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California's regulatory forest carbon market: Viability for northeast landowners

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A B S T R A C T

Carbon markets have the potential to reward landowners for improved forest management and forest conservation. To date, the Over the Counter (OTC) voluntary market represents the greatest opportunity for forest landowners to participate in carbon transactions. However, lack of a consistent carbon price signal and sporadic demand coupled by high transaction costs has prevented widespread participation from family forest landowners. Adoption of a U.S. based cap-and-trade program reduces price risk and may provide incentives for sustainable forest management across large areas. Yet few studies have examined the supply side of carbon offsets and factors affecting project financial viability. To address this gap, we assessed how (1) property characteristics (i.e. stocking level, forest type, size etc.); (2) silvicultural treatments; and (3) protocol and legislative requirements affect the financial viability of compliance forest offset projects, focusing on California's Air Resource Board (ARB) program due to its significance as the world's second largest carbon market. We used forest inventory data from 25 properties in the northeastern United States to examine the viability of the sites as ARB offset projects. We utilized the U.S. Forest Service Forest Vegetation Simulator for our growth and yield simulations. To examine the factors that influence project viability, we used a classification and regression tree analysis performed in S-Plus software. Results indicate C stocking and property size are the most important property characteristics driving return on investment. However, protocol requirements and legislative assumptions impacting long-term monitoring costs are also important factors. While reduced price risk in a compliance carbon market has the potential to improve forest management in North America; high initial project development costs, long-term monitoring obligations, and legislative uncertainty are significant barriers that will limit family forest landowner market participation. The model developed here can be used by U.S. landowners to assess the financial viability of their property as a compliance offset project and can be utilized by policymakers to develop cost-effective climate change policy.

1. Introduction

Opportunities are emerging for landowners to participate in carbon market trading schemes (Dickinson et al., 2012; Galik et al., 2009). Rapidly developing international and domestic carbon (C) markets could increase U.S. and global forest C sinks and reward landowners for improved forest management (Gunn et al., 2011; Fernholz et al., 2008; Birdsey et al., 2006; Malmsheimer et al., 2008). To date, the Over the Counter (OTC) voluntary market presents the greatest opportunity, with the vast majority of volume (>90% of forest C credits) and value of forest credits world-wide (Diaz et al., 2011). In 2011, forest offsets generated the greatest value to the global C market in history (Peters-Stanley et al., 2012). Despite the potential for C markets to incentivize sustainable forest management, several barriers impede landowner participation (Miller et al., 2012; Charnley et al., 2010; Fletcher et al., 2009).

Developing a C offset project can be a challenge due to market factors (i.e. price and demand) (Nepal et al., 2012; Lubowski et al., 2006) and transaction costs imposed on landowners for meeting offset protocol requirements (Yonavjak et al., 2011; Antinori and Sathaye, 2007). Most forest C projects originate in developing countries and command a relatively low price (e.g. \$5.6/tCO_2 in 2010) (Diaz et al., 2011). Low C prices are a challenge, because landowners must maintain sufficient cashflow to sacrifice revenue at time of harvest (Manley and Maclaren, 2012). In addition, prices vary greatly in the OTC market, making it difficult for landowners to incorporate projected C revenue in forest management plans. Prices ranged from \$1/tCO_2e to \$100/tCO_2e in 2011 (Peters-Stanley et al., 2012). Moreover, project development transaction costs incurred for forest inventory, growth-and-yield modeling, third-party verification, and monitoring can influence an offset project's break-even C price point (Foley et al., 2009; Galik et al., 2012).

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Compliance C markets have the potential to reduce price risk and cover the opportunity cost of lost revenue from timber harvesting (Manley and Maclaren, 2012; Nepal et al., 2012). In particular, research suggests that landowners would participate in C markets if offset prices reach those projected for California's Air Resources Board (ARB) compliance program (Miller et al., 2012). ARB compliance offset price is predicted to average $35/ton between 2013 and 2020 (Reuters, 2010). Reduced price risk in compliance markets may provide incentives for forest conservation across large areas. However, little information is available to guide forest landowners and planners in determining the financial viability of participation in cap-and-trade markets. To address this gap, we examined the property, forest management, and policy variables that affect the financial viability of ARB offsets. Understanding factors driving offset project viability provides vital information to policymakers developing cap-and-trade programs in the United States and worldwide.

1.1. Improved forest management and offset protocols

Extensive research has focused on the role that improved forest management (IFM) projects can play in sequestering C (Heath et al., 2011; McKinley et al., 2011; Birdsey et al., 1993). IFM projects are management activities intended to maintain or increase C stocks relative to business-as-usual (ARB, 2011) and are eligible offset project types in most greenhouse gas (GHG) programs (Gorte and Ramseur, 2010; Galik and Jackson, 2009). In regulatory programs, a cap-and-trade system sets a state, regional or national cap, or limit, on how many GHG emissions are permitted from regulated entities. Capped entities can meet their compliance obligation through emission allowances, auction or allocated to them by a governmental agency, or purchasing offsets from uncapped sectors. Forestry is considered an uncapped sector in compliance markets and IFM offsets can be created at lower costs compared to offsets from other sectors (McKinsey Company, 2009; Lubowski et al., 2006; Richards and Stokes, 2004; Newell and Stavins, 2000). If IFM projects are anticipated to deliver cost-effective emission reductions under cap-and-trade, it is critical to understand the nuances of how forest management and forest offset protocol requirements affect project viability.

Forest offset protocols define project eligibility criteria and accounting rules for different C markets, including regulatory (e.g. AB 32 and New Zealand Emissions Trading scheme) and voluntary systems (e.g. Climate Action Reserve (CAR), American Carbon Registry (ACR), and Verified Carbon Standard (VCS)). Research has shown that offset protocol accounting rules can have a significant impact on forest management (Gunn et al., 2011). On one hand, many studies have shown that even with accounting for C transfers to wood products, more C is sequestered with forest management practices incorporating lower harvesting frequencies (i.e. extended rotations) and higher structural retention (i.e. higher residual basal area) (Harmon and Marks, 2002; Nunery and Keeton, 2010). On the other hand, if C accounting rules take into account the avoided emissions from substituting wood products for other building materials (e.g. steel and concrete) that emit C during manufacturing, more intensive harvesting could result in greater net C benefit (Eriksson et al., 2007). Currently, C market protocols give credit for C stored in wood products, but not for substitution effects (ARB, 2011; CAR, 2010; VCS, 2012). Therefore, C markets reward landowners for shifting harvest intensity to lower-intensity practices that result in greater retention and more C storage (Gunn et al., 2011).

Choice of protocols can also have an impact on the financial viability of offset projects. Research suggests that differences in offset protocols can lead to a wide variation in C credits and revenue that can be obtained by forest landowners (Pearson et al., 2008). In applying the ACR and CAR voluntary protocols to a property in Vermont that removed larger diameter trees without regard to future productivity (i.e. high-grading), ACR consistently generated greater amount of credits over a 100-year period (Russell-Roy et al., 2014). A study comparing five voluntary protocols (U.S. Department of Energy (DOE) 1605(b), Georgia Forestry Commission, Chicago Climate Exchange, CAR, and the VCS), indicates that the DOE 1605 protocol yielded the most credits in early years under a hypothetical U.S. cap-and-trade program (Galik et al., 2009). While several studies have compared voluntary offset protocols, further research is needed to understand how the interaction of property characteristics and protocol requirements affect compliance offset financial viability. This is the first study we are aware of that uses field data to assess specific break-even thresholds for various property and policy conditions under a U.S. compliance protocol.

Identifying key factors influencing forest offset financials for northeast landowners is timely for several reasons. First, for the first time since the mid-1800s, average percent forest cover for all six New England states is declining due to urban and exurban sprawl and other types of development (Foster et al., 2010). Landowners from across the U.S. can generate offsets for sale to California's market. Thus, ARB's cap-and-trade program may become an important factor stimulating or incentivizing sustainable forest management and open space conservation in different U.S. regions. Second, there is an urgent need for planners, landowners, and investors (who finance project development) to access information related to property and policy factors driving offset financials. If compliance offset projects are expected to be a cost-effective climate change mitigation strategy, research is needed to incorporate information within investment portfolios and forest management plans.

In this study, we examine the primary factors driving the financial viability of ARB forest offset projects in the northeastern U.S. The research addresses the question of what effect key variables, including property characteristics (i.e. size, forest type, stocking level, site class, certifications), policy assumptions (i.e. policies that affect long-term monitoring costs), and silvicultural systems (i.e. varying harvesting frequency and post-harvest structure) have on the financial attractiveness of an ARB forest offset project.

2. Materials and methods

2.1. Study sites

Our study area encompassed a representative portion of the northern forest region, consisting of northern New York, Vermont, New Hampshire and Maine specifically. To ensure a robust sample of the various types of landowners and property characteristics, we selected a diverse set of 25 properties with respect to geography, forest type, ownership, size, stocking level and management objectives (Table 1). We worked with consulting foresters in northern New England to identify properties distributed geographically across the region (Fig. 1). Species composition at the properties was dominated by *Acer saccharum* (sugar maple), *Fagus grandifolia* (American beech), *Tsuga canadensis* (eastern hemlock), *Pinus strobus* (eastern white pine), *Acer rubrum* (red maple), *Quercus rubra* (northern red oak), *Picea rubens* (red spruce), and *Betula alleghaniensis* (yellow birch). All sites fell within 80 to 602 m above sea level and soil productivity ranged from low soil site class (V) to high site class (I) for dominant canopy species.

Forest ownership across our dataset included small and medium-sized non-industrial private landowners (i.e. individuals, Land Trusts, Foundations, and schools). Properties owned by Real Estate Investment Corporations were excluded to examine variables specific to family forest owners. Family forest owners are families, individuals, trusts, estates and family partnerships, which is a subset of nonindustrial private forest owners (Butler, 2008). Stand level stocking levels ranged from low to high (Table 1), which was indicative of the full spectrum of stand development conditions (Oliver and Larson, 1996; Franklin et al., 2002) encompassed by the properties in our dataset. For example, recently harvested sites in a stand initiation phase had 13 basal area (BA) m^2/ha^{-1} while some late-successional stands that had not been

Table 1
Initial property characteristics of 25 sites in New York and northern New England assessed for financial viability under Air Resources Board compliance offset protocol.

	Site info									
Property ID	Size (ha)	ARB supersection[a]	ARB assessment area/site class[b]	Basal area (m^2/ha^{-1})	Elevation (m asl)	% conifer by basal area	SDI	Trees per ha	QMD	Canopy height (m)
1	619	Maine–New Brunswick Foothills and Lowlands	Spruce–fir — low	25	97	81	245	1347	38	20
2	51	Adirondacks & Green Mountains	Northern hardwood — high	18	601	1	170	852	42	20
3	44	Adirondacks & Green Mountains	Northern hardwood — high	30	363	33	234	556	66	22
4	109	Adirondacks & Green Mountains	Northeast conifers — high	26	507	16	206	481	65	22
5	49	Adirondacks & Green Mountains	Northeast conifers — high	19	–	12	159	512	54	20
6	199	Adirondacks & Green Mountains	Northeast conifers — low	20	602	29	177	603	52	20
7	45	Adirondacks & Green Mountains	Northern hardwood — high	21	415	74	190	802	46	19
8	84	Adirondacks & Green Mountains	Northern hardwood — high	31	539	80	243	567	65	22
9	728	Adirondacks & Green Mountains	Northeast conifers — low	20	179	25	186	1008	39	17
10	39	Adirondacks & Green Mountains	Northern hardwood — high	23	455	5	193	597	56	21
11	218	Maine–1. New Brunswick Foothills & Lowlands; and 2. Central Maine & Fundy Coast & Embayment	Spruce–fir — low	45	80	86	418	2173	42	20
12	15	Adirondacks & Green Mountains	Northern hardwood — high	19	–	17	183	983	39	20
13	143	Adirondacks & Green Mountains	Northern hardwood — high	13	–	52	122	670	14	9
14	40	Adirondacks & Green Mountains	Northern hardwood — high	20	410	29	159	365	66	22
15	324	Adirondacks & Green Mountains	Northern hardwood — high	21	–	3	182	653	51	22
16	256	Adirondacks & Green Mountains	Northern hardwood — high	18	301	8%	187	1371	33	20
17	35	Adirondacks & Green Mountains	Northeast conifers — high	26	301	64	223	821	52	22
18	28	Adirondacks & Green Mountains	Northern hardwood — high	19	301	38	173	875	48	20
19	13	Adirondacks & Green Mountains	Northeast conifers — high	23	301	65	194	651	53	22
20	69	Adirondacks & Green Mountains	Northern hardwood — high	23	403	2	187	515	59	21
21	36	Adirondacks & Green Mountains	Northern hardwood — high	24	378	17	196	493	62	21
22	42	Adirondacks & Green Mountains	Northern hardwood — high	20	381	33	172	538	53	20
23	660	St Lawrence and Mohawk Valley	Northeast conifer — high	21	–	74	166	378	67	21
24	390	Adirondacks & Green Mountains	Mix of Adirondack high/low	13	554	17	110	369	51	11
25	444	Adirondacks & Green Mountains	Northern hardwood — high	30	416	19	260	949	50	19

[a] ARB uses FIA supersections to identify the natural geographic boundaries of project location.
[b] ARB uses assessment area and site class to define the regional forest C stocking (common practice) used in establishing the carbon project baseline. The assessment area defines the forest communities within FIA supersections. Site class is broken into two classes: high (US Forest site class I & II) and low (US Forest Service site class III–V).

harvested for over ~150 years had BA's above 42 m^2/ha^{-1}. The mean property size was 187 hectares (ha), greater than the average of 20.5 ha for northeastern U.S. family forest owners, but representative of those more likely to have active timber management (Butler, 2008).

2.2. Field data collection

We conducted a forest C inventory for 25 properties in the study area. The inventory collected biometrics for standing live and standing

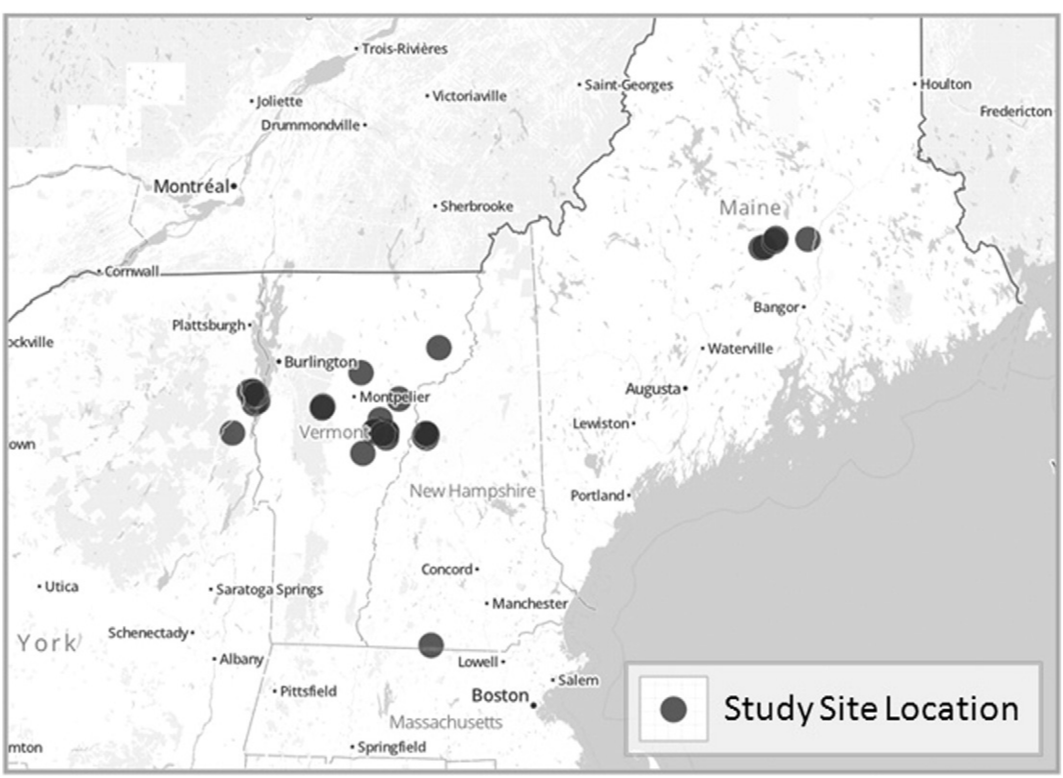

Fig. 1. Map of study sites.

dead C pools following forest offset protocols (ARB, 2011). We used either fixed-area permanent inventory plots or variable radius plots for each study site depending on the main purpose of the inventory. If the purpose of the inventory was for both timber and C estimates, a variable radius design was used. A fixed permanent plot was used for properties collecting data for only C. Both fixed and variable radius plots are allowed under California's forest carbon protocol. We tallied all trees with a minimum dbh of ≥12.7 cm at breast height (dbh, 1.37 m) and collected data on species, live or dead status and total height using a *TruPulse 200* laser range finder (Laser Technology Inc., USA). For nested, fixed plots, the fixed radius was 10 m for the inner plot and 20 m for the outer circle. Variable radius plots used prisms with 2.3 m basal area factor. For standing dead trees, we used a decay stage classification (1–4) following Brown et al. (2004).

We employed a systematic sampling method for each study site and installed a sufficient number of plots to achieve a sampling error of <±10% total C at the 90% confidence interval, which exceeded the minimum standard set in ARB's protocol. To account for the different plot types in our inventory statistics, we estimated above-ground (standing live & dead) and below-ground live (coarse roots) metric tonnes of carbon dioxide/acre for each sample point and processed the data in the same units. Combining individual sample plots expressed in the same unit basis is an appropriate method for conducting statistical analysis without bias (Iles, 2003). This resulted in 15 to 105 plots depending on property size and sampling error related to spatial variability. We conducted pre-inventory work using Geographic Information System (GIS) technology with ArcGIS 9.3.1 software. For selecting the location of the inventory plots, a priori grid was created by Hawth's extension tool in ArcGIS. The starting point for the grid was created by a randomly selected location on a site's periphery to ensure unbiased plot positions. The plot locations were uploaded onto a Trimble Juno Series GPS unit to identify plot locations in the field.

2.3. Data processing

ARB adopted United States Forest Service Forest Inventory and Analysis (FIA) methods for quantifying C. FIA uses species-specific volume equations to estimate volume and then applied the Component Ratio Method (CRM) to convert volume to biomass. The CRM approach converts wet sound volume of wood in the bole to biomass using species-specific wood densities and bark specific gravities (Heath et al., 2009). Biomass is calculated for tops and limbs as a proportion of the bole; stump biomass is calculated separately. We developed an Excel-based model (ARBMODEL) to quantify C stock using the CRM method, which provided an interface between the CRM method and the growth and yield model outputs. We calculated C using ARB's species-specific equations (Hahn, 1984; McClure and Cost, 2010; Scott, 1981) for a sub-sample of properties and compared the projected C for above-ground, below-ground, and standing dead to the predicted output for the same C pools using FVS' Fires and Fuels Extension (FFE). Results indicate C calculated using ARB's methods were within a range of ±10% of total C from FVS FFE results. Therefore, we used FVS FFE C outputs in the financial model in place of ARB's methods. The discrepancy between C outputs from FFE and ARB equations may be a function, in part, of FFE equations not including bark biomass (USDA, 2013).

Forest C offset projects require the application of growth and yield simulation models to estimate the baseline and project scenarios. The baseline scenario is the potential management practice in the absence of the offset project. A key variable in estimating the baseline scenario for ARB IFM projects is how the project's initial standing live C stocks compare to "Common Practice", defined as the average standing live C stocks in similar forest types within the same eco-region (ARB, 2011). The project scenario is the management practice as a forest C offset project. The difference between the project scenario and baseline scenario (after accounting for C stored in harvested wood products, secondary effects, inventory sampling error, etc.) is the issued offset credits.

We used the U.S. Forest Service Forest Vegetation Simulator (FVS) for our growth and yield simulations for the project and baseline scenarios. FVS is an individual-tree, distance-independent, growth and yield model (Dixon, 2002). We chose FVS as the growth and yield model, because it is approved by ARB and because it has been widely used for studies examining C fluxes from the stand level (Nunery and Keeton, 2010; Russell-Roy et al., 2014). Similar to other growth and yield models, FVS has limitations in its application. Studies have shown, for example, the growth and mortality function within the northeast variant (NE-FVS) for certain species may inaccurately reflect stand dynamics at a given location (Ray et al., 2009). However, Yaussy (2000) showed NE-FVS modeled volume predictions within 10 to 15% of actual volumes in northern hardwood forests. In addition, 77 to 99% modeling efficiencies were found in short term estimates, although site specific regeneration inputs are necessary to increase model accuracy projections greater than 20 years (Bankowski et al., 1996).

Because NE-FVS does not include a tree regeneration subroutine, we developed a regeneration submodel, adaptable to individual stands, to determine appropriate inputs for both background regeneration and pulse regeneration after harvest. The model predicts stand level regeneration and seedling availability based on stand level species composition, species shade tolerance, and canopy closure as influenced by simulated silvicultural prescriptions (Kerchner, 2013). We entered the regeneration estimates in the "Plant and Natural Regeneration" partial establishment model in FVS and ran for every simulation time step (10 years) (Table 2). Background regeneration was scheduled for every 10 year cycle with 494 sapling per ha and 80% survival. Pulse regeneration was scheduled the first cycle post harvest and included the following sapling regeneration inputs per ha: clearcut (2465); shelterwood (1971); group selection (1482); and individual tree selection (988).

2.4. Silvicultural treatments

Using FVS, we simulated 100 years of growth and stand development for both the baseline and project scenarios. The project scenario considered six different management scenarios, ranging from "no management" to more intensive silvicultural systems with low structural retention. The term "no management" in this paper is defined as passive management with no active logging. The active management scenarios represented common treatments in northeastern forests, but favored practices previously shown to sequester more C via extended harvest frequencies and greater structural retention (Lindenmayer et al., 2012; Nunery and Keeton, 2010; Gronewold et al., 2010). For active management systems, we applied two even-aged harvests (i.e. shelterwood and clear cut) and three uneven-aged management regimes (i.e. single-tree selection, group selection-distance dependent and irregular shelterwood) (Table 2).

2.5. AB 32 policy assumptions impacting long-term monitoring costs

Policy assumptions related to project monitoring costs are important variables affecting the financial viability of an ARB offset project. ARB's forest C protocol requires one hundred years of project monitoring after the last year of credits sold. For example, if a project starts in 2013 and has a 25 year crediting period (period in which credits are sold) it will end in 2038, but must continue monitoring and reporting until 2138. While the protocol mandates one hundred years of monitoring, there are several caveats in the legislation that could reduce monitoring costs. We considered three separate policy assumptions impacting long-term monitoring costs in our financial model.

Currently, the AB 32 C program ends in 2020. There are two potential outcomes: (1) AB 32 will be renewed post 2020; or (2) AB 32 will not be renewed for several reasons, such as lack of political will or cap-and-

Table 2
Parameters for silvicultural treatments modeled over 100 years in FVS simulations.

Treatment					
Single-tree-selection		*Group selection-distance dependent*		*Irregular shelterwood*	
Harvest schedule		Harvest schedule		Harvest schedule	
30 year cycle length		20 years — intermediate		Condition trigger — basal area (m^2/ha) of trees with DBH >12.7 cm	28
		Thinning			
		40 year cycle length		120 year before condition can be met	
Model parameters		Model parameters		Model parameters	
q-Factor	1.3	Tallest tree (m)	34	q-Factor	1.3
Residual basal area (m^2/ha)	16	Height multiple	1.5	Residual basal area (m^2/ha)	11
Min DBH class (cm)	5	Harvest tree age	200	Min DBH class (cm)	None
Max DBH class (cm)	61	Pre-commercial thin (trees/ha)	746	Max DBH class (cm)	18
No. of legacy trees (ha)	20	Basal area commercial thin (m^2/ha)	14	No. of legacy trees (ha)	20
Mean diameter of legacy (cm)	46			Cutting efficiency (%)	80
Treatment					
Shelterwood		*Clear cut*		*No management*	
Harvest schedule		Harvest schedule		Harvest schedule	
Condition trigger — basal area (m^2/ha) of trees >12.7 cm	23	Condition trigger — basal area (m^2/ha) of trees with DBH > 12.7 cm	23	No management	
100 year before condition can be met		100 year before condition can be met			
Removal cut 10 years after regeneration cut					
Model parameters		Model parameters		Model parameters	
Residual basal area (m^2/ha)	14	Min DBH class (cm)	5	None	
Min DBH class (cm)	18	No. of legacy trees (ha)			
Max DBH class (cm)	None	Harvest tree age	5		
No. of legacy trees (ha)	20	Min DBH of legacy tree	46		
Min DBH class in removal cut (cm)	18				

trade failure. In the former outcome, we modeled a scenario where AB 32 is renewed post 2020 and the project maintains the minimum crediting period of 25 years (assumption 1 in Table 3). A Reserve Fund of $200,000 is established from the sale of credits to pay for the 100 years of monitoring after the last year of the crediting period. The $200,000 Reserve Fund assumed increased efficiency in inventory methods through remote sensing and reduced monitoring costs. In the latter scenario where AB 32 is not renewed there are two likely outcomes: (1) legislation ends in 2020 and a bill is passed that requires 100 years of monitoring (assumption 2 in Table 3); and (2) legislation ends in 2020 and effectively terminates the requirement to monitor for 100 years (assumption 3 in Table 3). Although it is unlikely that 100 years of monitoring would be required if AB 32 is not renewed post 2020, we included it in our analysis to be conservative.

2.6. AB 32 policy assumptions impacting long-term monitoring costs

We recorded our time and costs when conducting the site inventory, growth and yield modeling and C quantification to accurately reflect project development cost. While some costs varied based on the project area size, such as the forest C inventory, most are fixed costs and do not vary significantly among project type, location or area size (i.e. growth and yield modeling and Project Reporting Document). Therefore, we applied the cost in Table 4 to all parcels, regardless of size.

To estimate project verification costs we solicited and received project verification quotes from a third-party verifier. The total average initial development cost per project was approximately $105,000 (Table 4). Our estimate was slightly less than estimates by project developers who place development costs between $125,000 and $200,000 per project (Jenkins and Smith, 2013). One explanation for the reduced costs is that our project sites were smaller than average for ARB and we did not include legal or administrative overhead fees. We used Modified Internal Rate of Return (MIRR) and Net Present Value (NPV) as financial indicators. We applied a 7% finance rate and a 10% reinvest rate for MIRR and a 7% discount rate for NPV. We utilized MIRR as the primary financial indicator, because it takes into account reinvestment rate of periodic free cash flows from investments and can more accurately reflect a project's profitability compared to NPV and IRR (Kierulff, 2008). NPV was also used because it is widely applied to investment analyses, offering a reference for project performance compared to other investment options.

Table 3
AB 32 policy assumptions affecting long-term monitoring costs used in financial model.

Policy assumption	Project response	Effect on long-term monitoring cost
1. AB 32 is renewed post 2020 and 100 year monitoring is required.	Project crediting period and sale of credits continues past 2020 and a "Reserve Fund" is established to pay for 100 monitoring costs.	Conservative assumption assumes 100 year monitoring costs. A "Reserve Fund" of $200,000 is established with sale of credits, interest accrues during crediting period and fund is dispersed over 100 year monitoring post last year of credit sale.
2. AB 32 is not renewed post 2020, but there is a mandate to monitor for 100 years.	Project purchases credits at reduced rates in 2020 to replace 100 year monitoring obligation.	AB 32 terminates and credits are purchased in 2020 at 10% value of original sale price to replace long-term monitoring obligation.
3. AB 32 is not renewed post 2020 and there is no obligation to monitor 100 years.	Since legislation is terminated so is the obligation of a project to monitor long-term.	Long-term monitoring cost is zero.

Table 4
Forest carbon project's initial project development and monitoring costs.

	Cost	Frequency
Initial development costs		
Registry opening account fee	$500	Once
Registry project listing fee	$500	Once
Labor for account opening and project listing	$1500	Once
GIS stratification & inventory	$15,000	Once
Growth and yield modeling and C quantification	$30,000	Once
Travels costs and lodging for inventory	$3500	Once
Project Reporting Document	$29,000	Once
Third-party verification and verification management	$25,000	Once
Total initial development costs	$105,000	Once
Monitoring costs		
Desk review verification	$3000	Annual
Registry fee	$500	Annual
Annual carbon accounting, modeling, monitoring & reporting	$5000	Annual
Inventory	$12,000	Every 12 years
On-site third-party verification	$15,000	Every 6 years
Other fees		
Brokerage fee	3%	
Registry credit issuance fee (per credit)	$0.02	
Prices per California carbon offset (CCO)		
2013–2017	$15	
2018–2020	$20	

To examine the factors driving MIRR of a forest C project under AB 32, we used a classification and regression tree (CART) analysis performed in S-Plus software (Statistical Sciences, 2002). CART has proven to be a highly useful tool in ecological studies, partly due to its ability to model nonlinear relationships (De'ath and Fabricius, 2000). CART applies a collection of rules that defines the tree, using a process known as 'recursive partitioning'. It is a robust nonparametric, binary procedure that partitions variance in a dependent variable through a series of splits based on values of the independent variables (Breinman et al., 1984). We selected CART based on its ability to rank and structure the predictive strength of multiple independent variables, both continuous and categorical, relative to partitioned variance in the dependent variable (MIRR) (Table 5). Two project finance options were compared in the scenario analysis comparing a self-finance option and project developer financed option. Project developers typically take 20–35% of credits in return for financing a project. Thus, the type of financing option may influence return on investment (ROI).

Table 5
Independent variables used in CART analysis.

Independent variable	Type	Levels
% conifer	Continuous	
Site class	Categorical	High (I–II) Low (III–V)
Hectares	Continuous	Numeric
% C above common practice	Continuous	Percentage
Silvicultural treatments	Categorical	No management Single-tree selection Shelterwood Irregular shelterwood Group selection Patchcut
Certification	Categorical	Yes No
Current use	Categorical	Yes No
Policy assumption	Categorical	1. ARB continues post 2020 with long-term monitoring 2. ARB expires 2020 — "buy your way out" 3. ARB expires 2020 — no long-term monitoring costs

3. Results

Results indicate that the financial attractiveness of projects is directly related to property characteristics, particularly initial C stocking level above Common Practice, and property size. The results also suggest that policy assumptions affecting long-term monitoring costs, in addition to property characteristics, have a significant effect on the financial viability (MIRR and NPV) of an ARB offset project. CART results ($n = 450$) suggest that the most important predictor of financial viability is a property's C stocking above the Common Practice. Project with >39% above Common Practice yields the greatest MIRR (Fig. 2). Financially viable projects ranged in size from 600 to 4800 ha, depending on the combination of C stocking level, management practice, and policy assumption. Thus, financial viability of ARB offset projects depends greatly on interaction among factors, such as stocking level, property size, management practice, policy assumptions and finance options, rather than a single predictor variable.

3.1. C quantification by property

Results indicate that the mean total C for all sites was 265 $MtCO_2e$/ha (74 $MtCO_2e$ std. dev.). The mean total C for sites above Common Practice was 322 $MtCO_2e$/ha (61 MtCO2e std. dev.) and the mean total C for sites below Common Practice was 230 $MtCO_2e$/ha (44 $MtCO_2e$ std. dev.) (Table 6). The mean standing live C for the twenty-five sites was 6% below the regional mean Common Practice, suggesting that our sample had slightly lower C stocking compared to average properties in the northeastern United States.

3.2. Factors affecting financial viability — CART results

To further examine the predictive structure of MIRR based on independent variables, we used a CART analysis. From the CART tree and node summary table (Fig. 2), the most important predictor of an ARB offset project MIRR was a property's initial above-ground C stocking (>39%) above Common Practice. The CART results illustrate that the mean financial return was 23% MIRR, which was generated from projects with stocking level >39% above Common Practice and a policy assumption reducing the long-term monitoring cost (second split on left side of tree) (Fig. 2). A policy assuming AB 32 ends in 2020 (Fig. 2; policies B & C) with reduced long-term monitoring costs was the strongest policy predictor of project financial attractiveness.

Property size was also an important predictor of mean MIRR. The second greatest mean financial return was 20% MIRR from projects greater than 417 ha with passive, "no management". These results suggest that a possible combination of initial C stocking above Common Practice and property size is an influential driver of offset viability. The lowest mean financial indicator (0% MIRR) was with properties <39% above Common Practice and were <125 ha. After the general range of MIRR was established by: (1) percentage of stocking above Common Practice; (2) property size; and (3) policy assumption affecting long-term monitoring cost, CART indicates that silvicultural treatment was an important predictor of MIRR. Forest management scenarios with increased structural retention had a greater mean MIRR. These results suggest a likely interaction between property characteristics, policy assumptions, and management that collectively influence financial outcome.

3.3. Principal factors affecting finances and cash flow

We examined how the interaction of the two most important predictors (initial C stocking and property size) of a project's financial attractiveness affects cash flow. The numerical splits identified by CART were used to determine the scenarios for each predictor (>39% above Common Practice and 417 ha property size). There were a total eight combinations (Fig. 3). Properties >417 ha with initial C stocking

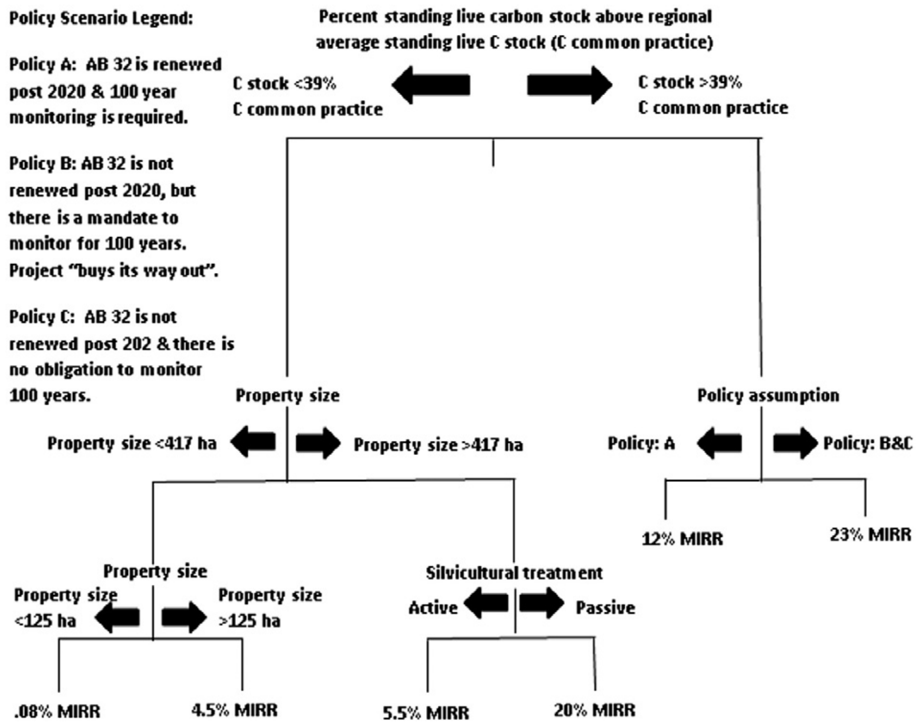

Fig. 2. Classification and regression tree (CART) output showing a series of splits based on values of the independent variables. The length of the vertical lines indicates the amount of deviance explained by the independent variables. The variable at the top of the tree is the most significant predictor of a project offset's financial viability. The independent variables used in the CART analysis are those from Table 5. The n in CART is calculated by multiplying the number of project sites (25) by silvicultural treatments (6) and policy assumptions (3). Total n is 450. Minimum number of observations used before split = 5; minimum node size = 10; minimum deviance required before split = 0.05.

>39% above Common Practice had the greatest cumulative cash flow of ~$344,000 in the short term (first five years). Properties with initial C stocking >39% above Common Practice had the second greatest cumulative cash flow of ~$223,500 in the short-term. Percentage of C stocking above Common Practice is the most critical factor in determining the cash flow in the first five years. In the long-term, (>10 years) initial C stocking becomes less important and property size becomes the most important variable in determining cash flow.

Similar to the short-term, properties >417 ha with initial C stocking >39% above Common Practice also had the greatest cumulative cash flow (~$965,600 in year 20) in the long-term. However, the second greatest cash flow scenario is different in the long-term compared to the short-term. Properties >417 ha have the second greatest cumulative cash flow ($760,000 in year 20) in the long-term. The third greatest cumulative cash flow ($690,000) scenario is with properties >417 ha and initial C stocking <39% above Common Practice. Four scenarios are not financially attractive and had either negative cash flow or relatively low cash flow in both the short-term and long-term. Those are in order of the least cash flow: 1) properties <417 ha and <39% above C Common Practice; 2) properties <417 ha; 3) properties <39% above C Common Practice; and 4) properties <417 ha and >39% above C Common Practice.

Table 6
Mean C in different pools for sites with stocking above and below the regional Common Practice.

	Standing live $MtCO_2e/ha$	Below-ground live $MtCO_2e/ha$	Standing dead $MtCO_2e/ha$	Total aboveground and below-ground $MtCO_2e/ha$
All sites (n = 25)				
Mean	204	51	11	265
Std. dev.	60	13	5	74
Sites with C stocking above Common Practice (n = 12)				
Mean	250	61	11	322
Std. dev.	46	13	6	61
Sites with C stocking below Common Practice (n = 13)				
Mean	161	41	10	213
Std. dev.	40	6	5	44

3.4. Scenarios examining sensitivity of interaction between most influential variables

To further examine the sensitivity of the interaction between the four most influential variables identified by CART, we chose 120 hypothetical scenarios (factorial permutations) combining a spectrum of: a) property sizes; b) stocking levels; c) policy assumptions impacting long-term monitoring costs; and d) management scenarios (Table 7). We included a fifth variable to examine the affects finance options (i.e. landowner self-finance and third-party investor) have on financial feasibility. The scenario with the greatest NPV ($5.2 million) and greatest MIRR (80%) had initial C stocking >40% above Common Practice, was 4800 ha, adopted passive management and assumed a 100 year monitoring as a policy assumption (Table 7, scenario 3 at 4800 ha). The greatest ROI for the third-party investor was 53% MIRR in scenario 3 at 4800 ha and scenario 9 at 4800 ha. While MIRR and NPV are helpful indicators of a project's financial attractiveness, using a clear benchmark for a project's viability helps landowners clearly identify break-even points of property characteristics.

We identified a project's financial viability break-even point at 25% MIRR, which is slightly lower than the average return on investment (27% IRR) of institutional investors (Wiltbank and Boeker, 2007). A total of 53 out of 120 scenarios were financially viable (Table 7). Of the 120 scenarios, 30 scenarios passed the break-even point of >25% MIRR for landowners who self-financed project development. Of the scenarios financed by a third-party investor, 22 scenarios were financially viable. The break-even points for a financially viable project depended on various property-level and policy variables.

The smallest financially viable property was 600 ha (Table 7, scenarios 2, 3, 8 and 9). The scenarios included properties with high initial C stocking, passive forest management, and were self-financed by a landowner. If financed by a project developer, the smallest

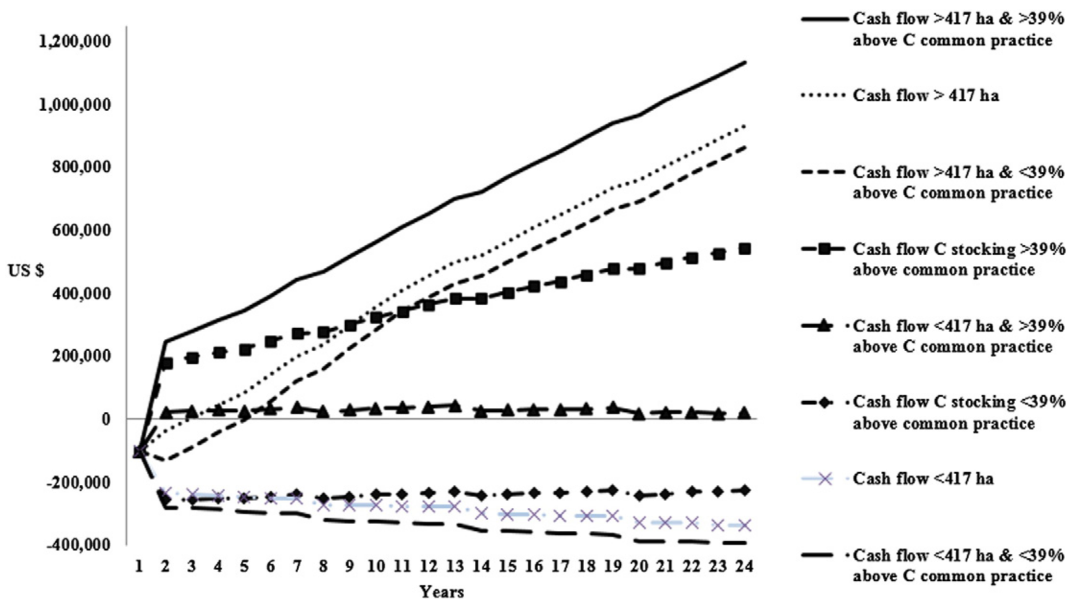

Fig. 3. Cash flow of two most important predictors of financial attractiveness: 1) initial C stocking above Common Practice; and 2) property size. There are a total eight combinations with four combinations resulting in positive cash flow.

financially attractive project was 1200 ha in size, given the same C stocking and management conditions. On the other end of the spectrum, an IFM project with low stocking conditions, active forest management and financed by a project developer was not financially viable at the largest size property (4800 ha) (Table 7, scenario 6). Thus, our results suggest that a project's financial viability depends on the interaction of factors, including stocking level, size, forest management, policy assumptions, and financing mechanism.

Five scenarios, self-financed by the landowner and with initial C stocking below the Common Practice, exceeded the financial viability benchmark. Properties below Common Practice applying active management and assuming long-term monitoring costs were financially viable above 4800 ha (Table 7, scenario 4). Properties below Common Practice with passive management and assuming a reduced long-term monitoring cost (policy B) were financially attractive above 2400 ha (Table 7, scenario 7). Properties below Common Practice were financially viable at larger sizes compared to properties with C stocking above Common Practice.

Consistent with CART results, initial C stocking was an important variable driving project viability. Properties with initial C stocking >20% above Common Practice, passive management, landowner financed and long-term monitoring costs (policy A) were financially viable above 600 ha (Table 7, scenario 2). If scenario 2 was financed by a project developer, it was financially attractive above 1200 ha. Properties with initial C stocking >40% above Common Practice and practicing passive management were financially viable above 600 ha if financed by a landowner and 1200 ha if financed by a project developer (Table 7, scenarios 3 and 9). A property with C stocking >40% above Common Practice, but actively managed and self-financed by a landowner was viable above 2400 ha (Table 7, scenario 6). However, the same scenario was not financially viable if financed by a project developer (Table 7, scenario 6).

4. Discussion

Our research is among the first to explore break-even points for variables affecting the financial viability of U.S. compliance forest offset projects. Findings from our research suggest that ROI is not dependent on solely one variable, but rather that financial viability is highly sensitive to interactions among property size, property stocking level, management regime, long-term monitoring policy assumptions, and financing mechanism. The break-even points identified in scenarios generated for this study will help landowners and project developers determine when and where C projects have the greatest financial prospect and thus potential for success. Further, our findings can help policymakers understand the potential supply of low-cost abatement opportunities from the forestry sector, which is vital to designing a successful cap-and-trade system to mitigate climate change.

4.1. Critical factors driving forest offset financial viability

Initial C stocking is clearly one of the most important variables driving the financial attractiveness of IFM projects based on the CART results. With the exception of one scenario, offset projects with C stocking below the Common Practice were only viable for properties above 4800 ha in size (Table 7). Initial C stocking is critical to project success, because landowners receive a quantity of CCOs equivalent to the difference between a property's initial C stocking and the regional Common Practice. This helps landowners cover initial project development costs and generate immediate revenue. For example, project site number eleven (Table 1) had C stocking 157% above Common Practice, which resulted in 198 issued CCOs per ha at the time of project registration. A project with 400 ha and 157% above Common Practice would be issued 79,200 CCOs at registration. At current prices, this results in $700,000–$1,000,000 in revenue. The same 400 ha project with stocking level below Common Practice would be issued zero credits at registration. Because the number of time steps to recuperate initial investment is an important determinant of financial indicators like MIRR and NPV, the quantity of CCOs issued at project registration has a significant impact on ROI.

Property size is also an important variable in determining the financial attractiveness of a project. In our data set, financially viable projects ranged in size from above 600 to 4800 ha. Previous research has also found a strong correlation between property size and offset transaction costs (Galik et al., 2012; Antinori and Sathaye, 2007). The analysis in this study differs in scope and methods from previous studies. We assessed break-even points for the interaction of factors, identified in CART, driving IFM offset financial viability. Other studies examined break-even C price points by assessing transaction costs (Galik et al., 2012). Instead of break-even C price points, we identified break-even thresholds for various property and policy conditions. California's regulatory market has a fixed cap and sets a floor price, which reduces the

Table 7
Scenarios examining the sensitivity of the interaction between the four most influential variables identified by CART.

Scenario			Hectares				
			200	600	1200	2400	4800
1	Stocking: below Common Practice Management: passive management Policy A	NPV	−$255,251	−$112,319	$102,078	$530,874	$1,388,465
	Landowner finance	MIRR	−21%	1%	13%	24%	36%
		Financially viable	N	N	N	N	Y
	Project developer finance	MIRR	−35%	−11%	9%	19%	30%
		Financially viable	N	N	N	N	Y
2.	Stocking: >20% above Common Practice Management: passive management Policy A	NPV	−$119,215	$295,790	$918,298	$2,163,313	$4,653,342
	Landowner finance	MIRR	−16%	30%	47%	62%	78%
		Financially viable	N	Y	Y	Y	Y
	Project developer finance	MIRR	−29%	15%	26%	38%	51%
		Financially viable	N	N	Y	Y	Y
3.	Stocking: >40% above Common Practice Management: passive management Policy A	NPV	−$95,723	$366,266	$1,059,249	$2,445,216	$5,217,149
	Landowner finance	MIRR	−11%	33%	49%	64%	80%
		Financially viable	N	Y	Y	Y	Y
	Project developer finance	MIRR	−23	17%	28%	40%	53%
		Financially viable	N	N	Y	Y	Y
4.	Stocking: below Common Practice Management: Shelterwood Policy A	NPV	−$270,861	−$159,147	$8,423	$343,564	$1,013,846
	Landowner finance	MIRR	−26%	−3%	8%	20%	31%
		Financially viable	N	N	N	N	Y
	Project developer finance	MIRR	−49%	−20%	4%	13%	25%
		Financially viable	N	N	N	N	Y
5.	Stocking: >20% above Common Practice Management: Shelterwood Policy A	NPV	−$185,096	$98,146	$523,008	$1,372,734	$3,072,186
	Landowner finance	MIRR	−100%	17%	32%	46%	61%
		Financially viable	N	N	N	N	N
	Project developer finance	MIRR	−100%	−10%	20%	31%	42%
		Financially viable	N	N	N	Y	Y
6.	Stocking: >40% above Common Practice Management: Shelterwood Policy A	NPV	−$171,476	−$29,888	$91,817	$335,227	$822,047
	Landowner finance	MIRR	−100%	7%	16%	27%	38%
		Financially viable	N	N	N	Y	Y
	Project developer finance	MIRR	−100%	−7%	2%	11%	21%
		Financially viable	N	N	N	N	N
7.	Stocking: below Common Practice Management: passive management Policy B	NPV	−$23,682	$66,266	$201,187	$443,317	$983,002
	Landowner finance	MIRR	0%	12%	19%	26%	31%
		Financially viable	N	N	N	Y	Y
	Project developer finances	MIRR	−13%	−2%	6%	18%	26%
		Financially viable	N	N	N	N	Y
8.	Stocking: >20% above Common Practice Management: passive management Policy B	NPV	$28,290	$390,136	$932,905	$2,018,4442	$4,189,517
	Landowner finance	MIRR	13%	34%	47%	61%	75%
		Financially viable	N	Y	Y	Y	Y
	Project developer finance	MIRR	−4%	13%	23%	35%	48%
		Financially viable	N	N	N	Y	Y
9.	Stocking: >40% above Common Practice Management: passive management Policy B	NPV	$44,751	$447,498	$1,051,620	$2,259,862	$4,676,347
	Landowner finance	MIRR	14%	36%	49%	63%	78%
		Financially viable	N	Y	Y	Y	Y
	Project developer finance	MIRR	0%	17%	28%	40%	53%
		Financially viable	N	N	Y	Y	Y
10.	Stocking: below Common Practice Management: Shelterwood Policy B	NPV	−$103,245	−$2,967	$162,284	$413,936	$979,901
	Landowner finance	MIRR	−18%	7%	17%	24%	29%
		Financially viable	N	N	N	N	Y
	Project developer finance	MIRR	−29%	−7%	4%	15%	26%
		Financially viable	N	N	N	N	Y
11.	Stocking: >20% above Common Practice Management: Shelterwood Policy B	NPV	−$32,275	$215,877	$588,105	$1,332,561	$2,821,473
	Landowner finance	MIRR	7%	23%	34%	46%	59%
		Financially viable	N	N	Y	Y	Y
	Project developer finance	MIRR	−6%	7%	17%	28%	39%
		Financially viable	N	N	N	Y	Y
12.	Stocking: >40% above Common Practice Management: Shelterwood Policy B	NPV	−$16,000	$255,998	$664,025	$1,480,080	$3,122,189
	Landowner finance	MIRR	8%	24%	35%	48%	61%
		Financially viable	N	N	Y	Y	Y
	Project developer MIRR	MIRR	−3%	11%	21%	32%	44%
		Financially viable	N	N	N	Y	Y

uncertainty in price fluctuation. Thus, for the purpose of this analysis we kept price constant at $15 between 2013 and 2017 and $20 between 2018 and 2020. However, if AB 32 included additional offset project types (e.g. offsets from landfill methane) the offset supply would increase and consequentially decreases offset prices and affects project viability. While previous research is useful to identify the offset price necessary to cover transaction costs, this research adds to literature helping landowners and policymakers assess specific property thresholds.

Forest management is also an important indicator of project financial viability. Consistent throughout the results (Table 7) passive, "no management" had a higher MIRR and NPV compared to the scenarios with active forest management. Other studies have also shown that, at sufficient C price payments, landowners, harvesting frequency and post-harvest retention could increase C storage. For example, Nepal et al. (2012) found that C prices at $50/tCO_2e and $100/tCO_2e would incentivize landowners in Mississippi to extend rotations by 5 and 10 years, respectively. A unique finding from our research sheds light on how the timing of harvesting in forest management could affect the financial attractiveness of a project. If AB 32 is not renewed passed 2020 and there is no obligation to monitor (policy C), then a landowner could potentially delay harvesting until post 2020 after credits were registered and issued. Thus, the timing of harvesting together with a policy that does not enforce long-term monitoring could make a project financially attractive given the right conditions.

This presents an inherent conflict between landowner interest in avoiding long-term monitoring costs and the public policy objective of achieving a long-term climate change benefit (i.e. net reduction in greenhouse gas emissions combined with net increase in terrestrial C storage). Previous research has pointed toward a similar concern that C markets may focus on generating offsets as quickly and cheaply as possible while sacrificing ecological restoration and sustainable forest management (Galatowisch, 2009). While the policy assumptions reducing long-term monitoring cost post 2020 (policies B & C) may enable landowner participation in C markets at the early stages, it will likely have an adverse impact on climate change mitigation. Thus, without a mechanism to monitor the permanence of ARB offsets if AB 32 is not renewed post 2020, there will be potential for reversals.

Our study expands on previous research examining the financial viability of IFM projects (Galik et al., 2012; Nepal et al., 2012; Newell and Stavins, 2000), by taking into account different finance options. The financing option for project development, verification, and monitoring is an important factor to consider based on our findings. IFM offset projects self-financed by landowners have a greater ROI compared to projects financed by third-party investors. In several scenarios, the break-even point of a project's viability was determined by the financing option. For example, scenarios 2 and 3 (Table 7) were financially attractive at 600 ha if self-financed by the landowner, but were only viable at 1200 ha if financed by a third-party entity. A third-party investor plays an important role in covering the upfront project development costs. However, our study indicates a project financed by a third-party entity would require higher stocking levels above Common Practice and/or more acreage compared to a landowner self-financed project.

4.2. Barriers to northeast family forest owners participating in Air Resource Board's compliance market

Findings suggest that participation of northeastern family forest owners in California's state cap-and-trade program will remain limited, in the immediate future, for three main reasons. First, our research demonstrates that the smallest financially viable project, given favorable C stocking and management conditions, is 600 ha. With the average northeastern family forest owned property <20.5 ha (Butler, 2008), property size is a significant barrier to widespread participation. Some ARB offset properties smaller than 600 ha may be financially viable as individual projects if other conditions are met, such as exceptionally well stocked forests, and exceptionally high C prices. However, until ARB accepts aggregation mechanisms to reduce transaction costs and help small-scale landowners gain economies of scale, family forest owners are unlikely to participate directly in compliance markets. While research has shown that aggregation mechanisms could reduce the inventory and monitoring costs for family forest owners (Albu and Griffiths, 2006), ARB has yet to adopt an aggregation protocol. Thus, few mechanisms currently exist in ARB's compliance market to reduce costs for small-scale landowners.

Second, our analysis shows that the initial C stocking level above the regional Common Practice is a key variable driving finances. Projects >39% above the Common Practice had a higher mean MIRR, which gave smaller properties (<2400 ha) the necessary revenue to exceed the financial break-even point of 25% MIRR. This presents a challenge for poorly stocked properties; by one estimate about 50% of productive timberland in the northeast is less than fully stocked due to past management (Hoover and Heath, 2011). In recent decades, increased demand for high quality hardwoods resulted in over harvesting in some areas (Nyland, 1992). This often employed high-grading or diameter limit cutting, which removes the most valuable trees without adequately considering regeneration or future composition, growth, and stand quality (Kenefic et al., 2005). Therefore, many properties currently may not have high enough stocking to be financially viable as measured against the current Common Practice baseline. Yet by the same measure, well-stocked properties may enjoy a market opportunity comparatively. Carbon markets may stimulate a gradual increase of stocking over time, and therefore Common Practice can be expected to change accordingly.

Finally, the third main barrier that inhibits northeast forest owners from participating in ARB is uncertainty related to long-term monitoring costs. ARB requires projects to monitor, verify, and report harvesting and management activities for 100 years following final sale of credits. Our results illustrate that, in many cases, the policy scenario can significantly reduce the economic viability of a project. For example, an ARB offset project with an initial stocking level of >39% above the regional Common Practice in conjunction with a policy scenario with less burdensome long-term monitoring requirements had a 23% MIRR (Fig. 2). The same project site with 39% C stocking above the regional common practice, but that placed $200,000 in a 'Reserve Fund' for long-term monitoring had an 11% MIRR (Fig. 2). Our findings support previous research that suggests that the accounting requirements of specific protocols is an important factor in determining offset viability (Galik et al., 2012; Russell-Roy et al., 2014). However, a finding from our data suggests that the principal accounting variable affecting project viability is the 100 year monitoring compared to findings from other studies, which focus on project development expenses (e.g. registration fees, inventory, planting costs, verification).

We assumed that the cost of land acquisition and property taxes have already been incurred and thus cannot be recovered (i.e. sunk cost). Therefore, we did not use these costs in our project financials. This is consistent with other studies that did not use land acquisition or tax benefits/costs (Galik et al., 2012; Huang and Kronrad, 2001; Newell and Stavins, 2000; Russell-Roy et al., 2014). Thus, fund managers or Timber Investment and Management Organizations should consider land acquisition and other costs (i.e. legal fees and management costs) that may be incurred when investing in a forest C offset project.

5. Conclusion

Our analysis highlights the importance of examining break-even points for individual factors and the interaction of factors when assessing the potential economic viability of an ARB forest offset project. From our data, CART results show that projects with initial C stocking >39% above the regional Common Practice and reduced long-term monitoring costs had the greatest MIRR (23%). The second greatest mean financial return was 20% MIRR from projects on properties

>417 ha in size that also adopted a passive forest management approach. After the general range of MIRR was established by: 1) percentage of stocking above common practice; 2) property size; and 3) policy assumption affecting long-term monitoring cost, CART results illustrate that the type of silvicultural treatment affected MIRR. A 'no management' scenario generated the most credits among forest management practices. However, results also show that properties practicing active forest management can be financially viable, though they may need to be larger in size.

Our scenario analysis tells a more nuanced story about factors driving ARB project viability. Projects were financially attractive under a spectrum of property sizes, ranging from 600 to 4800 ha. On one hand, a property with C stocking >20 above Common Practice, practicing 'no management', and landowner financed was profitable at 600 ha. On the other hand, a property with low stocking, actively managed forest, and financed by a third-party investor was profitable at 4800 ha. Thus, it is the interaction of several variables, such as stocking level, property size, silvicultural treatment, policy assumption, and finance option that determines the financial viability of ARB offset projects, rather than a single factor. While ARB has the potential to affect forest management across large areas, opportunities for family forest owners will remain limited until an aggregation protocol is accepted by ARB and there is reduced policy risk affecting long-term monitoring costs. The model developed here allows landowners to assess the economic viability of ARB forest C offset projects and can be more broadly applied to other U.S. regions.

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