arrangements for conservation on working forests. Natural Resour. Model. 35(4):e12351.

Tahvonen O, Rautiainen A. 2017. Economics of forest carbon storage and the additionality principle. Resource and Energy Economics 50:124-134.

TMS. 2023. TimberMart-South: https://http://www.timbermart-south.com/. Last accessed February 24, 2023.

Zhao D, Kane M, Teskey R, Markewitz D. 2016. Modeling aboveground biomass components and volume-to-weight conversion ratios for loblolly pine trees. For. Sci. 62(5):463-473.