Economic Analysis of Carbon Sequestration under Risks in Forest management

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Abstract: Internalizing carbon value for forest landowners has the potential to increase carbon supply in forests and mitigate CO_2 in the atmosphere. In this study, we developed a modified Hartman model to investigate how payments of carbon offsets impact the optimal management of hardwood forests in Kentucky considering price uncertainty and the risk of catastrophic events such as fire or storm damage. An Expected Value (E-V) model was used to conduct a sensitivity analysis of landowner aversion to price uncertainty. Best management strategies were examined to achieve maximized financial return for landowners in the face of both catastrophic risk and price variability.

Key words: carbon sequestration, catastrophic events, E-V model, Kentucky forests, the modified Hartman model

1. Introduction

It is widely recognized that forests contribute greatly to the global carbon cycle by sequestering and storing carbon (Brand 1998). By sequestrating atmospheric CO_2, trees convert anthropogenic and natural greenhouse gases into biomass. CO_2 is released when the trees or their products decay (Creedy and Wurzbacher 2001). The increasing recognition of this role induced the emergence of carbon markets. In 1998, the Kyoto Protocol to the United Nations Framework Convention on Climate Change opened the opportunity to trade GHG emissions for increased sequestration of CO_2 by forests (Creedy and Wurzbacher 2001). Since then governments throughout the world have actively pursued policies to reduce their GHG emissions via permits, GHG offsets, and financial incentives (i.e., taxes, subsidies, etc.) (Binkley and Delcourt 1995).

Both voluntary and mandatory carbon markets have been established, such as the Chicago Climate Exchange (CCX), Regional Greenhouse Gas Initiative (RGGI), and California's Cap and Trade Program. Treating carbon as a forestry product has the potential to both help mitigate Greenhouse gas (GHG) emissions and increase forest landowners' financial return (Dwivedi et al. 2009). Thus, it seems crucial to know how carbon markets influence forest management. Carbon prices in existing markets can vary significantly. For example from $0.11 per metric ton in the Chicago Climate Exchange (CCX 2009) to $16.53 per metric ton in the carbon market run by the Mountain Association for Community and Economic Development (MACED) (Scott Shouse, personal communication, February 12, 2013). Estimates of the social cost of carbon can be even higher. For example, Tol (2008) did a meta-analysis of about 211 estimates of the social cost of carbon and found a mean of about $23 per metric ton.

Due to the long growth period for trees forest landowners have to face risk from catastrophic events that cause forest damage and uncertain future prices for forest products. Risk can come from forest fires, insect outbreaks, or severe weather. Take, for example, fire; the interval between fires in southern U.S.

forests may be as short as a year or as long as centuries. Catastrophic events are inevitable, and once they happen, they will bring financial loss for landowners and ecological damage to forests. From the view of both forest landowners and society, the consideration of risk from such events is important in management decisions.

Another factor that has to be considered due to the time it takes to forest maturity is the economic uncertainty of forest product markets. Unlike most agricultural products that have to be harvested annually, forests are harvested much less frequently. Uncertain prices for forest products make it more difficult to determine the financially optimal harvest age. Due to the unpredictable nature of the economy, forest landowners need to consider price uncertainty in management decisions. In order to do this, it is essential to have information on how price uncertainty will affect financial return.

Previous studies have investigated the issues related to the impacts of carbon sequestration, catastrophic risk, and price uncertainty on optimal forest management. However, there are only a few studies (Creamer et al. 2012; Stollery 2005) that combine the effects of catastrophic risk, carbon sequestration, and price uncertainty to investigate their joint effects. To our knowledge none have been done in the central hardwood region of the U.S. This paper uses a modified Hartman model to investigate the joint production of timber and carbon offsets considering both fire risk and uncertain prices for both timber and carbon. In addition, an Expected Value (E-V) model is employed to conduct a sensitivity analysis to different levels of landowner aversion to price uncertainty. LEV, optimal rotation age, sawtimber, and carbon supply are estimated.

2. Literature Review

The Faustmann model is one of the foundations in forest economics and has been used in numerous applications (Forboseh et al. 1996; Chang 1998). However, the Faustmann model's validity is questioned because it rests upon a series of over-simplified assumptions, which rarely, accord with reality (Grainger

1968; Buongiorno 2001). One of the most common criticisms is that the formula gives the value of forestland under deterministic assumptions regarding future growth and prices.

Several studies have analyzed the impact of catastrophic events like fire on the optimal rotation age using Faustmann (Routledge 1980; Reed 1984; Stainback and Alavalapati 2004). These studies have shown that catastrophic events generally decrease Land Expectation Value (LEV) and optimal rotation age. Routledge (1980) incorporated the likelihood of catastrophic events into the Faustmann model and the results showed that the size of errors from neglecting catastrophes depended on growth rates, hazard rates, and expected salvage portion. Reed (1984) extended the Faustmann model by adding fire risk as a premium to the discount rate. Englin, Boxall, and Hauer (2000) explored the joint effect of fire risk and non-timber amenities on timber harvesting. Their results showed that the inclusion of amenities in the model increased the rotation age at every level of fire risk. Stainback and Alavalapati (2004) using Reed's (1984) included carbon into the analysis. Their results showed that risk of catastrophic mortality decreased the land value and rotation age for all carbon prices.

Studies have also analyzed the impact of price uncertainty on forest management (Norstrom 1975; Haight and Smith 1991; Buongiorno 2001). Norstrom (1975) showed that on average, individual forest owners were better off with fluctuations in prices than with a constant price equal to the long-run average of actual prices. Brazee and Mendelsohn (1988) applied an asset sale model to estimate the optimal rotation age with unpredictable price fluctuations. Results showed that the optimal rotation age of harvest was slightly longer than the Faustmann rotation age with zero price variation. Buongiorno (2001) used a Markov decision process to determine the optimal rotation age. Both growth and stumpage prices were assumed to be stochastic and the results showed that the Faustmann formula was a special case of a Markov decision process model, in which the transition probabilities were unity or zero.

Finally, Susaeta, Alavalapati, and Carter (2009) developed an integrated Black-Scholes and modified Hartman model to analyze the impacts of price uncertainty on nonindustrial private forest management. Their results showed that increasing price volatility increases LEV slightly, which could offset the cost of performing silvicultural activities like thinning. Although their model examined the influence from both fire risk and price uncertainty, they did not consider these impacts under a carbon offset market.

3. Theoretical Model

To investigate the impact from catastrophic risk and price uncertainty, we combine the modified Hartman model with the E-V model to calculate the land expectation value and optimal rotation age under different market circumstances on even-aged forestland.

3.1 Modified Hartman Model

The standard Faustmann model is used to determine the land expectation value and optimal rotation age when there is no risk of catastrophic events, price uncertainty, or carbon offset markets. Equation (1) lists the general form of Faustmann model.

$$LEV(t) = \frac{P*Q(t)*e^{-rt}}{1-e^{-rt}} \quad (1)$$

Where *LEV (t)* is the land expectation value at time *t*, *P* is the price of forest products, Q_t is the volume of forest products as a function of time *t*, *r* is the real discount rate, and *t* is the stand age. Here *t* ranges from 0 to 80 years – the typical range for the optimal rotation age in the central hardwood region of the U.S. Following van Kooten et al. (1995), we use the Hartman model (1976) to include annual income from a standing forest from carbon sequestration benefits. The general form of Hartman model that includes carbon value is given in equation (2).

(2) $$LEV(t) = \frac{P_s * Q_s(t) * e^{-rt} + \sum_0^t P_c * (Q_c(t) - Q_c(t-1)) * e^{-rt} - P_c * Q_d(t) * e^{-rt}}{1 - e^{-rt}}$$

Where, P_s is price of timber products (sawtimber), $Q_s(t)$ is the volume of timber products, P_c is carbon price for both carbon sequestration and carbon emission, $Q_c(t)$ is the carbon sequestration increment in each year, and $Q_d(t)$ is the volume of carbon emissions.

During the time required for tree growth, forest landowners face catastrophic risks like fire, insect outbreak, or severe weather; which could influence the optimal rotation age. Reed (1984) modified the Faustmann model to incorporate these catastrophic risks. This model is presented in equation (3).

(3) $$LEV(t) = \frac{\lambda + r}{r * (1 - e^{-(\lambda + r) * t})} * \left(P_s * Q_s(t) * e^{-(\lambda + r) * t}\right)$$

Where λ is the probability of a catastrophic event each year. We follow Stainback and Alavalapati (2004) to include both carbon and catastrophic risk in the Hartman model modified along the lines of Reed (1984) as represented in equations (4) – (8).

(4) $$\theta = \frac{\lambda + r}{r * (1 - e^{-(\lambda + r) * t})}$$

Where θ discounts future rotations.

(5) $$f(t) = P_s * Q_s(t) * e^{-(\lambda + r) * t}$$

(6) $$g(t) = \sum_{t=1}^{T} (P_c * (Q_c(t) - Q_c(t-1)) * e^{-(\lambda + r) * t})$$

(7) $$h(t) = P_c * Q_d(t) * e^{-(\lambda + r) * t}$$

(8) $$i(t) = P_c * Q_c(t) * e^{-(\lambda + r) * t}$$

The discounted timber value *f(t)*, the discounted carbon benefits *g(t)*, the value of carbon emissions from decay *h(t)*, and the value of carbon emission from fire *i(t)* are expressed in equations (5), (6), (7), and (8) respectively.

Here $Q_d(t)$ is carbon emissions from decay of timber products when there is a catastrophic event.

Combining equations (4)-(8) LEV can be calculated as shown in equation (9).

(9) $$LEV(t) = \theta * (f(t) + g(t) - h\ (t))$$

3.2 E-V Model

The underlying assumption of mean variance theory involves people's attitudes towards risk: risk averse is the reluctance of a person to accept a bargain with a lower but certain payoff; risk seeking is the willingness to take a risk to seek high payoff, yet with a chance of losing value; risk neutral is the attitude of indifference towards uncertainty and certainty. The aforementioned theory dictates the selection of the E-V model: it provides the interaction of price movement with different attitudes toward price variability. The application of the E-V model helps us to investigate whether price uncertainty affects landowners' decisions based on historical price trends, and it also reveals the sensitivity of these impacts to different levels of aversion to price uncertainty.

Essentially, mean variance uses the average value minus the penalty for price uncertainty to represent the value that includes aversion to price uncertainty. Under this assumption, the E-V model for price uncertainty is represented in equation (10):

(10) $$\mathrm{PR} - \Phi * \mathrm{VPR}$$

Where *PR* is the profit, *Φ* is the aversion coefficient, and *VPR* is the variance of profit. Specifically, the resultant formula used to estimate the aversion coefficient is in equation (11) (Dillon, 1992).

(11) $$\Phi = 2\mathrm{Z_a}/\mathrm{S_y}$$

Where Z_a is the standardized normal Z value for a level of significance and S_y is the standard deviation of expected value for the non-aversion case.

Both sawtimber and carbon price uncertainty will cause variation in LEV. In order to estimate the variance of LEV, we calculate the LEV under all combinations of sawtimber and carbon price. Each LEV contains the financial return from stand age of 1 to 80. Thereafter, the average LEV, variance, and standard deviation of all price combinations for each stand age are estimated. Furthermore, price uncertainty aversion parameters for each stand age are calculated using equation (11). Equation (12) represents the adjusted LEV at each stand age.

$$LEV(t) = MLEV(t) - \Phi(t) * VLEV(t) \quad (12)$$

Where $LEV(t)$ is the adjusted LEV reflecting price uncertainty with respect to stand age, $MLEV(t)$ is the mean LEV with respect to stand age, $\Phi(t)$ is the aversion coefficient with respect to stand age, and $VLEV(t)$ is the variance of LEV with respect to stand age. We model price uncertainty aversion parameters from 50% (risk neutral) to 95% with 5% increments.

4. Data

4.1 Growth and Yield Data

The U.S. Department of Agriculture (USDA) Forest Service conducted research for more than 20 years to measure the growth and yield of hardwoods in the Central States (Kentucky, Ohio, Missouri and Iowa). Based on this research, Gingrich (1971) developed growth and yield tables of sawtimber and pulpwood from age 20 to age 80 with 10-year intervals according to stand characteristics.

The yield data from Gingrich (1971) was fitted using nonlinear regression estimated by Stata using equation (13):

$$Q(t) = a * t^b * e^{-ct} \quad (13)$$

Where Q is the volume of sawtimber or pulpwood, t is stand age, and a, b, c are parameters to be estimated. Figures 1 and 2 show the original and fitted yield data of sawtimber and pulpwood respectively. The adjusted R^2 [1]is high, which means the estimated parameters predict realistic timber yields. The merchantable volume was calculated by adding the volume of sawtimber and pulpwood together. The ratio of above ground tree biomass to merchantable volume for hardwoods in the south central area of the U.S. was assumed to be 2.12 (Birdsey 1996).

4.2 Carbon Market

The total aboveground tree biomass consists of sawtimber, pulpwood, and residue. In terms of carbon markets, carbon sequestration is calculated from the volume of total aboveground tree biomass. There are two sources of carbon emissions: one involves the carbon emitted at harvest from decay of forest products; the other is carbon emissions caused by catastrophic events such as fire. Carbon emissions of decay are estimated from volume of sawtimber[2] while carbon emissions from catastrophic events are estimated from the volume of the total aboveground tree biomass.

The amount of carbon sequestration was estimated by multiplying the total aboveground tree biomass by the conversion factor 19.82 to obtain carbon in pounds (Birdsey 1996). Sequestered carbon was converted into carbon in metric tons and then was multiplied by 3.67 to convert it to carbon dioxide

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[1] The adjusted R^2s are showed in Graph1 and 2.

[2] Pulpwood markets are very limited throughout much of Kentucky (Catron et al. 2013) thus it was assumed that pulpwood volume is used for woodenergy. Carbon emissions from pulpwood and residue is not included because they would be offset by the reduction of carbon emissions due to avoided fossil fuel combustion.

equivalents.

Carbon emitted from decay of sawtimber was modeled based on a half-life decay function. Here the half-life is assumed to be 100 years for sawtimber (Dwivedi et al. 2012). This means that half of the carbon stored in sawtimber will be released in the atmosphere in 100 years after harvest. The decay function is given in equation (14):

(14) $$Q_{\mathrm{i}}(t) = Q_i * e^{-\mu * t}$$

Where Q_d *(t)* is the current quantity of sawtimber at age *t* that accounts for carbon emission from decay, Q_i is the initial quantity, μ is the half-life decay parameter, and *t* is stand age.

In the base scenario (*sawtimber only* scenario), sawtimber is the only product from which landowners can earn income. In the carbon market scenario, we assume that carbon payments start after a baseline determined by the optimal rotation age. The landowner only gets paid for carbon sequestration that would occur in addition to that which would have occurred without carbon offset payments.

4.3 Price Data

Timber prices were taken from Timber Market South. The dataset included quarterly stumpage prices of sawtimber in Kentucky from the second quarter in 1980 to the second quarter in 1994 for a total of 57 quarters. Prices were converted to 2013 dollars using the Consumer Price Index (CPI) provided by the U.S. Bureau of Labor Statistics (2014). It can be seen, in Figure 3, that generally the price tends to increase over time but there does not appear to be any particular seasonal trend. Thus annual data is used (see Figure 3). The average of sawtimber price is $18.83 per green ton and its variance is 26.42. Since the pulpwood market is limited in Kentucky (Catron et al. 2013), it is assumed that pulpwood is used for woodenergy.

Carbon price is estimated from the trade price of carbon from the Chicago Climate Exchange. The Chicago Climate Exchange is the world's first and North American's only voluntary, legally binding integrated trading system to reduce emissions of all six major greenhouse gases (GHGs), with offset projects worldwide (CCX 2009). Carbon prices were relatively low around 2003 when this project started and around 2010 when the project closed. The carbon price data is daily trade data from 2003 to 2011, which is compressed to annual data and is deflated to 2013 dollars using the CPI. The adjusted carbon price is presented in Figure 4. Carbon price is volatile for the whole period, especially after 2008 when the economy was depressed. The average price of carbon is $2.34 per metric ton, and the variance is 3.16.

5. Results

We analyzed two market scenarios (sawtimber only, and sawtimber and carbon) in order to investigate the impact of a carbon market in the face of risk and price uncertainty. In the first market scenario, only sawtimber was considered as a forest product; in the second market scenario, carbon was also included as a forest product. The individual and joint influences of catastrophic risk and price uncertainty is demonstrated through the results of adjusted LEV, optimal rotation age, sawtimber supply, and carbon supply.

5.1 Sawtimber Only Scenario

When sawtimber is treated as the only forest product, the adjusted LEV is reduced under the circumstances of catastrophic risk. Adjusted LEV without catastrophic risk is always higher than the adjusted LEV with risk for every level of aversion to price uncertainty (Figure 5). The optimal rotation age is shortened by fire risk and this impact is the same for every level of aversion (Figure 6).

In face of price uncertainty, the adjusted LEV decreases as the level of aversion to price uncertainty increases. The decreasing rates of adjusted LEV show high similarity between cases without risk and with risk. When the level of price uncertainty aversion increases from 50% to 95%, the adjusted LEV decreases by nearly 90%. Also, adjusted LEV is decreasing at an increasing rate in general as the level of aversion to price uncertainty increases. For example, adjusted LEV without fire risk decreases by 8.8% when level of aversion to price uncertainty increases from 50% to 55% and decreases by 11.1% when level of aversion to price uncertainty increases from 65% to 70%. Adjusted LEV shows similar but larger extend impact with fire risk. Correspondingly, optimal rotation age with fire risk declines. However, the optimal rotation age does not change under different levels of aversion to price uncertainty without fire risk.

5.2 Carbon Market Scenario

When carbon offset payments are also considered in the analysis as a forest product, the adjusted LEV will still decline under increasing risk of catastrophic loss. The adjusted LEV without catastrophic risk ranges from two to three times higher than the adjusted LEV with catastrophic risk (Figure 5). And the optimal rotation age without risk is 5 to 7 years longer than with risk (Figure 6). Correspondingly, the sawtimber annual supply decreases by 0.11 to 0.13 green tons/acre when risk of catastrophic loss is considered (Figure 7). Finally, the carbon supply with risk is 10.66 to 14.67 metric tons/acre (Figure 8) less than the case without risk.

With an increase in aversion to price uncertainty, the adjusted LEV decreases substantially. For example, when the level of aversion to price uncertainty increases from 50% to 95%, the adjusted LEV decreases by around 80%. In addition, the optimal rotation age increases with the increase of aversion to price uncertainty. Without risk of catastrophic loss, the optimal rotation age starts to change when aversion to price uncertainty reaches 85%. With risk, the optimal rotation age starts to change when aversion to price uncertainty reaches 75%. Correspondingly, the sawtimber annual supply and carbon total supply follow similar trends.

In the carbon market scenario, the adjusted LEV in carbon scenario is always higher than the one in sawtimber only scenario higher and it is also decreasing with respect to fire risk and level of aversion to price uncertainty. The impact of fire risk is smaller compared with sawtimber only scenario, since the decreasing of LEV due to the influence is smaller. In terms of the impact of aversion to price uncertainty, adjusted LEV decreases at an increasing rate, too. But, the decreasing rate is smaller than the one in sawtimber only scenario in general. For example, the adjusted LEV without fire risk decreases by 10.2% in carbon market scenario and decreased by 8.3% in sawtimber only scenario when level of aversion to price uncertainty increases from 70% to 75%. The optimal rotation age is longer than sawtimber only scenario as we expected, since carbon payment is an incentive to delay harvesting. However, optimal rotation age shows increasing trend as level of aversion to price uncertainty increases: optimal rotation age without fire risk increases from 64 years to 67 years; optimal rotation age with fire risk increases from 62 years to 65 years.

6. Conclusion

This study shows the influence of risk of catastrophic mortality, carbon offset payments and price uncertainty on LEV, optimal rotation age, and stand supply of sawtimber and carbon. It is shown that risk of catastrophic loss and price uncertainty are important factors that affect market decisions, financial return to landowners, and social benefits. Thus it is important to understand landowner aversion to price uncertainty and risk into account in economic analyses of carbon offset markets. Moreover, landowner aversion to price uncertainty substantially influences the impact of price volatility. Both risk and aversion to price uncertainty decrease the land expectation value. The optimal rotation age is shorter with the risk of catastrophic mortality. However, price uncertainty does not change the optimal rotation age when sawtimber is the only forest product.

When carbon offset payments are considered, both the land expectation value and optimal rotation age increase as expected. However carbon offset payments reduce the impacts of fire risk and price uncertainty, and the effect is expressed in adjusted LEV and optimal rotation age. Landowners with higher aversion to price uncertainty expect to have lower reduction in adjusted LEV if carbon payment is included. If only sawtimber is sold, landowners with higher aversion to price uncertainty tend to harvest much earlier. However, if both sawtimber and carbon are considered as forestry products, landowners with higher aversion to price uncertainty tend to harvest slightly later. Thus in designing carbon market offset programs it would be advantageous to consider how landowners respond to price volatility and the risk of catastrophic mortality events such as fire.

There are several avenues for future research. First, other harvesting and management scenarios can be considered such as selective harvesting , thinnings, and other silvicultural prescriptions. Second, changing market conditions from one harvesting period to another could be modeled. Finally, other forest types and regions can be investigated.

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8. Figures

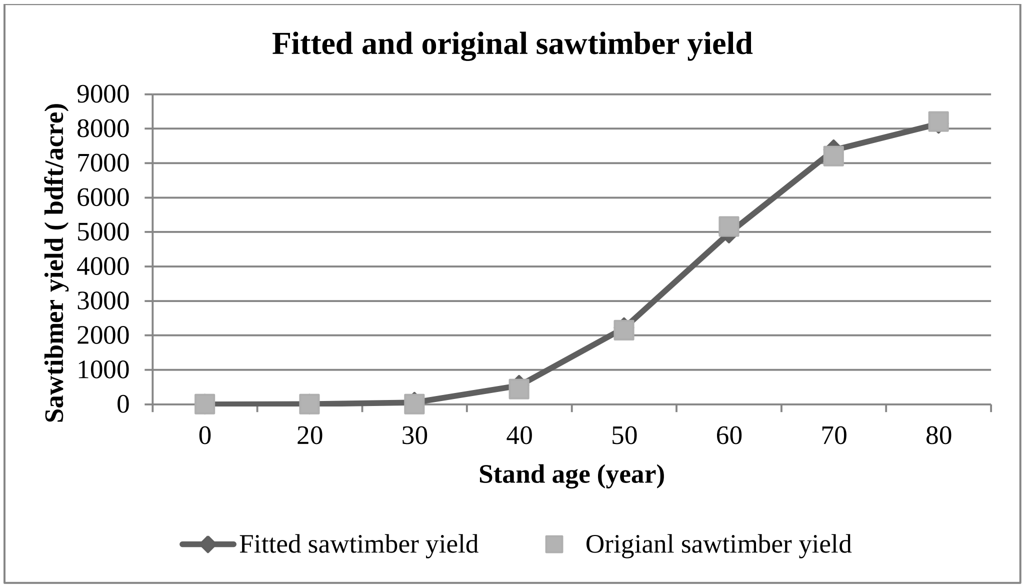

Figure 1. Comparison of original and fitted yield data for sawtimber (bdft) Note: The estimated parameters a, b, and c for fitted sawtimber yield is 5.14E-18, 14.49375, and 0.1837197. The R^2 for regression is 0.9983 and adjusted R^2 is 0.9974.

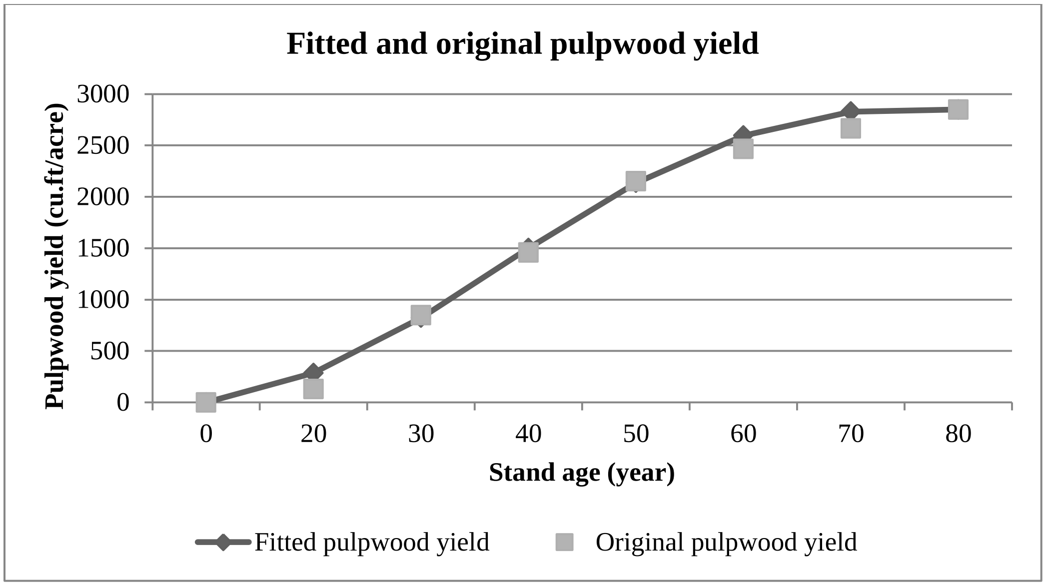

Figure 2. Comparison of original and fitted yield data for pulpwood (cuft). Note: The estimated parameters a, b, and c for fitted pulpwood yield is 0.0076, 3.856281, and 0.050801. The R^2 for regression is 0.9983 and adjusted R^2 is 0.9974.

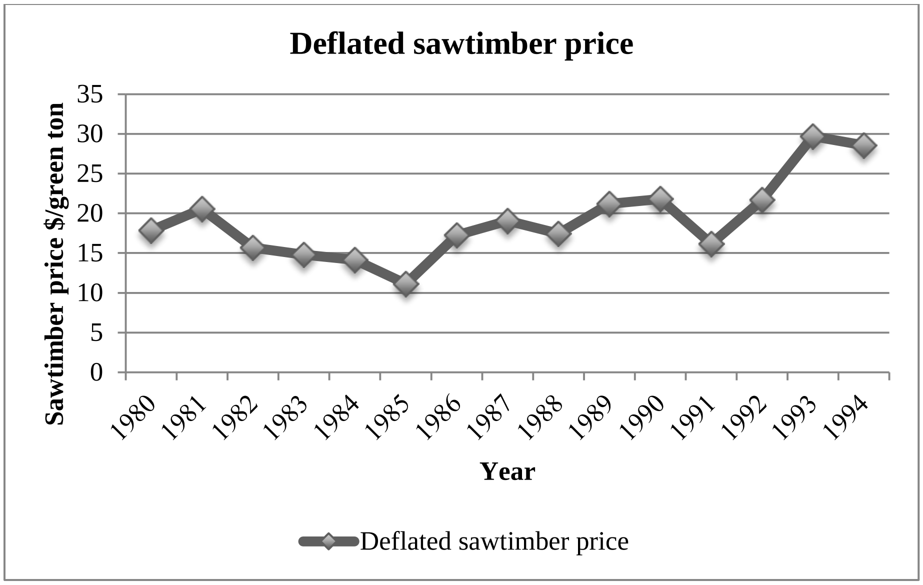

Figure 3. Annual deflated sawtimber price ($/green ton) from 1980 to 1994.

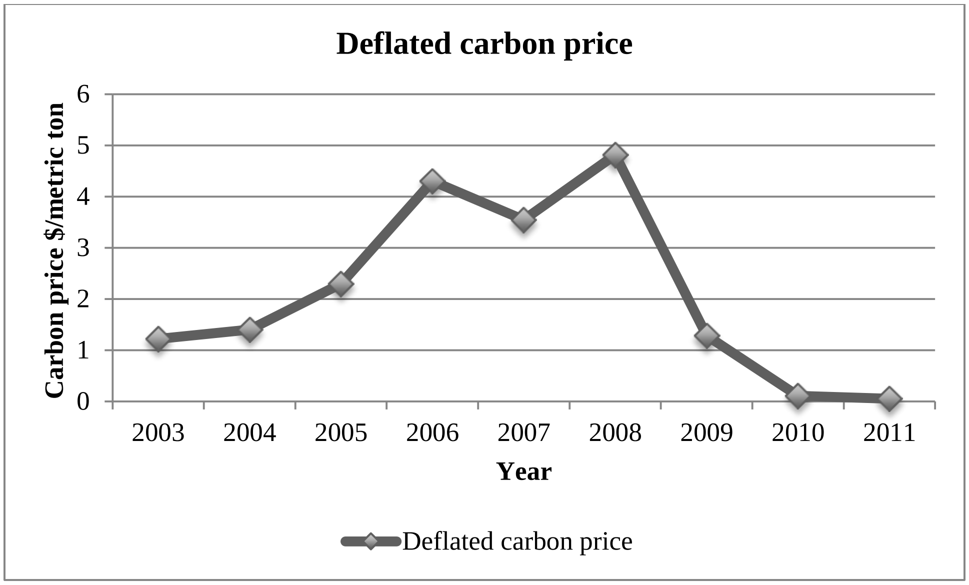

Figure 4. Annual deflated carbon price ($/metric ton) from 2003 to 2011.

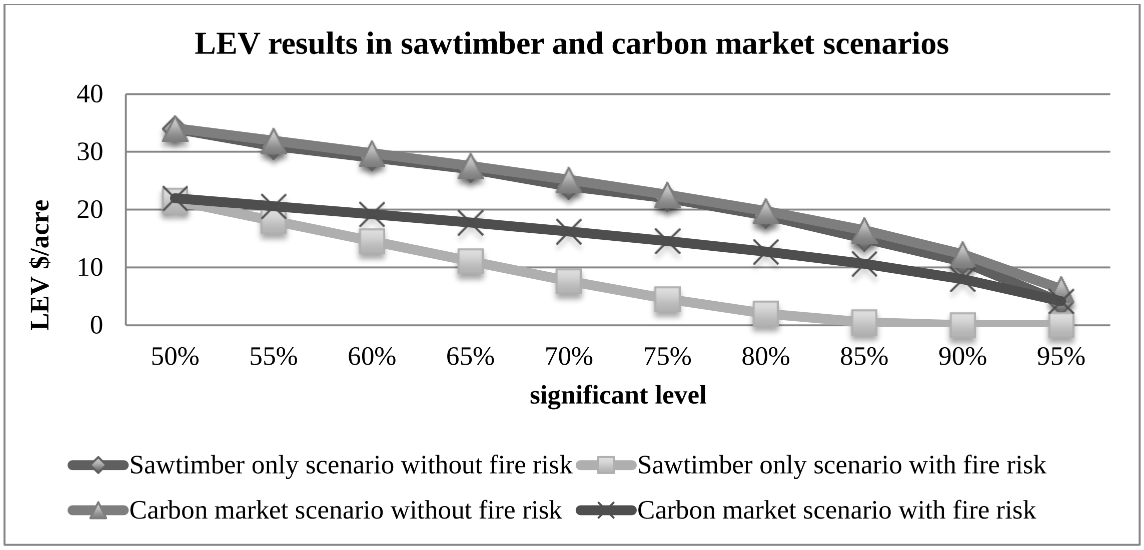

Figure 5. Land expectation value results in different scenarios ($/acre). "Without catastrophic risk" indicates the situation where catastrophic risk is not considered; "With catastrophic risk" indicates the situation where catastrophic risk is considered. "Sawtimber only scenario" represents the situation where sawtimber is treated as the only forest product in the market; "carbon market scenario" represents the scenario where carbon is also a forest product.

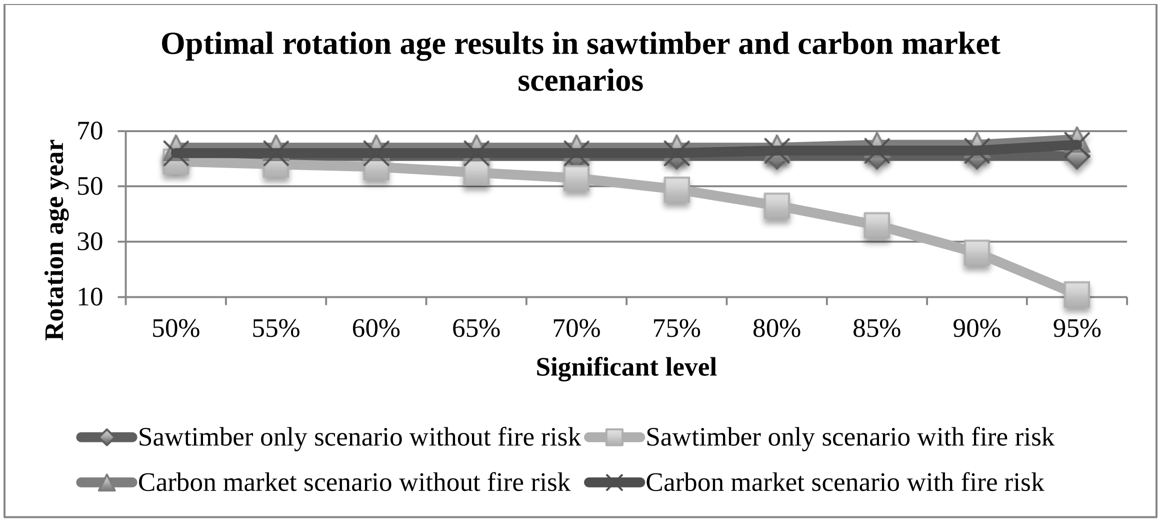

Figure 6. Optimal rotation age results in different scenarios. “Without catastrophic risk” indicates the situation where catastrophic risk is not considered; “With catastrophic risk” indicates the situation where catastrophic risk is considered. “Sawtimber only scenario” represents the situation where sawtimber is treated as the only forest product in the market; “carbon market scenario” represents the scenario where carbon is also a forest product