Effects of Private Insurance on Forest Landowners' Incentives to Sequester and Trade Carbon under Uncertainty: Impact of Hurricanes

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Abstract

We evaluate incentives of forest landowners for sequestering and trading carbon, given the risk of carbon loss from hurricanes, and an opportunity to insure their losses. Results of simulation model reveal that the effect of hurricane risk depends on the variability of returns from carbon and timber and landowners' ability to mitigate risk by diversifying forest holdings across regions or transferring risk by purchasing insurance.

INTRODUCTION

The provision of trading emission rights under the Kyoto Protocol[1] to the United Nations Framework Convention on Climate Change will provide greenhouse gas (GHG) emitters a way to reduce costs of meeting emissions targets and will provide landowners the opportunity to reap financial gains from sequestering carbon and selling the rights to emit carbon. Non-permanence or reversibility of carbon sink projects is a major concern because between sequestering an actual ton of carbon in forests, and having that ton available to be used as an offset by a carbon emitter operating under a regulated carbon abatement program is the likelihood that the sequestered carbon may be emitted back into the atmosphere as a result of market (regulatory changes) as well as non- market (natural disasters like hurricanes or tornadoes) risks and uncertainties.

Landowners may be liable for repaying all or some of the proceeds received in the past for sequestering carbon and generating carbon credits when forests are damaged by natural calamities like hurricanes or tornadoes, which cause extensive mortality and subsequent emission of carbon dioxide from decomposing biomass. Carbon loss could impose financial penalties in an accounting scenario that holds carbon-credit producers liable for non-delivery within the contract period. These costs would be in addition to salvage costs and damage to timber which are likely to reduce future returns from timber sales. If the costs and penalties are too high, landowners, especially small and risk averse landowners, will simply avoid the carbon market.

These costs may become a serious deterrent to decision makers who are risk averse. Without some form of risk management or risk protection, landowners are not likely to be motivated to participate in carbon sequestration trading even though they recognize the potential of financial gains. There is a need, therefore, to document and analyze the impact of private insurance on a forest landowner's portfolio of strategies, given the risk of carbon loss due to hurricanes. Buying private insurance is gaining popularity as a tool (Cohen; de Figueiredo, Herzog and Reiner; Subak; Wong and Dutschke) to mitigate the financial consequences for participating landowners from carbon loss. An investment company or a large forest company may be able to tolerate the losses from a forest fire or hurricane, but for a small forest owner with a valuable 30-year old plantation the financial losses are enormous.

Insuring against financial losses due to hurricanes will help persuade landowners to participate in land management practices to sequester carbon. There are very few studies (Subak; Wong and Dutschke) that evaluate the role of insurance in creating the incentives for non-capped sources especially forest landowners to sequester and trade carbon in the face of various market and non-market risks and uncertainties that can lead to non-permanence. This analysis will focus on answering the following questions:

- Does purchasing private insurance impact the optimal portfolio strategies of a risk averse landowner?
- Does purchasing private insurance encourage greater landowner participation, especially for risk averse landowners?
- How do diversification of forestry investment locations and buying insurance compare in terms of reducing landowners' risk from forestry investments for sequestration and timber purposes?

The research evaluates incentives of an individual forest landowner for sequestering and trading carbon, given the risk of carbon loss from hurricanes, and an opportunity to reduce risks through insurance and diversification. The risk-return trade-off for a landowner who has a choice of buying insurance for protection against carbon loss in a hurricane risk prone region is analyzed against the risk-return trade off for a landowner who has the choice of diversifying landholdings into three regions of South Carolina. These regions are incongruent in terms of hurricane landfall probabilities and carbon sequestration rates. Optimal combinations of landholdings for carbon sequestration and trading and timber sale purposes are assessed for alternative levels of risk aversion. The potential trade-off is examined between planting in locations with higher exposure to hurricanes but higher rates of sequestration or in locations with lower exposure to hurricanes and lower rates of sequestration. Our framework is a step towards analyzing how risk management strategies can increase landowners' incentives to participate in carbon markets. The analysis will be limited to new forest plantation projects.

FOREST CARBON INSURANCE UNDER CATASTROPHIC RISK

Carbon insurance against catastrophic risks offers a cost-efficient tool for spreading risks across large groups of people and recovering damage costs (Wong and Dutschke). Like hail and fire insurance the traditional problems of moral hazard and adverse selection, which are a result of asymmetric information, have limited applicability to hurricane insurance. The occurrence of specific hazards is easily identified by the insurer as by the insured landowner, and the potential losses are easier to assess on a region-by-region basis (Goodwin and Smith, p. 34). Traditionally catastrophic risk insurance/aid in the US has been offered as part of the multiple peril crop insurance program (Hueth and Furtan; Goodwin and Smith). In the US, catastrophic risk insurance involves government subsidization because catastrophic events like hurricanes or floods are correlated across regions (Duncan and Myers; Wong and Dutschke). This might lead to very large losses which a private insurer might not be able to recover through pooling risks faced by all landowners (Skees and Barnett; Duncan and Myers). Rainfall and hail crop insurance is offered by private insurance companies (Hueth and Furtan; Goodwin and Smith) because these risks are not correlated across regions. Specialized forestry insurance against losses from natural hazards is offered in a few countries such as, New Zealand, Australia, Norway and Japan (Subak; Wong and Dutschke). Carbon insurance has not developed as a specialized risk management tool; however, the possibility of including land-based carbon offset credit trading under the Kyoto Protocol and the concerns over non-permanence of these credits might lead insurance companies to offer competitive carbon insurance.

The availability of reinsurance or the opportunity of spreading risk across uncorrelated risks might affect the supply of insurance, but would not affect insurance demand. We focus on the demand for insurance by landowners and assume that insurers are willing to offer actuarially fair insurance against loss of carbon credits due to hurricanes. For this paper it is assumed that insurers are able to use the law of large numbers for eliminating the aggregate risk by insuring different types of catastrophic risks across different geographic regions or by reinsuring with diversified reinsurance firms (Duncan and Myers).

BASIC OPTIMIZATION MODEL

Based on the model by Grover, Bosch and Prisley, the focus is on the state of South Carolina which is divided into three major sub-regions – coastal, piedmont and upland (Figure 1). The accounting and liability mechanism or carbon payment scheme considered is a Rental Approach of accounting with Full Landowner Liability (RAFL) which prescribes that carbon credits are rented on an annual basis instead of being sold. This system provides full credit at the time of sequestration in return for full liability if the sequestered carbon is later released. Under this system the liability resides with the activity host or the landowner so long as a rental contract is in place but reverts to the buyer/renter of credits when the rental contract expires (in one year). At the end of the rental agreement the buyer/renter incurs an emissions debit and is liable to either renew the carbon rental contract for another year or to find another way of meeting her emissions reduction obligations, and the host is released from further liability. If the carbon remains sequestered, the host/landowner could (a) renew the lease (b) lease the credit to another buyer/renter, (c) retain the credit for his/her own use, or (d) harvest the forest plantation for timber sale.

The problem of the landowner under the RAFL approach is to choose the optimal amount of land acquired in region(s), A_i at the beginning of the project period, i.e., at t =1, for the purpose of creating carbon credits and selling timber so as to maximize the certainty equivalent[2] (CE) of expected net present value of returns, x:

(1) $\underset{A_i}{Max}$ CE = Expected profits – Risk Premium

(2) $$\underset{A_i}{Max}\ \text{CE (x)} = \text{E(x)} - \frac{\lambda}{2}\sigma^2(x)$$

(3) Subject to: $$x = \sum_{i=1}^{n} Q_i$$

x refers to the expected net present value of returns from carbon credits and timber over the entire planning horizon, Q_i is the expected net present value of returns from carbon and timber from the first rotation, i is the number of regions under consideration, T is the terminal time period, r is the risk-free rate of time preference (assumed to be 5%), λ refers to Arrow-Pratt coefficient of absolute risk aversion; $\sigma^2(x)$ is the variance of returns, and $\frac{\lambda}{2}\sigma^2(x)$ is an expression for risk premium derived by Pratt (Pratt; Robison and Barry).

Q_i is defined as follows for the RAFL:

(4) $$Q_i = \left\{ \sum_{t=1}^{T} \frac{pB_{it} - py_{it}M_{it} + qy_{it}\overset{m}{K}_{it} - H_{it} - Z}{(1+r)^t} + \frac{qJ_{iTi}}{(1+r)^T} - \sum_{i=1}^{n} C_i \right\} A_i$$

B_{it} represents the volume of carbon credits per acre created in past periods plus the new credits created in the current period available for renting over the remainder of the project period for a constant (real) price *p*, M_{it} is the volume of credits lost per acre due to hurricanes in all past periods plus the credits lost in the current period. y_{it} is a binary random variable which takes on value 1 when there are one or more hurricanes in a given period and value 0 in years with no hurricanes, J_{iTi} is the volume of timber available for sale per acre after *Ti* (which is the rotation age in region *i*) years have elapsed from the year in which the forest was planted. Planting occurs at the beginning of the project or following a hurricane. Additional timber might be available for sale in years in which a hurricane strikes, represented by the estimated volume $\overset{m}{K}_{it}$ per acre. The timber is assumed to be sold at a price *q*, which is also assumed to be constant during the planning horizon. C_i represents the stand establishment cost per acre incurred at the initial time. H_i is the base monitoring and verification cost per year per acre and is incurred in both hurricane and non-hurricane years. N_i is the cost of monitoring and verification per acre in hurricane years, which is in addition to base monitoring cost. F_i is the site preparation cost per acre and is incurred in years following hurricanes which might result in the stand being harvested or destroyed at younger ages when the biomass in not merchantable. S_i is the cost of pre-commercial thinning per acre of land and is incurred when a hurricane(s) leads to partial destruction (between 20%-40%) of the forest stand. A_i represents the amount of land investment in the three regions. The rotation age *Ti* and A_i are choice variables for the landowner.

Hurricane Damage

Total carbon credits available for renting under the RAFL are defined as follows:

(5) $$B_{it} = R_{it} + B_{it-1}, B_{i0} = 0$$

R_{it} is the estimated quantity of incremental carbon credits per acre in a given year *t*.

M_{it} under the RAFL is defined as follows:

(6) $$M_{it} = \overset{m}{D}_{it} + M_{it-1}$$

$\overset{m}{D}_{it}$ is the cumulative quantity of carbon credits lost per acre from *m* hurricanes in a given year *t*, and is defined as follows:

(7) $$\overset{m}{D}_{it} = \sum_{m=1}^{m-1} \overset{m}{D}_{it} + \overset{m}{d}_{it}(1-ke)\left(\sum_{t} R_{it} - \sum_{m=1}^{m-1} \overset{m}{D}_{it}\right);\ \overset{m}{d}_{it},\ e = [0,1];\ \overset{0}{D}_{it} = 0,\ m = 0,1,2,3\ldots$$

The proportion of additional damage to accumulated carbon due to m^{th} hurricane in the current period is represented by the term $\overset{m}{d}_{it}$ and is same as the proportion of downed biomass. The term *e* represents the proportion of the carbon content that was prevented from being emitted due to timber that was converted into wood products after salvage of part of the downed wood following a hurricane. The proportion of carbon that remains sequestered over time in wood products and landfills over a period of 100 years were obtained from Birdsey (1996), who estimated the percentage of carbon remaining in harvested wood. *k* represents the proportion of downed forest biomass (timber) that is salvaged and converted into wood products.

For this research it is assumed that hurricane strike in a region in a given year *t* will lead to a random damage to the forest stand. Table 1 presents the average damages in the coast, piedmont and upland from hurricane HUGO, which was used to estimate the random damage proportions for the regions. Damage proportions for each of the regions were randomly generated from hurricane HUGO data (Table 1) in South Carolina using the software 'Best Fit' (Palisade Corporation, http://www.palisade.com/html/bestfit.asp). Damage proportions were assumed to be independent between regions and years.

Timber Harvest, Salvage and Rotation Age

J_{iTi} , the volume of timber available for sale per acre after *Ti* (which is the rotation age in region *i*) years have elapsed since the forest was planted initially or replanted following a hurricane is defined as follows:

$$(8) \qquad J_{iTi} = G_{it} - \sum_t y_{it} E_{it} \text{ , } E_{it} = \sum_{m=1}^{m} \overset{m}{d}_{it} G_{it}$$

E_{it} is the cumulative timber loss due to hurricanes up till period *t*. $\overset{m}{K}_{it}$ represents the quantity of sale of salvaged timber[3] from *m* hurricanes in each region per acre of land in years of hurricane strike and is defined as follows:

$$(9) \qquad \overset{m}{K}_{it} = \overset{m-1}{K}_{it} + k\,\overset{m}{d}_{it}\left(G_{it} - \sum_{m=1}^{m-1} \overset{m}{K}_{it} \right)$$

It is assumed that any hurricanes that strike prior to age 15 in coastal region, age 18 in piedmont region and age 21 in upland region do not leave any merchantable salvaged timber. The landowner is assumed to undertake carbon sequestration projects in the *i* regions under RAFL up to a maximum time of $T \geq max\ [Ti]$. *Ti* is the rotation age in region *i* and T, the planning horizon is assumed to be 100 years. The optimal rotation age in each region is that which maximizes the expected net present value of returns over a 100 year planning horizon (Grover, Bosch and Prisley). The model is designed to take account of the damage-salvage scenarios presented in Table 2 (Grover, Bosch and Prisley).

Insurance Model

Our insurance model is based on design of the existing crop insurance program in the U.S (Barnett and Coble; Goodwin and Smith; Hueth and Furtan). It is assumed that only losses of yield of carbon credits are insured. Also, only losses in yield resulting from hurricane events are insured. The level of yield coverage and the level of price coverage are chosen by the landowner.

It is assumed that insurance yield is based on an estimate of the potential yield of carbon credits per acre. We assume that φ_d is the coverage level chosen by the landowner and $0 \le \varphi_d \le 1$. The carbon credits are insured at the market price for these credits.

The yield guarantee per acre is equal to the estimated yield multiplied by the level of coverage chosen by the landowner. If landowner's actual yield is equal to or greater than the yield guarantee, no indemnity is paid. If the yield per acre is less than yield guarantee, the indemnity paid is equal to the yield difference times the indemnity price, which is market price of carbon credits. Indemnity is defined as follows:

(10) $$I_i = p[\varphi_d B_{it} - (B_{it} - y_{it} M_{it})]$$

It is assumed that the insurance company is able to offer actuarially fair insurance such that the insurance premium that a landowner pays in a given period *t* is equal to the expected indemnity payment:

(11) $$\pi_{id} = \sum_{m=1}^{m} \overset{m}{\mu}_{it} I_{it}$$

where, π_{id} is the insurance premium per unit of coverage level in region *i*, subscript *d* indicates demand, $\overset{m}{\mu}_{it}$ is the probability of *m* hurricanes in region *i* in year *t*. The expected net present value of income for a landowner who buys insurance in region *i* is given by:

(12) $$Q_i' = Q_i + \left\{ \sum_{t=1}^{T} \frac{I_i - \pi_{id}}{(1+r)^t} \right\} A_i$$

For our model it is assume that the landowner chooses 100% insurance coverage level, or $\varphi_d = 1$.

Hurricane Landfall Probability

Hurricane landfall occurrence is assumed to follow a Poisson distribution in all three regions (Parisi and Lund; Haight, Smith and Straka; Jagger, Niu and Elsner; Grover, Bosch and Prisley):

(13) $P(m) = \dfrac{e^{-\pi_{it}} \pi_{it}^{\ m}}{m!}$; E $(m) = \pi_{it}$; Var $(m) = \pi_{it}$

where, π_{it} is the average rate of hurricane arrival and $0 \leq m < +\infty$. π_{it} is estimated from historical North Atlantic Tropical Cyclone Tracks, 1851-2003, created by National Oceanic and Atmospheric Administration, Tropical Prediction Center/National Hurricane Center (http://hurricane.csc.noaa.gov/hurricanes/download.html). Historically the coast in the state of South Carolina has a 16% probability of getting hit by a hurricane in a given year, the piedmont has a 7% probability and the upland has a 3% likelihood of hurricane strike in a year. The historical hurricane landfall probabilities are input into @Risk for simulating random hurricane strikes in region(s) under consideration. Storms are assumed to occur independently of each other per time period but not spatially. Using the historical data on hurricane landfall in the state of South Carolina from 1889 – 1989 the historical correlation between probability of hurricane landfall in the coast and piedmont regions was estimated to be 0.629, between the piedmont and upland regions to be 0.641 and between the coast and upland regions to be 0.403.

Forest Biomass Yield and Carbon Conversion

This paper focuses on one predominant species of trees in the region of study, loblolly pine. The following timber yield function, which gives total volume per acre at a given period of time, was used (Chang; Amacher, Brazee, and Thomson):

(14) $G_{it}(t, SI, w) = e^{9.75 - \frac{34.01}{t^2} - \frac{3418.10}{tw} - \frac{740.82}{tSI} - \frac{1527.66}{SI^2}}$

t refers to stand age and w refers to planting density which is assumed to be 750 trees per acre in all three regions and SI refers to the site index. The site indices for the three regions obtained from the FIA data on loblolly pine in South Carolina for base age 25 were 68, 62 and 58 for the coast, piedmont and upland regions, respectively. It is assumed that the marginal increase in volume per acre becomes zero at age 35 for the coast, at age 38 for the piedmont and 41 for the upland (Personal Communication with Greg Amacher and Stephen Prisley, Department of Forestry, Virginia Tech).

The biomass is converted into carbon dioxide equivalents in a four-stage process. First, growing-stock volume is converted to total forest tree volume by multiplying by a biomass expansion factor of 1.408 (Birdsey, 1992) to account for the additional tree volume excluded from estimates of growing-stock volume: tops and branches, foliage, rough and rotten trees, small trees, standing dead trees, stump sections, roots, and bark. Second total tree volume in cubic feet is converted to carbon in pounds. One cubic foot of wood is assumed to be equal to 16.9 pounds of carbon (Birdsey, 1992). Third the carbon volume in pounds is converted into carbon volume in metric tons. Fourth, carbon volume is converted into carbon dioxide equivalents by multiplying carbon equivalents by 44/12 (the ratio of the molecular weight of carbon dioxide to carbon). These conversions are represented by a carbon conversion constant c, and the carbon conversion equations is as follows:

(15) $$R_{it} = c(G_{it} - G_{it-1})$$

Carbon Credit and Timber Price

It is assumed that price for temporary carbon credits has been market determined and given to the landowner. Price of temporary credits is likely to be much lower than GHG permits generated by permanent emissions reduction (e.g., reduction in fossil fuel usage). In order to analyze the sensitivity of landowner's decisions to different carbon credit (CO_2 equivalent) prices we consider carbon prices of $0.10 and $1 per sequestered ton of CO_2 equivalents per year.

Stumpage prices are reported net of logging and transportation costs. Based on prices available from Timber Mart South (http://www.tmart-south.com/tmart/) the average pulp wood (2004) prices are $6.53 per ton ($17.5/cord) and average timber price for the same period is $38.0 per ton ($285.9/ thousand board feet). We divided biomass into average proportions of timber and pulpwood by age for the three site indices 68, 62 and 58 at base age 25 (Grover, Bosch and Prisley). Timber prices may be affected following a hurricane (Prestemon and Holmes). Based on estimates presented by Prestemon and Holmes, we assume that hurricanes lead to a 30% decline in timber and pulpwood prices in hurricane years in all three regions and come back up to the level prior to the hurricane in the following year.

Site Preparation and Planting Cost

Site preparation cost on conventional sites or following a normal harvest is assumed to be $109.0 per hectare ($ 63.0 per acre) and site preparation cost following hurricanes is $189.0 per hectare ($ 76.0 per acre). The tree planting cost is assumed to be $114.0 per hectare ($ 46.0 per acre) on both conventional and hurricane affected sites. These costs are based on estimates provided by Straka et al. and are 2004 prices, obtained by using an average inflation rate of 2.68% for U.S. for the years 1990 – 2004.

Monitoring and Verification Cost

Monitoring and verification costs are lumped together and are assumed to be incurred every year on a per acre basis. Table 3 presents the cost of monitoring above ground carbon

(Grover, Bosch and Prisley) for a single measuring event for two different project types: contiguous and non-contiguous parcels (Mooney, Brown and Shoch).

Initial and Terminal Land Value

L_i represents per unit cost of acquiring land in each of the regions. The amount of land acquired in each of the regions is decided at the beginning of the project period. It is assumed that land prices remain constant during the investment period and that land is not bought or sold after the initial investment decision has been made. W_0 refers to the risk free initial wealth that the landowner has to purchase land in each region and is thus a constraint.

(16) $$\sum_{i=1}^{n} L_i A_i \leq W_0$$

L_i, which is the per unit price of land at the time of stand establishment, is estimated by the expected net present value of returns at the end of the 100-year planning horizon assuming the stand is planted in year 1 and replanted after harvest or hurricanes. It is assumed that the landowner has an initial risk free wealth of $500,000 and has the option of buying land in all three regions of the study area.

SIMULATION AND OPTIMIZATION MODEL

@Risk software offered by Palisade Corporation is used to generate simulation data on expected returns from forestry and carbon credit sales under different accounting and liability scenarios with and without insurance coverage using Monte Carlo simulations. The simulation data are used to estimate the variance-covariance matrix of returns between the three regions, the expected net present value of returns, the optimal rotation ages in three regions and land prices. These data are input into a Quadratic Programming model, which is solved using General Algebraic Modeling System (GAMS), to determine the optimal amount of land that the landowner will invest in the three regions under various scenarios. Equation (1), the objective function is maximized to determine the optimal amount of land A_i that the landowner invests in at the beginning of the planning horizon subject to the land constraint equation (16). The optimal amount of land is estimated for different levels of risk aversion for the forest landowner by parametrically changing the risk aversion coefficient λ. A range of risk aversion parameters is considered between zero for a risk neutral landowner to 80 for a highly risk averse landowner (McCarl and Spreen). These data are then used to develop the mean-variance efficient frontier for the landowner.

RESULTS AND DISCUSSION

Expected Net Present Value

Table 4 presents the expected net present value (NPV) of returns over a 100 year planning horizon for RAFL under two different simulation scenarios for individual study regions. Under $0.10 and $1/ton CO_2 equivalents/ year, the expected NPV is highest in the coast followed by upland and then piedmont under all scenarios except under insurance with a carbon price of $1/ton CO_2 equivalents/ year, where it is highest in the coast, followed by piedmont and then upland. The expected net present value of returns should remain the same with and without insurance because actuarially fair insurance is assumed and the insurance premium paid by the landowner is equal to the expected value of indemnity. The expected net present values that we are observing are either remaining the same or increasing, though not very significantly, in all the regions because of some randomness in our simulation model. The expected NPV also reflects the land value or the value at which the landowner can purchase land at the beginning of the planning horizon.

Variance of Expected Net Present Value

Table 5 presents the variance-covariance of expected net present value of returns in all three regions. For the scenario with \$1/ton CO_2 equivalents/year the variance in the coastal region is decreasing by more than 50% when the landowner buys insurance from \$637,744/acre to \$293,697/ acre. A similar trend can be seen in the variance of expected net present value in the piedmont and the upland. Under the scenario with \$0.10/ton CO_2 equivalents/year the variance in all three regions a declining but the decline is not as significant as the decline under \$1/ton CO_2 equivalents/year. With insurance the variance should decline almost to zero, however we do not seeing this under either of the scenarios because timber losses are not insured. Moreover, the decline in variance under \$0.10/ton CO_2 equivalents/year is less significant than the decline in variance under \$1/ton CO_2 equivalents/year because timber returns are outweighing carbon returns for lower carbon price and are thus the major source of variance in returns.

Optimal Land Investment

In terms of land investment the simulation results for RAFL at a carbon price of \$1/ton CO_2 equivalents and no insurance reveal that a risk neutral landowner invests in land only in the coast (165 acres, Table 6) and a risk averse landowner diversifies into all three regions, coast, piedmont and upland, with the highest level of investment in the coast. Hurricane risk is correlated across the three regions, with the correlation being the highest between piedmont and upland and with upland having the lowest hurricane strike probability. Since the expected NPV in upland is higher than expected NPV in piedmont (Table 4), and the hurricane risk is highest in the coast, as the level of risk aversion increases the landowner is motivated to shift a major portion of his/her investment to the upland followed by piedmont and then the coast. When the landowner has the option of buying insurance in all three regions the risk neutral investor still invests only in the coast and the risk averse buyer diversifies into all three regions. The risk averse landowner is still diversifying into all three regions because not all risk has been insured, timber losses which are not insured are still a source of risk for investment and a cause for large variance in returns. The overall amount of land investment for the risk averse landowner increased because with the availability of insurance the variance of expected net present value of returns declines thereby providing an incentive for the landowner to increase land investment. Specifically, the total land investment for the most risk averse landowner with a risk aversion coefficient of 0.0025 increased from 85 acres to 167 acres. The land investment for the risk neutral landowner declined marginally because of the marginal increase in expected net present value of returns, which also represent the value at which the landowner can purchase the land at the beginning of the planning horizon given the fixed initial investment budget.

The overall results in land investment are similar for a carbon price of \$0.10/ton CO_2 equivalents (Table 7); although the overall amount of land investment for the risk averse landowner is much lower as compared to the scenario with carbon price of \$1/ton CO_2 equivalents. Timber returns outweigh carbon returns at low carbon price and timber losses from hurricanes are not insured and are thus major source of variance in returns, providing a disincentive for high land investment for carbon and timber purposes in hurricane prone regions.

Mean-Variance Frontier

Figure 2 presents the mean variance (EV) frontier for the different levels of risk aversion with and without carbon insurance for the RAFL accounting approach with both carbon price scenarios. Availability of higher carbon price from \$0.10 to \$1/ton CO_2 equivalents shifts the EV frontier upward and to the left. The returns to the risky asset (land) have become more favorable, meaning that at any given level of risk (variance) the expected returns have increased.

Availability of carbon insurance also shifts the EV frontier further to the left. The returns to risk asset (land) have become less variable, meaning at any given level of expected returns the variance of returns has decreased.

CONCLUSION

Our results imply that landowners would receive high benefits from carbon sequestration contracts under positive carbon prices and availability of carbon insurance encourage higher ladn investment. From Table 6 and Table 7 it can be seen that a risk averse investor's land investment is higher with insurance under both $0.10 and $1/ton CO_2 equivalents/year. The investor's land investment is higher under $0.10 and $1/ton CO_2 equivalents/year without insurance due the lower value at which the land can be purchased under that scenario given the fixed investment budget. However with availability of insurance, the landowner is compensated for all carbon losses and the value of carbon credits is much higher with $1/ton CO_2 equivalents/year, thus providing incentive for higher land investment at high carbon price with insurance.

Our simulations reveal that the effect of hurricane risk on landowners' behavior depends on the variability of returns from carbon and timber and the ability of landowners to mitigate the losses from risk by diversifying the portfolio of land (region) investment or their ability to transfer the risk to an insurance company. A risk averse landowner has the choice of choosing a level of 'acceptable risk' corresponding to a given level of expected return and variance by diversifying holdings over more regions or by purchasing insurance for carbon losses. Availability of carbon insurance has the potential for providing incentive for higher land investment; this will especially be beneficial in bringing marginal or waste land into forest plantation use for the purpose of carbon sequestration. Availability of government subsidization or cost-share for carbon sequestration projects in forestry might increase landowner participation in such projects, especially for risk averse landowners who might not be able to spread or diversify risk of natural disaster, especially hurricanes or small landowners who might not have a very high initial risk-free wealth for investing in land for carbon sequestration purposes.

Our analysis here could be extended in several directions. Firstly, we assume damage to forests does not depend on forest age. Younger trees might have more strength to withstand damage from hurricanes and older trees might be more prone to breakage and damage. Secondly, we assume that the damage to forests is independent of the hurricane intensity, although the hurricane strike probabilities and damage proportions are generated randomly based on historical data. Further analysis could examine the effects of correlating hurricane damages across different regions. Finally, it would be interesting to see the behavior of landowners with the availability of timber insurance along with carbon insurance. Insuring timber losses from hurricanes in addition to insuring carbon losses will provide an incentive to invest in land only in the coastal region which has the highest sequestration rate which results in higher carbon and timber returns.

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Table 1: Hurricane Damage Proportions

Region	**Distribution**	**Mean Damage**
Coast	Log Logistic	24.5%
Piedmont	Uniform	24%
Upland	Inverse Gaussian	12%

Table 2: Hurricane Damage – Tree Salvage Scenarios

		DAMAGE		
		0-20%	**20-40%**	**40% +**
AGE	**0-8**	Do Nothing	Do Nothing	Re – Site Prep & Re – Planting
	8-Merchantable Age	Do Nothing	Pre-commercial Thin	Re – Site Prep & Re – Planting
	Merchantable Age +	Do Nothing	Salvage	Harvest, Site – Prep & Replanting

Table 3: Measurement and Verification Costs

	Mean Cost ($/ha)	**Mean Cost ($/acre)**
Contiguous Parcels – Above Ground Carbon		
No Risk Assumption	5.54	2.25
Risk Assumption	6.09	2.47
Non-contiguous Parcels – Above Ground Carbon		
No Risk Assumption	9.83	3.98
Risk Assumption	11.30	4.57

Source: Mooney et al., 2004

Table 4: RAFL: Expected Net Present Value of Returns (Per Acre)

	$1/ton CO2e/year			**$0.10/ton CO2e/year**		
	Coast	Piedmont	Upland	Coast	Piedmont	Upland
No Insurance	3,030	2,725	2,900	1,919	1,470	1,627
100% Insurance	3,333	3,027	2,947	1,949	1,497	1,630

Table 5: RAFL: Variance-Covariance of expected Net Present Value of Returns ($/Acre)

Scenario	**$1/ton CO2e/year**			**$0.10/ton CO2e/year**		
	No Insurance			**No Insurance**		
Region	**Coast**	**Piedmont**	**Upland**	**Coast**	**Piedmont**	**Upland**
Coast	637,744	9,343	5,855	432,386	4,641	11,982
Piedmont	9,343	441,403	17,331	4,641	207,127	2,591
Upland	5,855	17,331	84,623	11,982	2,591	45,558
	100% Insurance			**100% Insurance**		
	Coast	**Piedmont**	**Upland**	**Coast**	**Piedmont**	**Upland**
Coast	293,697	-3,151	891	398,735	4,033	11,005
Piedmont	-3,151	133,706	5,118	4,033	180,954	2,731
Upland	891	5,118	27,678	11,005	2,731	41,075

Table 6: RAFL - Optimal Land Investment for $1/ton CO2e/year (Acres)

	No Insurance			100% Insurance Coverage		
Risk Aversion Coefficient	**Coast**	**Piedmont**	**Upland**	**Coast**	**Piedmont**	**Upland**
0.0000	165	0	0	150	0	0
0.00025	9	10	66	14	24	129
0.00050	4	5	33	11	19	103
0.00075	3	3	22	7	13	68
0.00100	2	2	16	6	9	51
0.00150	1	2	11	4	6	34
0.00200	1	1	8	3	5	26
0.00300	1	1	5	2	3	17
0.00500	< 1 acre	< 1 acre	3	1	2	10
0.01000	< 1 acre	< 1 acre	2	1	1	5
0.01100	< 1 acre	< 1 acre	1	1	1	5
0.01250	< 1 acre	< 1 acre	1	< 1 acre	1	4
0.01500	< 1 acre	< 1 acre	1	< 1 acre	1	3
0.02500	< 1 acre	< 1 acre	1	< 1 acre	< 1 acre	2
0.05000	< 1 acre	< 1 acre	< 1 acre	< 1 acre	< 1 acre	1
0.10000	< 1 acre	< 1 acre	< 1 acre	< 1 acre	< 1 acre	1

Table 7: RAFL - Optimal Land Investment for $0.1/ton CO2e/year (Acres)

	No Insurance			100% Insurance Coverage		
Risk Aversion Coefficient	**Coast**	**Piedmont**	**Upland**	**Coast**	**Piedmont**	**Upland**
0.0000	261	0	0	257	0	0
0.00025	7	13	69	8	15	76
0.00050	3	7	34	4	8	38
0.00075	2	4	23	3	5	25
0.00100	2	3	17	2	4	19
0.00150	1	2	11	1	3	13
0.00200	1	2	9	1	2	10
0.00300	< 1 acre	1	6	1	1	6
0.00500	< 1 acre	1	3	< 1 acre	1	4
0.01000	< 1 acre	< 1 acre	2	< 1 acre	< 1 acre	2
0.01100	< 1 acre	< 1 acre	2	< 1 acre	< 1 acre	2
0.01250	< 1 acre	< 1 acre	1	< 1 acre	< 1 acre	2
0.01500	< 1 acre	< 1 acre	1	< 1 acre	< 1 acre	1
0.02500	< 1 acre	< 1 acre	1	< 1 acre	< 1 acre	1

Figure 1: Historical Hurricane Tracks S.C: 1850-2003

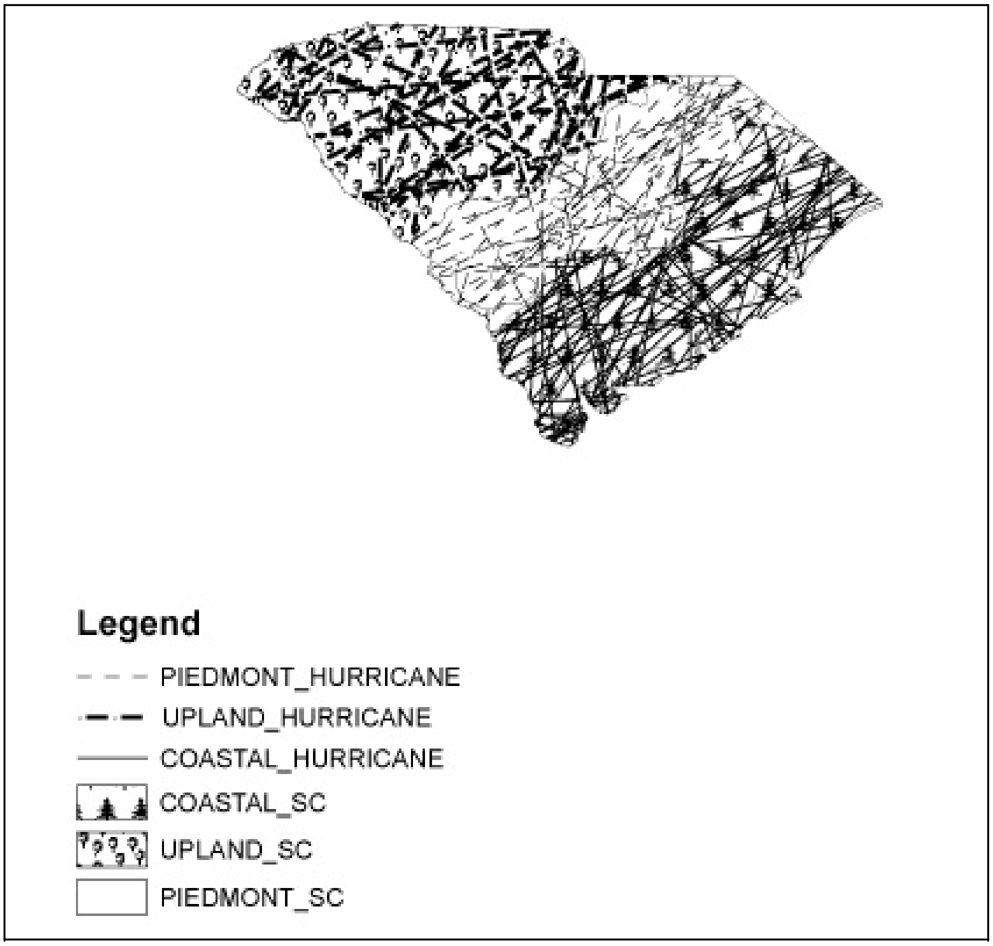
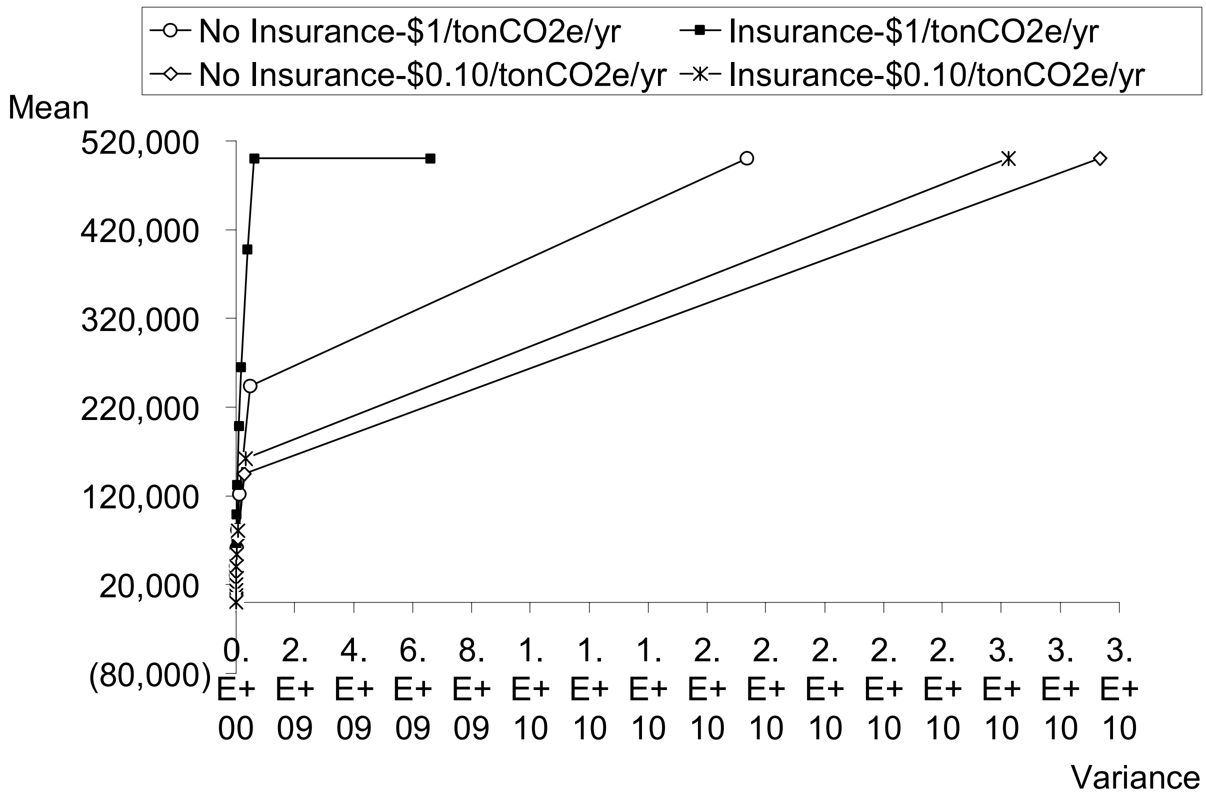


Figure 2: Mean-Variance (E-V) Frontier



Footnotes

[1] The Kyoto Protocol, agreed upon by 159 nations that attended the 3rd COP to the United Nations Convention on Climate Change in Kyoto, Japan in December of 1997, specifies the deadlines and specific levels of greenhouse gas reductions that signatory countries are to achieve. Overall, developed countries are to reduce greenhouse gas emissions by 5.2% between 2008 and 2012 as measured against their 1990 emission levels (http://www.emissionstrading.com/glossary.htm#K).

[2] Certainty equivalent of a risky investment is the certain or risk free return which yields the same utility as the risky investment.

[3] For the present research it is assumed that 15 % of the damaged timber is salvaged.