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On the carbon additionality of working forests

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Abstract

Purpose – Using a 62,742-ha working forest in New Brunswick, Canada, we examine the benefit and cost of carbon additionality at the landscape level.

Design/methodology/approach – The baseline scenario is set to maximize timber profit over a 100-year planning period, whereas the carbon scenario is set to have a 5- or 10-year rotation extension.

Findings – At a carbon price of \$8/tCO_2e, the benefit of additional carbon sequestration from the working forest cannot offset its cost. For the benefit-cost ratio to be one, the respective break-even price needs to be \$21/tCO_2e for the 5-year rotation extension and \$25/tCO_2e for the 10-year rotation extension.

Originality/value – This study analyzes the carbon additionality and economics of working forests at the 50–100 thousand hectare scale. Specifically, we examine the change in benefit and cost between a baseline scenario of timber management only and a scenario of rotation extension for both timber and carbon sequestration.

Keywords Climate change, Carbon credits, Timberland investment, Nature-based solutions, Faustmann model

Paper type Research paper

Introduction

Working forests refer to forestlands actively managed to provide a steady supply of wood for lumber, energy, paper and packaging (National Alliance of Forest Owners, 2024; Working Forests Initiative, 2024). In addition to those forest products, working forests can support many other critical natural assets such as fisheries, clean water, open space, wildlife habitats, biodiversity and carbon sequestration. Thus, working forests are essential to a region's and the world's economic and ecological future (Li *et al.*, 2019). While the values of timber products are well reflected by local and regional forest product markets, those for forest-based ecosystem services, as public goods, are less developed.

Deemed as the leading cause of global warming, CO_2 concentration in the atmosphere has increased by more than 30% in the past century (Wenzel *et al.*, 2016). To mitigate climate change, improving forest management to assimilate atmospheric CO_2 has been a central nature-based solution that can reduce and remove carbon emissions (Griscom *et al.*, 2017; Li *et al.*, 2022; Parkatti *et al.*, 2024; Roe *et al.*, 2019). It is shown that global forests account for about 45% of terrestrial carbon storage (Pan *et al.*, 2011). With the climbing interest in carbon offsets trading of carbon credits in the voluntary carbon market has skyrocketed in the last

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2 decades. Prior to 2005, the size of the total voluntary carbon market was only $301m; in 2021 and 2022, it settled at around $2bn, of which 70% came from the forestry and land use category [1] (Forest Trend's Ecosystem Marketplace, 2023). This momentum of voluntary carbon trading is expected to continue despite a shift toward high-quality credits (Forest Trend's Ecosystem Marketplace, 2023).

A central question in forest carbon markets and research is about additionality, which is defined as the demonstrated increase or avoided decrease in carbon sequestration resulting from an enrolled project in a carbon offset program (Gren and Aklilu, 2016). While theoretically sound, demonstrated additionality – a concern regarding the effectiveness of improved forest management (IFM) protocols in sequestering carbon – is challenging (e.g. Mason and Plantinga, 2013; Rossi *et al*., 2023; Tahvonen and Rautiainen, 2017). For instance, Badgley *et al*. (2022) estimated that the California Air Resources Board had over-credited 30 million tCO_2e worth $410m carbon credits between 2004 and 2020; West *et al*. (2020) demonstrated overestimated carbon emission reductions from voluntary REDD + projects in the Brazilian Amazon [2]. Therefore, there is an urgent need for sufficient evidence of carbon additionality above the baseline scenario.

Previous research has evaluated additionality through various lenses. One method is based on forest sector models with counterfactual climate policy scenarios so that any mitigation is additional to the no-policy baseline (e.g. Daigneault *et al*., 2022; Frank *et al*., 2021). Another method is the evaluation at the project or stand level, in which the baseline scenario is defined by the Faustmann model (Faustmann, 1995), while the carbon scenario is characterized by deferred harvesting beyond the baseline (e.g. Mei, 2023a, c). A third method is to use spatial analytics and regression-based projections to construct the baseline (e.g. Randazzo *et al*., 2023). Furthermore, Rossi *et al*. (2023) examined additionality in a dynamic market context by incorporating the feedback effects of changing roundwood prices on the baseline of the offset market itself and the unexpected demand shocks to the timber market.

In brief, past studies of forest carbon focus on either the macro-regional and/or global level or the micro-stand level. While the macro-level analyses reveal social benefit and cost of forest carbon, they usually contain limited information on how forest landowners can contribute to the carbon markets. Likewise, while micro-level analyses demonstrate the optimal decision-making for individual landowners, they often overlook the aggregation issue in supplying carbon credits. In other words, there has been a lack of midground analysis illustrating how to account for carbon additionality at the more practical landscape or forest level with IFM, which conveys a critical message to large forestland owners and managers (e.g. timber real estate investment trusts and timberland investment and management organizations) as well as large corporate carbon emitters contemplating trading forest carbon credits in the voluntary markets. We attempt to fill this knowledge gap to improve the transparency of the voluntary carbon markets and reduce the risk of greenwashing (i.e. overstating climate commitments without meaningful actions).

This study analyzes the carbon additionality and economics of working forests at the 50–100 thousand hectare scale. Specifically, we examine the change in benefit and cost between a baseline scenario of timber management only and a scenario of rotation extension for both timber and carbon sequestration. Under the linear programming framework, we investigate the timber and carbon management strategies for multiple tree species in a working forest and explicitly measure the benefit and cost of carbon additionality using the discounted cash flow technique. Results from this study can shed light on the economics of forest carbon in an increasingly more active global voluntary carbon market. The following section explains the material and methods for the analysis. The third section presented the empirical results. The last section concludes with some policy implications.

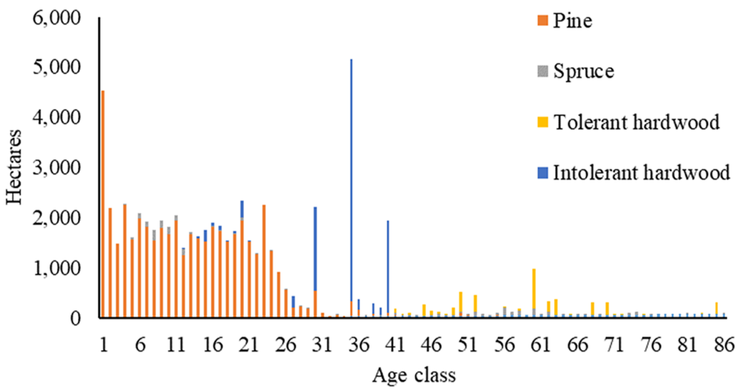
Material and methods

The modeled 62,742-ha working forest under study is located in New Brunswick, Canada (Figure 1), consisting of four primary species groups: pine (46,988 hectares), spruce

Source(s): Remsoft (2024)

Figure 1. The modeled 62,742-ha working forest under study that consists of pine, spruce, shade-tolerant hardwood (ash, maple and beech), and shade-intolerant hardwood (aspen, birch, and poplar) in New Brunswick, Canada

(2,254 hectares), shade-tolerant hardwood (3,525 hectares) and shade-intolerant hardwood (9,975 hectares) [3]. The initial age class distribution of the forest is shown in Figure 2. The forest is well stocked with merchantable timber but also has some young stands of pine and spruce from recent artificial regenerations. In total, there are 18.7 million m^3 of standing timber in stock, with 7.7 million m^3 in pulpwood, 7.1 million m^3 in stud wood and 4.0 million m^3 in sawlog. Future management regimes for even-aged pine and spruce forest plantations include site preparation, planting, fertilizer and herbicide applications, two thinnings and a



Source(s): Remsoft (2024)

Figure 2. Age class distribution of the 62,742-ha working forest in this study

clearcut. In contrast, those for uneven-aged hardwood forests include natural regeneration and partial harvests. Data for forest growth and yield, timber prices and silviculture costs are provided by Remsoft (2024).

Timber prices, along with silviculture costs, are summarized in Table 1. Costs include those for site preparation, planting, fertilizer, weed control, overhead and thinning. A carbon price of \$8/tCO_2e is used for carbon accounting, and a discount rate of 5% is used on the cash flows for the baseline net present value (NPV) calculation, based on recent reports and studies of voluntary carbon trading (e.g. Forest Trend's Ecosystem Marketplace, 2023; Mei, 2023b; Sun *et al*., 2022). Using the American Carbon Registry standard (ACR at Winrock International, 2021), the baseline forest management model is set to maximize the NPV of timber production (Π) for a 100-year planning horizon according to:

$$\max_{A_{it}} \Pi(A_{it}) = \sum_{t=0}^{100} \{[R_t(A_{it}) - C_t](1+r)^{-t}\} \tag{1}$$

where A_{it} is the decision variable that denotes the optimal harvest age for $i \in$ (pine, spruce, tolerant hardwood and intolerant hardwood), $R_t(A_{it}) = \sum_i \sum_j P_{jt} Y(A_{it})_{jt}$ for $j \in$ (pulpwood, stud wood and sawlog) is the total timber revenue at time t calculated as timber price P_{jt} times timber yield Y_{jt} that is summed across the three timber products, C_t is the total cost at time t and r is the discount rate. Despite a 100-year planning horizon, carbon credits are calculated for a 20-year crediting period as set by the American Carbon Registry standard (ACR at Winrock International, 2021). That is, the benefit and cost of forest carbon are evaluated for a 20-year crediting period using the results from Equation (1).

Given the long planning horizon, Equation (1) is approximately equivalent to the Faustmann model, especially for even-aged pine and spruce plantations [4]. The optimal harvest age A_{it}^F is solved under the linear programming framework by Woodstock using the Mosek solver (Remsoft, 2024) and recorded is the corresponding optimal NPV for timber production $\Pi(A_{it}^F)$. Considering the working forest status, an even wood flow constraint is included in the optimization, which limits the variation of annual harvest volume to be within $\pm$10%.

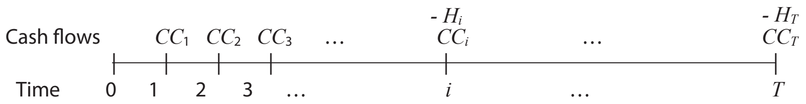
This serves as the baseline or the business-as-usual scenario for the working forest. In IFM carbon credit protocols, deferred harvests are one way to achieve carbon additionality, which is the approach we use in this study. For example, if the average harvest age is deferred by n years for n-year carbon additionality, then stands are harvested at suboptimal levels for timber production at age A_{it}^C so that $\overline{A}^C = \overline{A}^F + n$, where $\overline{A}^F$ and $\overline{A}^C$ are the respective average harvest age for the timber and carbon scenarios over the 100-year planning period. The corresponding NPV for timber production with harvest deferrals is $\Pi(A_{it}^C)$. For carbon additionality, forest operation is suboptimal and the NPV for timber production becomes less, i.e. $\Pi(A_{it}^C) < \Pi(A_{it}^F)$. The reduction of timber income, $\Pi(A_{it}^F) - \Pi(A_{it}^C)$, calculates the cost for landowners to supply forest carbon.

For carbon accounting, we use the same framework as in Sun *et al*. (2022) and Mei (2023a, c), which is also consistent with the American Carbon Registry standard. A carbon credit is generated each year as long as there is net forest growth, whereas a carbon release penalty is triggered when there is a harvest (Figure 3). The conversion equation from forest biomass volume in m^3 to carbon weight in tCO_2e is $0.355 \times 0.5 \times 3.667 = 0.65089$, where 0.355 is the volume to dry weight conversion factor, 0.5 is carbon content and 3.667 is the molecular weight ratio of CO_2/C (ACR at Winrock International, 2021). The harvest release is related to the decay rates of different forest products, i.e. the decomposition of harvested wood over time. For example, lumber products usually have a lower decay rate than paper products, and therefore, a larger portion of carbon is stored in lumber than paper products for 100 years. In this study, an average release rate of 60% is used according to the decay rates of seven wood product classes

Table 1. Summary of the economic data for the forest and carbon valuation

	Timber price ($/m^3)			Cost ($/ha)					
	Pulpwood	Stud wood	Sawlog	Site prep	Planting	Fertilizer	Herbicide	Overhead	Thinning
Pine	10	20	45	250	600	300	250	10	400
Spruce	10	20	45	250	550	300	250	10	400
Tolerant hardwood	12	25	50	–	–	–	–	10	400
Intolerant hardwood	10	20	40	–	–	–	–	10	400
Discount rate	5%								
Carbon price ($/t$CO_2$e)	8								

Source(s): Authors' own creation



Note(s): CC_t is carbon credit at time t, H_t is carbon release penalty at time t, i is the time for a thinning, and T is the time for the final harvest
Source(s): Authors' own creation

Figure 3. A timeline with cash flows associated with forest carbon within a harvest cycle

(softwood lumber, hardwood lumber, softwood plywood, oriented strand board, non-structural panels, miscellaneous products and paper) published by the American Carbon Registry (ACR at Winrock International, 2021).

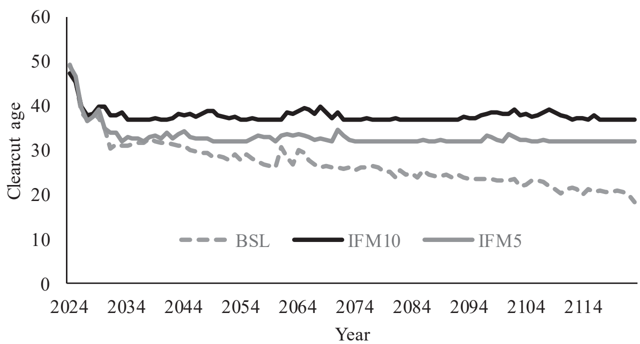
To assess the additionality, two NPVs for carbon cash flows (Ω) are calculated: one for the optimal timber rotation A_{it}^F and the other for the lengthened carbon rotation A_{it}^C. The difference between the two, $\Omega(A_{it}^C) - \Omega(A_{it}^F)$, measures the benefit of additional carbon storage beyond the baseline. The benefit-cost ratio (BCR) of forest carbon on the voluntary market can therefore be calculated as follows:

$$BCR = \frac{\Omega\left(A_{it}^C\right) - \Omega\left(A_{it}^F\right)}{\Pi\left(A_{it}^F\right) - \Pi\left(A_{it}^C\right)} \tag{2}$$

If BCR is greater than one, then the benefit of forest carbon outweighs the cost, indicating that carbon credit prices are higher than the cost to produce the credits. If the BCR is less than one, forest landowners are less willing to provide carbon credits.

Results

In this study, two carbon scenarios with IFM are considered. IFM5 represents a 5-year extension of the rotation scenario, while IFM10 represents a 10-year extension of the rotation scenario (Figure 4). For the two carbon scenarios of IFM5 and IFM10, the average clearcut age over the 100-year planning period is higher than that of the baseline, especially toward the end



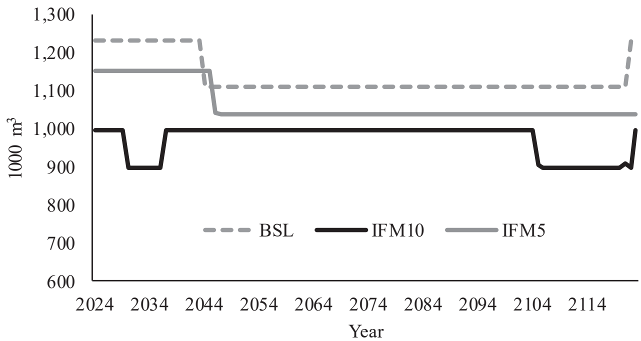
Note(s): BSL for the baseline scenario, IFM5 for the 5-year extension of the rotation scenario, and IFM10 for the 10-year extension of the rotation scenario
Source(s): Authors' own creation

Figure 4. Average clearcut age per year over the 100-year planning horizon for timber and carbon scenarios for the 62,742-ha working forest

of the planning period. As specified in the constraints, IFM5 and IFM10 must have an average clearcut age of 5 and 10 years older than the baseline. Corresponding to the rotation extension, the total harvest volume from the working forest is less than the baseline (Figure 5). Over the 100-year planning period, total timber removal from the baseline scenario is 113.7 million m^3, whereas those for IFM5 and IFM10 are 106.2 million m^3 and 97.2 million m^3, respectively. The indentation shape of the harvest volume curves implies that the even wood flow constraint is binding. Total area of timber removal follows the same trend as the volume. Over the same planning period, 573,815 hectares have been cut for pine and spruce and 22,418 hectares for hardwood in the baseline scenario, whereas the corresponding numbers are 467,263 and 22,418 for IFM5 and 341,339 and 22,414 for IFM10. Because the vast majority of the modeled working forest is composed of pine and spruce and the minority hardwood stands are mature, the changes in forest management come primarily from pine and spruce stands.

With a lower level of timber removal, timber income is reduced. For the 20-year crediting period, the NPV for timber production decreases from the baseline level of \$339.7m to the IFM5 level of \$316.9m and the IFM10 level of \$258.9m (Table 2). Hence, to generate 5- and 10-year carbon additionalities over the 20-year crediting period on this 62,742-ha working forest, the respective opportunity costs are \$22.7m and \$80.8m. No doubt that IFM10 has a higher cost than IFM5. While timber profit is reduced in the scenarios of IFM5 and IFM10, total growing forest stock and carbon storage in the working forest achieve a higher level (Figure 6). Regardless of the management scenario, total growing stock has declined, indicating a net timber removal during the 100-year planning period. The initial age class distribution, the status of a working forest, the objective to maximize timber income and the even wood flow constraint all impact the results.

Table 2 also shows the calculation of NPV for carbon cash flows. The three columns under “timber harvest” show annual timber removal from the 62,742-ha working forest under the baseline, IFM5 and IFM10 scenarios. These harvests trigger partial releases (60%) of carbon stored in forest products, which are counted as cash outflows. The three columns under “forest stock” exhibit the total growing stock of the 62,742-ha working forest. The three columns under “marginal growth” calculate the annual gain (loss) in total growing stock, which translates into carbon credits (debits). Echoing Figure 6, in most years, marginal growth is negative, implying carbon cash outflows. The three columns under “carbon cash flows” are the net cash flows for forest carbon after accounting for carbon credits (debits) and carbon release penalty using a carbon price of \$8/tCO_2e.



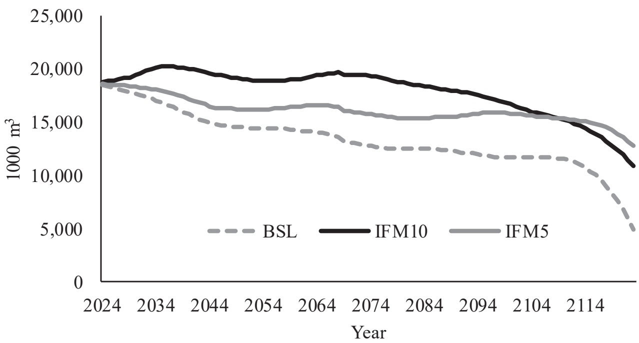
Note(s): BSL for the baseline scenario, IFM5 for the 5-year extension of the rotation scenario, and IFM10 for the 10-year extension of the rotation scenario
Source(s): Authors’ own creation

Figure 5. Annual timber removal from the 62,742-ha working forest for timber and carbon scenarios

Table 2. Benefit and cost of carbon additionality from the modeled 62,742-ha working forest during a 20-year crediting period

Year	Timber harvest (1,000 m^3)			Forest stock (1,000 m^3)			Marginal growth (1,000 m^3)			Carbon cash flow (million $)		
	BSL	IFM10	IFM5	BSL	IFM10	IFM5	BSL	IFM10	IFM5	BSL	IFM10	IFM5
2023				18730.0	18730.0	18730.0						
2024	1233.4	996.9	1152.1	18560.3	18785.4	18641.3	−169.7	55.4	−88.7	−4.7	−2.8	−4.1
2025	1233.4	996.9	1152.1	18422.6	18869.7	18585.8	−137.7	84.2	−55.6	−4.6	−2.7	−3.9
2026	1233.4	996.9	1152.1	18294.0	18962.8	18544.9	−128.5	93.1	−40.9	−4.5	−2.6	−3.8
2027	1233.4	996.9	1152.1	18164.3	19059.2	18505.0	−129.8	96.4	−39.9	−4.5	−2.6	−3.8
2028	1233.4	996.9	1152.1	18029.9	19160.5	18464.7	−134.3	101.3	−40.3	−4.5	−2.6	−3.8
2029	1233.4	996.9	1152.1	17884.7	19260.0	18418.0	−145.3	99.5	−46.7	−4.6	−2.6	−3.8
2030	1233.4	897.2	1152.1	17729.6	19452.7	18356.9	−155.0	192.7	−61.1	−4.7	−1.8	−3.9
2031	1233.4	897.2	1152.1	17558.2	19643.0	18279.3	−171.5	190.3	−77.6	−4.7	−1.8	−4.0
2032	1233.4	897.2	1152.1	17437.0	19827.3	18244.6	−121.2	184.3	−34.7	−4.5	−1.8	−3.8
2033	1233.4	897.2	1152.1	17258.5	19997.1	18162.7	−178.5	169.8	−81.9	−4.8	−1.9	−4.0
2034	1233.4	897.2	1152.1	17070.7	20135.2	18059.4	−187.8	138.1	−103.3	−4.8	−2.1	−4.1
2035	1233.4	897.2	1152.1	16876.6	20234.2	17944.6	−194.1	99.0	−114.8	−4.9	−2.3	−4.2
2036	1233.4	897.2	1152.1	16658.7	203020	17818.6	−218.0	67.8	−125.9	−5.0	−2.5	−4.3
2037	1233.4	996.9	1152.1	16432.6	20244.5	17665.6	−226.0	−57.5	−153.1	−5.0	−3.4	−4.4
2038	1233.4	996.9	1152.1	16182.8	20187.8	17516.4	−249.8	−56.7	−149.2	−5.2	−3.4	−4.4
2039	1233.4	996.9	1152.1	15963.1	20135.6	17363.9	−219.7	−52.2	−152.5	−5.0	−3.4	−44
2040	1233.4	996.9	1152.1	15743.0	20049.5	17206.8	−220.1	−86.1	−157.2	−5.0	−3.6	−4.4
2041	1233.4	996.9	1152.1	15519.4	19949.1	17048.2	−223.6	−100.4	−158.6	−5.0	−3.6	−4.4
2042	1233.4	996.9	1152.1	15293.0	19840.0	16882.9	−226.4	−109.1	−165.3	−5.0	−3.7	−4.5
2043	1233.4	996.9	1152.1	15061.3	19727.0	16714.5	−231.7	−113.0	−168.4	−5.1	−3.7	−4.5
NPV (million $)	339.7	258.9	316.9							−59.3	−33.0	−50.6
ΔNPV (million $)		80.8	22.7								26.3	8.7
BCR		0.33	0.38									

Note(s): BSL for the baseline scenario, IFM5 for the 5-year rotation extension scenario, IFM10 for the 10-year rotation extension scenario, NPV for net present value, and BCR for benefit-cost ratio. NPV is calculated using the economic data in Table 1
Source(s): Authors' own creation



Note(s): BSL for the baseline scenario, IFM5 for the 5-year extension of the rotation scenario, and IFM10 for the 10-year extension of the rotation scenario

Source(s): Authors' own creation

Figure 6. Total growing stock of the 62,742-ha working forest for timber and carbon scenarios

The respective NPVs for carbon over the 20-year crediting period for the baseline, IFM5 and IFM10 are \$59.3m, \$50.6m and \$33.0m. Therefore, the corresponding benefits for 5- and 10-year carbon additionalities for the 62,742-ha working forest over the 20-year crediting period are \$8.7m and \$26.3m. Matching the benefit with the cost, the 5- and 10-year carbon additionalities have BCRs of 0.38 and 0.33, respectively. Therefore, despite increasing amounts of total carbon sequestration, IFM10 has a lower BCR than IFM5, implying a decreasing economic efficiency of carbon sequestration with increasingly extended rotations. As for the break-even analysis, it is not until the carbon price rises to \$21/tCO_2e and \$25/tCO_2e that the BCRs of IFM5 and IFM10 become one.

Discussion and conclusions

Using a modeled 62,742-ha working forest in New Brunswick, Canada, this study examines the carbon additionality resulting from the extension of rotation for 5 or 10 years. Results show that, at a carbon price of \$8/tCO_2e, the benefit of additional carbon sequestration from the working forest cannot offset its cost or the loss of timber income from deferred harvests. Compared with the 5-year rotation extension scenario, the 10-year rotation extension scenario sequestered more additional carbon. However, the higher total benefit of forest carbon came with the tradeoff of an even lower BCR. This finding corroborates those from previous studies (e.g. Mei, 2023a; Sun *et al.*, 2022), which can be explained by the sigmoid growth function of a tree. At a younger age, a tree grows faster and absorbs more atmospheric CO_2 than the same tree at an older age. Despite more carbon stored, if not harvested, older trees are subject to lower rates of carbon absorption and absorption plateaus, along with higher fire, pest and disease risks (Zhao *et al.*, 2023). When rotations are properly extended, older trees can be harvested for sawlog sales for long-term carbon storage and replaced by vigorously growing seedlings, which can maximize the carbon sequestration potential of a working forest from the life-cycle perspective.

Since the cost of forest carbon outweighs the benefit, it is unlikely that working forests would become major credit suppliers in the voluntary carbon market in the absence of any government intervention or higher credit prices. This is particularly true when timber harvesting is an intensely privileged management goal for working forests. Some carbon incentives and cost-sharing programs at the state or federal government level or innovative carbon finance vehicles [5] should be designed to help cover some of the timber income that landowners forgo from delayed harvests to improve the BCR. Alternatively, the government could put in place or expand the regulatory carbon market, which historically has higher prices than the voluntary carbon market. Otherwise, we might need to wait for a while for the invisible hand to work. That is, it is not until the carbon price triples its current level, resulting primarily from the surge in demand for carbon credits, that forest carbon projects can break even.

Another aspect of carbon credits is the quality. The recent upswing in the size of the voluntary carbon market is mainly driven by the demand for high-quality carbon credits with a price premium (Forest Trend's Ecosystem Marketplace, 2023). In the past few years, several initiatives on carbon credit quality have been launched, e.g. the Carbon Credit Quality Initiative and the Voluntary Carbon Markets Integrity Initiative, which aim to improve the quality of carbon credits and transparency. When the latest science and technology are incorporated into the carbon credit standards, we believe that the quality of forest carbon would keep ratcheting upward and the quality premium could induce more supply of forest carbon.

Moreover, a preferential tax rate on forest carbon income would incentivize participation of working forests. Right now, carbon income is treated in the same way as ordinary income and is subject to higher federal tax rates and social security self-employment tax as incomes from other non-timber sources, e.g. hunting and fishing leases, fee activities and mineral rights. A lower tax rate on forest carbon income results in a higher after-tax net gain, all else being equal, which could help stimulate the supply of carbon credits from working forests. Future research should explore the value of capturing other co-benefits (e.g. water and biodiversity) from working forests in addition to carbon credits and the corresponding optimal forest operation strategies.

In summary, this study shows how to quantify the additionality of forest carbon in monetary terms at the more implementable landscape or forest level. Despite the focus on New Brunswick of Canada, the analysis can be easily extended to other regions of the world by updating the growth and yield data using well-established biometric models for those locally dominant tree species. Accordingly, some key variables need to be adjusted, e.g. the timber-to-carbon weight conversion factor and the carbon release factor at harvest. Intuitively, the higher the carbon density, the more carbon stored in the wood. However, a higher carbon density does not necessarily result in a more economically efficient additionality, as measured by the BCR, for the same extension length of rotation (Mei, 2023a, c). A higher carbon release at harvest, on the other hand, tends to lead to a longer extension of rotation so as to delay the penalty from releasing carbon back to the atmosphere. The comparative statics is similar to that of the regeneration cost on the rotation length in the Faustmann model.

Notes

1. In this paper, all monetary values are in US dollars.
2. REDD + stands for reducing emissions from deforestation and forest degradation in developing countries.
3. Tolerant hardwood primarily includes ash, maple and beech; intolerant hardwood primarily includes aspen, birch and poplar.
4. Toward the end of the 100-year planning period, many cutover lands are not replanted so as to reduce capital expenditures and therefore maximize the NPV with a terminating year. It would be slightly different should the planning period be perpetual. For the valuation purpose, a 100-year planning period resembles well forest practices in the real world. A longer planning period results in negligible valuation differences but at the price of a more computational burden in the optimization.
5. For example, the use of "green bonds," in which bonder holders (lenders) receive carbon credits instead of coupon payments or the principle payback.

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