A Real Options Method for Estimating the Adoption Potential of Forestry and Agroforestry Systems on Private Lands in the Lower Mississippi Alluvial Valley, USA

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The Lower Mississippi River Alluvial Valley (LMAV), once was the largest forested bottomland area in the continental United States, but has undergone widespread loss of forest through conversion to farmland. Restoration of forest functions and values has been a key conservation goal in the LMAV since the 1970s. This study utilizes a partial differential real options method to determine the optimal switching price and return thresholds between agriculture and forestry and agriculture and agroforestry systems for specific marginal land types in the LMAV. A good land manager will value practices that give him/her the option to change or postpone decisions in order to adapt to changing conditions. Real options techniques value flexibility under variable conditions, known as option value, whereas traditional cost-benefit methods (NPV, SEV, etc.) assume deterministic returns and that farmers' decisions will not change in the future. Loss of option value incurred by switching from agriculture to forestry or agroforestry may partially explain adoption rates that are lower than predicted by cost-benefit methods. The price conditions under which farmers are likely to adopt forestry/agroforestry are calculated and compared to empirical evidence from government forestry incentive programs. Agroforestry and forestry systems were shown have potential for adoption on the most marginal lands in the LMAV, but are not likely to be adopted on soils of average productivity. Easement payments or incentive payment programs such as payments for ecosystem services would be needed to encourage adoption.

Keywords: real options, agroforestry, adoption, alley cropping

Introduction

The Lower Mississippi River Alluvial Valley (LMAV), a geographical region encompassing the historical floodplain of the Mississippi River below the convergence of the Ohio River (**¡Error! No se encuentra el origen de la referencia.**), once was the largest forested bottomland area in the continental United States, but has since undergone widespread loss of forest through conversion to farmland (Stanturf, Schweitzer, & Gardiner, 1998). Restoration of forest functions and values has been a key conservation goal in the LMAV since the 1970s.

Some programs, such as the Wetlands Reserve Program (WRP) have encouraged adoption of forestry systems on marginal farmlands (Gardiner & Oliver, 2005; King, Twedt, & Wilson, 2006), but public and non-profit agencies hope more land will be reforested. Agroforestry and production forestry systems that provide income to farmers might potentially be adopted on land that is less marginal. Therefore, there is a need for a better understanding of the economic choices landowners make, and which systems have the greatest economic potential for farmers.

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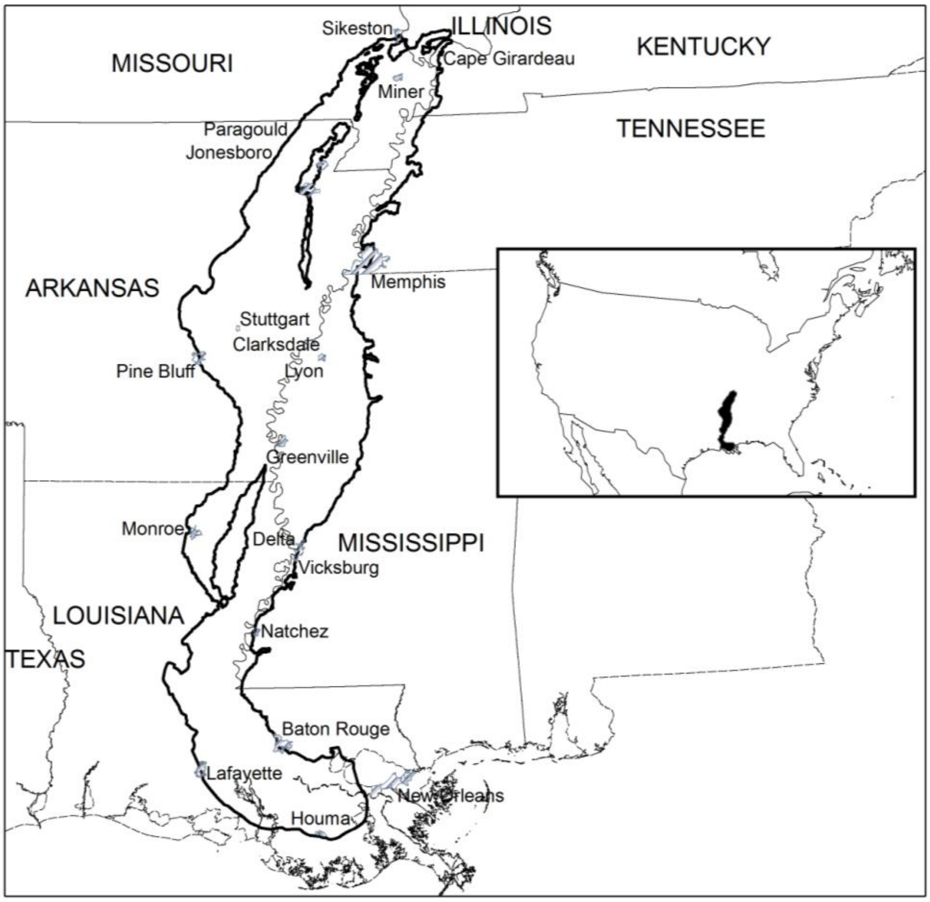

Figure 1. Geographic extent of the Lower Mississippi Alluvial Valley (LMAV) (LMVJV, 2002)

In general, estimating expected returns can help anticipate which systems are the most profitable and thus the most likely to be adopted by private landowners, who must make money to stay in business. However, farmers may also value other financial aspects of systems. A good land manager will value practices that give him/her the option to change or postpone decisions in order to adapt to changing conditions. Real options (RO) techniques place value on flexibility, as opposed to traditional cash-flow (NPV, SEV) methods which assume a deterministic return and a "locked-in" decision. We utilized a real options simulation with a stochastic model of returns to determine which forestry and agroforestry systems can compete with agriculture on marginal and average lands in the LMAV.

Materials and Methods

Real options (RO) analyses are based upon the Bellman equation, which states that decision-makers choose a management regime to maximize the sum of the present and discounted expected future payouts. For an infinite-horizon model, the Bellman equation is (Miranda & Fackler, 2002):

$$V(s) = \max_{x \in X} \left\{ f(s,x) + \delta \cdot E_{\varepsilon} \left[V\left(g(s,x,\varepsilon) \right) \right] \right\},$$

where $V(s)$ is the value function, $f(s,x)$ is the payout or reward given by making decision x under state s, $\delta = \dfrac{1}{1+\rho}$ is the discount factor (where ρ is the discount rate), and $E[\cdot]$ is the expectation operator. $g(\cdot)$ is the transition function from states and actions and some shock epsilon (variability, risk) one year to states in the next year. The key difference between the Bellman equation and cash-flow counterparts such as net present value (NPV) and soil expectation value (SEV) is the recursive nature of the decision-making process. It assumes that decisions made in one year can also be put off until the next. This is the flexibility we seek to model.

Dichotomous choice: Afforestation/deforestation

RO modeling has become an important part of forest economics in the past decade. Most importantly, RO has been used to estimate optimal timber harvest rotations and thinning regimes under stochastic prices (Haight & Holmes, 1991; Plantinga, 1998). RO provides insight into the optimal timber rotation because harvesting is a decision that can generally be put off until the future if conditions are not ideal; it is a flexible decision.

Another flexible decision relating to forestry is the decision to afforest or reforest. Assuming that land is currently used for agriculture, a landowner may easily put off the decision to afforest and continue farming until the following year. Behan, McQuinn, and Roche (2006) and Wiemer and Behan (2004) showed that showed that it is optimal for a farmer to wait longer to afforest under RO than under standard discounted cash-flow assumptions. This is because of the barrier to entering forestry in terms of establishment costs, and also because of the irreversibility of the decision to switch to forestry.

Although the decision to switch to forestry has been modeled as irreversible, we know that this is not necessarily the case. In fact, many forests are deforested for conversion to agriculture. Forest conversion to agriculture also involves costs that create a barrier to shifting to agriculture. We therefore view the decisions to switch from agriculture to forestry (or agroforestry) and from forestry (or agroforestry) to conventional agriculture as a dichotomy of choices that allows switching from one land use to another, and switching back: the adoption and disadoption choices. Forestry decisions have not been modeled in this way in the published literature

Solving the Bellman equation

One way to solve for the Bellman equation, and thus determine the optimal regime for each state, $x(s)$, is to use a partial differential collocation method (Miranda & Fackler, 2002). $V(s)$ is approximated by a set of known basis functions ϕ such that

$$V(s) \approx \sum_{j=1}^{n} c_j \phi_j(s),$$

where c_j is the unknown coefficient for basis function ϕ_j, which we have chosen to be linear. The c_j coefficients are estimated to solve the Bellman equation at n nodes in the state space S. Let $i=1,\ldots,n$ index the nodes and $j=1,\ldots,n$ index the basis functions and their respective coefficients. By having n nodes and n basis function coefficients, we create a system with n equations and n unknowns (Miranda & Fackler, 2002):

$$\sum_{j=1}^{n} c_j \phi_j(s_i) \approx \max_{x \in X(s_i)} \left\{ f(s_i, x) + \delta \cdot E_\varepsilon \left[\sum_{j=1}^{n} c_j \phi_j \left(g(s_i, x, \varepsilon) \right) \right] \right\} \forall i.$$

This can be solved using Newton's method (Miranda & Fackler, 2002).

In order to estimate the value of the expectation within $v_i(c)$, the distribution of the stochastic shock ε is discretized into K shocks ε_k, each with weight w_k (Miranda & Fackler, 2002).

Operationalizing the PDE collocation method

We utilized the discrete-time dynamic programming solver for MATLAB dpsolve.m, designed by Miranda and Fackler (1997), to solve the Bellman equation in the manner explained above.

In order to solve this PDE collocation problem for the agriculture versus forestry optimal switching problem, we must define the state space, S, the action set, X, the state transition function, g(·) and the reward function, f(·). Agriculture was modeled as yearly net returns (gross revenues minus costs excluding land rental and management) per acre. Forestry was modeled as net returns for a given year in the rotation.

State variables

There are three state variables in the model. In practice the analyst must condense state variables into as few as reasonably possible to allow computational tractability. First, the yearly net returns to agriculture per hectare was a state variable, represented by s^{AG}. s^{AG} was modeled as a mean reverting variable, with mean and standard deviation based on empirical data from the LMAV (Frey, 2009).

The second state variable is timber stumpage price or pecan (*Carya illinoinensis*) nut price, represented by s^{TIMB} or s^{NUT}. Growth and yield of timber were modeled deterministically. Even though growth in any given year may vary because of weather variability, over a number of years yield should even out to a relatively predictable value for a given site. In order to limit the number of state variables, pulpwood and sawtimber price are modeled together. s^{TIMB} represents pulpwood price per ton. To estimate sawtimber price, then, we multiply by the ratio of the mean sawtimber price to the mean pulpwood price from the mean reversion model. In the case of species that might have sawtimber prices that tend to be lower or higher than the mixed hardwood sawtimber price, we include an adjustment factor.

s^{TIMB} was modeled as a mean-reverting variable, with mean and standard deviation based on annual pulpwood prices from the Louisiana Quarterly Report of Forest Products for the years 1991 to 2007 (Frey, 2009). National prices for pecan were obtained from the USDA National Agricultural Statistics Service's Noncitrus Fruits and Nuts Summary .

The final state variable is land condition/stand age. This is a discrete variable, s^{SA}, ranging from 0 to the maximum allowable stand age. If s^{SA} is 0, the land is in agriculture. If s^{SA} is 1, this represents the beginning of the first year of a stand of trees, whether it is forestry or agroforestry.

Decision variable

The decision variable x, can be 0, 1 or 2. $x = 0$ represents the decision to continue or switch to agriculture, $x = 1$ represents the decision to switch to forestry or maintain a forest stand, and $x= 2$ represents timber harvest with subsequent return to forestry. As long as $x = 1$, s^{SA} will continue increasing until it the maximum allowed stand age.

It is important to note that, while the model allows for switching between forestry and agriculture at any time, there are monetary barriers to going back and forth. To switch from agriculture to forestry involves site preparation and plantation. To switch back involves digging up the stumps and roots of the trees. These barriers make a farmer more likely to stay in the same regime that he is in currently rather than switching back and forth with every minor shift in prices.

Value function

For a relatively simple forestry management regime, such as cultivation of cottonwood (*Populus deltoides*) for pulpwood with no intermediate thinning, the reward function would be:

$$f(s,x) = \begin{cases} s^{AG} \mid s^{SA} = 0 \\ SPREP \mid s^{SA} = 1 \\ CC \mid s^{SA} = 2 or 3 \\ GY(s^{SA}) * s^{TIMB} \mid x = 2 \\ GY(s^{SA}) * s^{TIMB} + LCLEAR \mid s^{SA} \neq 0 \,\&\, x = 0 \\ 0 \mid otherwise \end{cases} \tag{16}$$

Where *SPREP* is the cost of site preparation, *CC* is the cost of competition control in years 2 and 3, $GY(s^{SA})$ is the growth and yield which is a function of stand age and *LCLEAR* is the cost of land clearing for agriculture (stump removal), all on a per hectare basis.

State transition function

The state transition function assumes that agricultural net returns and timber prices follow a mean-reverting random walk, as previously discussed. This assumption means that agricultural net returns per acre per year and timber returns are serially correlated, but tend to move back to a long-run equilibrium value over time. The randomness of the walk is driven by a shock, ε. The εs for agriculture returns and timber price can be modeled independently or with covariance. Assumptions other than mean-reversion (geometric Brownian motion, standard Brownian motion with drift) are possible, but we believe the mean-reversion assumption is the most plausible, as noted above. The standard state transition function is as follows:

$$s_{t+1}^{AG} = s_t^{AG} + \alpha^{AG}(AGeq - s_t^{AG}) + \varepsilon^{AG}$$
$$s_{t+1}^{TIMB} = s_t^{TIMB} + \alpha^{TIMB}(TIMBeq - s_t^{TIMB}) + \varepsilon^{TIMB}$$
$$s_{t+1}^{SA} = \begin{cases} 0 \mid x = 0 \\ s_t^{SA} + 1 \mid x = 1 \\ 1 \mid x = 2 \end{cases} \qquad (17).$$

In total, then this RO approach allows us to model the ability of landowners to utilize the most profitable land use, and switch between those land uses based on their returns from previous years and expectations for future returns based on past data as well. This new approach provides a powerful and realistic reflection of the actual decisions that landowners do make, and significantly extends previous analyses of farm, forest, and agroforestry decision-making.

Results and Discussion

The real options (RO) model was used to compare agriculture to various forestry and agroforestry systems selected by a panel of experts for the LMAV (Frey, 2009). A few figures of the types of data that can be provided by the RO analysis will help the reader understand the models and their outputs. In **¡Error! No se encuentra el origen de la referencia.** one observes a comparison of agriculture and a hard hardwood alley cropping system. This figure assumes that the land that is being considered for conversion to alley cropping is currently being used for agriculture. On the x-axis is the price per ton of timber, and on the y-axis is the return to agriculture per hectare. The black-colored cells represent the points at which the optimal decision is to remain in agriculture, while the white colored cells represent the points at which it is optimal to switch to alley cropping. That is to say, if the pulpwood price in the current year was $10/ton and the agricultural returns in the current year were $100 per hectare, it is optimal for a farmer to continue agriculture. If, however, the agricultural this year produced a loss of $800 per hectare, then it would be optimal to switch to alley cropping.

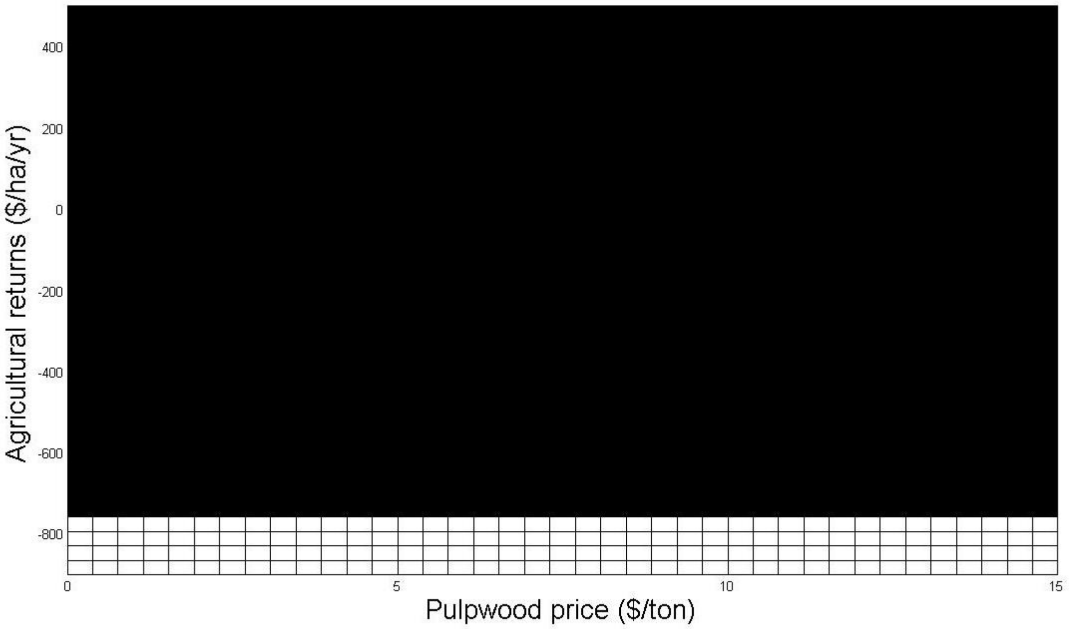

Figure 1. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land currently in agriculture. White cells represent switching to alley cropping, black cells represent staying in agriculture

One thing that is clear from the graph is that the pulpwood price plays very little role in the decision to afforest or not. The decision is driven almost entirely by agricultural returns. This is seen by the fact that the division between the white and black cells is horizontal. The reason for this is the assumption of mean-reversion and the relatively long time period until timber harvest, compared to agriculture. That is to say, regardless of today's timber price, given the assumption of mean reversion, the expected value of timber prices far in the future (greater than say, 10 years) is very close to the equilibrium timber price.

The level at which a farmer crosses from non-adoption of alley cropping to adoption (moving downwards on the graph) we call the "RO adoption threshold". Because the level of this threshold is largely unaffected by timber prices, it is convenient to summarize this as the level of agricultural returns per hectare below which a farmer/landowner would find it optimal to switch to alley cropping, at the equilibrium timber price.

The following **¡Error! No se encuentra el origen de la referencia.** shows the same decision, but on land that has recently been planted to a hardwood alley cropping system. In this graph, the white represents maintaining the alley cropping system at least until next year, while the black represents clearing the planted trees and returning to agriculture. In this case, the agricultural returns level above which a landowner returns from the alley cropping system to agriculture would be the "RO disadoption threshold". This disadoption threshold will vary depending on the age of the stand. We can see that, while the decision is still mostly driven by agricultural returns rather than timber prices at this young stand age, the agricultural returns level at which one reverts to agriculture is much higher than the level at which one remains in agriculture.

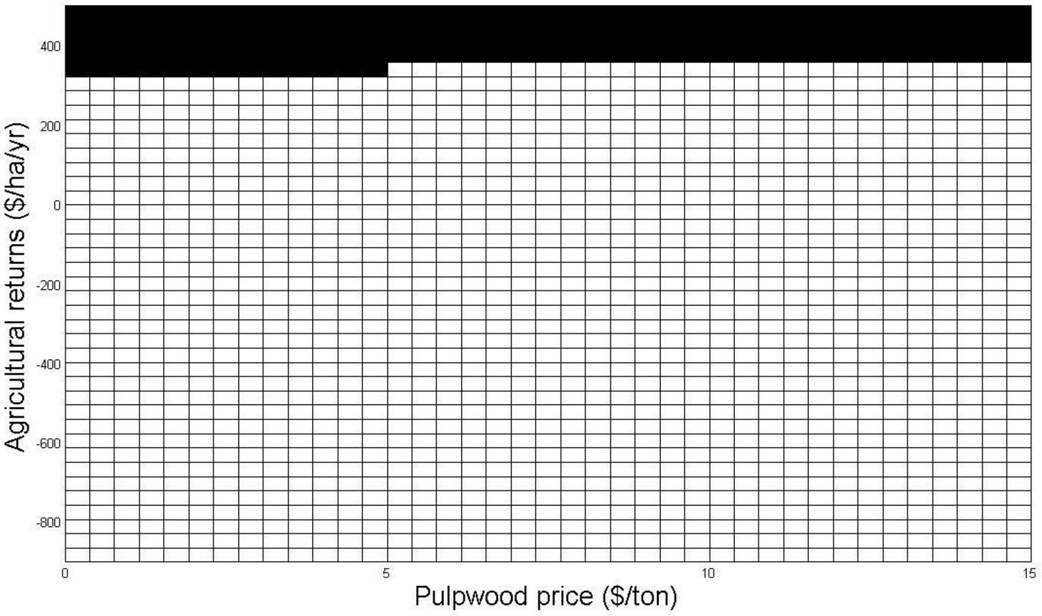

Figure 3. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land recently planted to alley cropping

White cells represent staying in alley cropping, black cells represent switching to agriculture.

Our research is primarily concerned with the adoption threshold, rather than the disadoption threshold. However, it is useful to continue with this example to see how the RO model works.

The following two figures represent land that is used as an oak alley cropping system at stand age 5, respectively. As the stand ages, the landowner becomes less likely to clear, especially at low timber values, because he/she is getting closer to the age at which the trees will be of value for sawtimber, a more valuable product. If he/she were to harvest immediately, he/she would receive pulpwood prices, but by waiting can achieve more value.

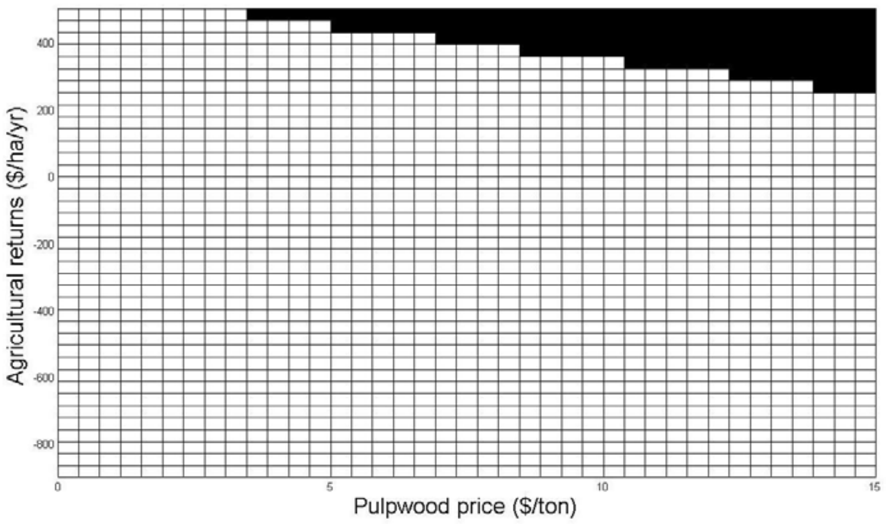

Figure 4. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 5-year-old alley cropping stand

White cells represent staying in alley cropping, black cells represent switching to agriculture.

The following Figure 5 skips several years during which, over the range of agricultural returns and pulpwood price values we have used, it is optimal for the landowner to wait. There are still silvicultural activities in those years, such as thinning. However, this figure presents the stand at age 40, when the landowner is considering harvest. Here the figure includes a third color, grey, to represent the third possible action: to harvest the timber and replant the alley cropping system. That is, black represents harvesting the timber and clearing the stumps to return to agriculture, white represents keeping the forest stand at least one more year and grey represents harvesting the timber and restarting the alley cropping rotation. At low levels of timber prices, it is optimal to wait, to see if the price will increase in the future.

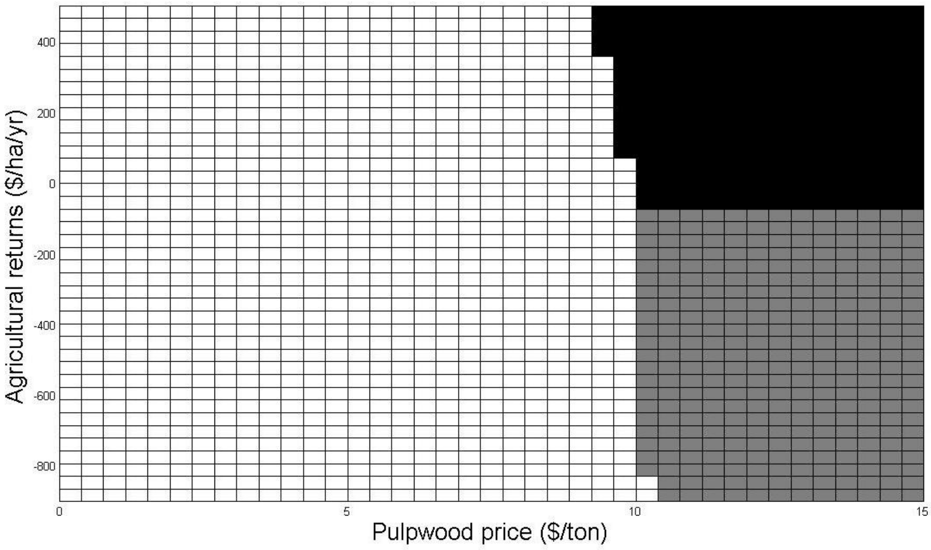

Figure 5. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 40-year-old stand

White cells represent staying with hardwood, black cells represent clearcutting and switching to agriculture, grey cells represent clearcutting and replanting alley cropping system.

As noted, our research is primarily interested in the adoption threshold of various production forestry and agroforestry systems for land that is currently in agriculture. We summarize the adoption thresholds for marginal and average soils in Table 1.

At first glance, the outlook for most forestry and agroforestry activities in the LMAV looks bleak because the graph indicates that agricultural returns must become significantly negative for pulpwood to become optimal. However, we should consider that this does not mean that agricultural returns must be negative over a long period; they only have to be that low one year for the farmer to decide it is worthwhile to plant trees. It seems reasonable that net returns on marginal land will occasionally be negative.

In the tables, we also include the probability of agricultural returns reaching the threshold level, based on the mean agricultural returns, standard deviation and assumed distributional form of agricultural returns. One can observe that, on marginal soils, several forestry and agroforestry systems have greater than a 10% chance of being adopted on any given plot in any given year.

The real options value is the numerical value estimated for the value function, V(s), assuming forestry/agroforestry at the year of site planting, at equilibrium mean reversion prices. This is comparable to the soil expectation value (SEV) in some cases, but allows for increased value from numerous options, including the option to switch back to agriculture. In fact, in many cases on average soils, on recently planted forestry or agroforestry land, at equilibrium prices, it is optimal to switch back to agriculture immediately. In these cases, which are noted in the table, it is not necessarily appropriate to compare to the SEV.

For comparison, we include values for the soil expectation value (SEV) and the Annual Equivalent Value (AEV) for the SEV. The AEV can be viewed as the "SEV adoption threshold", that is, the level of agricultural returns below which it is optimal to switch to the forestry or agroforestry system, utilizing SEV assumptions. The SEV does not allow for either the option value of waiting a year to convert agricultural land to forestry or the option value of selecting the optimal year to harvest timber because of changing timber prices.

In most cases, the RO analysis shows a more negative threshold of agricultural returns for switching to forestry or agroforestry than the SEV analysis. This means that, if farmers value the flexibility provided by different production systems, in most cases they will be less likely to adopt forestry or agroforestry than a SEV analysis might suggest. This fairly pessimistic finding for forestry prospects does at least provide more insight why so little conversion to forestry or agroforestry has occurred. This is useful to have models that do generally conform with farmers' decisions. Despite their pessimism, however, it is useful to help identify the level of government interventions that actually would be needed to encourage these practices if deemed socially desirable.

To be specific, on marginal sites, the RO adoption threshold was significantly more negative (i.e. more difficult to reach) than the SEV adoption threshold (the AEV) for Wetlands Reserve Program enrollment, cottonwood timber plantation, short-rotation woody crops, hard hardwood timber plantation, cottonwood-oak intercrop plantation, pecan alley cropping and hardwood alley cropping. The RO adoption threshold was slightly lower than the SEV adoption threshold for cottonwood alley cropping.

The reason why the real options threshold is lower than the SEV threshold for WRP enrollment is the clearest. In our model, we have assumed that once a plot of land is enrolled in WRP, it can never return to agriculture. Also, no timber harvest is permitted. The only income after the easement payment is income from a hunting lease. This means that WRP has essentially no flexibility. Still, it is important to note, that even with this lack of flexibility, the returns to WRP enrollment on marginal land are high enough that it is a more attractive option in the RO model than many of the other forestry and agroforestry regimes.

Of the forestry and agroforestry production systems, the most attractive in the RO cottonwood alley cropping and cottonwood plantation. Alley cropping systems appear to be about the same in terms of adoptability as conventional forestry systems. For instance, there is a 39% in any given year of agricultural returns crossing the threshold for cottonwood alley cropping compared to 31% for conventional cottonwood. For hard hardwoods, there is a 0.1% chance of crossing the threshold for alley cropping and 0.3% for the conventional system.

Table 1. RO and SEV adoption thresholds in terms of agricultural returns per hectare, and RO value and SEV for production forestry and agroforestry systems on land capability class 5 (marginal) land ($/ha)

	Real options adoption threshold	Prob. of crossing threshold	Annual Equivalent Value (SEV threshold)	Real options value	SEV
Wetlands Reserve Program	-247	11%	112	2236	2233
Cottonwood	-29	31%	61	3804	1210
Short Rotation Woody Crop	-429	3%	-113	1841	-2253
Hard hardwoods	-667	0.3%	-6	1136	-129
Cottonwood-Oak intercrop	-415	3%	1	1571	18
Pecan Alley Crop	-451	2%	-12	1834	-235
Hard Hardwoods Alley Crop	-774	0.1%	0	1405	-8
Cottonwood Alley Crop	29	39%	68	3583	1367

On sites of moderate productivity (land capability class 3), the real options analysis paints a much bleaker picture of the adoptability of production forestry and agroforestry systems. This is an important finding, as approximately 40-50% of the LMAV land is on moderate productivity soils, and any large-scale effort at reforestation would need to include these soils. All of the systems analyzed have less than a 0.1% chance of agricultural returns in any given year reaching a level low enough that adoption of the forestry or agroforestry system is optimal.

Table 2. RO and SEV adoption thresholds in terms of agricultural returns per hectare, and RO value and SEV for production forestry and agroforestry systems on land capability class 3

(average) land ($/ha).

	Real options threshold	Prob. of crossing threshold	SEV threshold	Real options value	SEV
Wetlands Reserve Program	<-900	<0.1%	112	2236	2233
Cottonwood	<-900	<0.1%	59	5548*	1180
Short Rotation Woody Crop	<-900	<0.1%	-111	6645*	-2217
Hard hardwoods	<-900	<0.1%	3	5553*	52
Cottonwood-Oak intercrop	<-900	<0.1%	8	5553*	158
Pecan Alley Crop	<-900	<0.1%	118	5414*	2355
Hard Hardwoods Alley Crop	<-900	<0.1%	42	6641*	843
Cottonwood Alley Crop	<-900	<0.1%	107	6226*	2144

* It is optimal to switch back to agriculture under mean agriculture and timber returns at stand age 1.

Conclusions

We utilized a real options (RO) model to estimate The RO model produced some interesting results. On the most marginal land, several systems, including pine and hardwood silvopasture, and cottonwood alley cropping and timber plantation, were more likely to be adopted than the WRP program. Since we know that the WRP has been adopted by many landowners, this may be an indicator of potential for adoption of those other systems. On the other hand, many landowners may adopt WRP because it is a good way to get out of farming altogether, which is a non-market value that cannot be modeled in RO, and could make WRP more favorable than agroforestry. On average-quality LMAV land, almost none of the forestry or agroforestry systems showed much potential. This suggests that some alternative incentives would be necessary to convince landowners to adopt forestry or agroforestry. These might include easement payments or some system of payment for ecosystem services.

Real options methods place a value on flexibility ("option value") under stochastic conditions. Previous literature has found that option value can play an important role in land use decisions including forestry. This previous research can be split in two parts: those that use real options to model the timber harvesting decision (Haight & Holmes, 1991; Plantinga, 1998) and those that use real options to model the afforestation decision (Behan *et al*., 2006; Weimers & Behan, 2004). The timber harvesting literature has shown that flexibility in deciding when to harvest can add significant value to timberlands. The afforestation literature, on the other hand, has shown that the option value of agriculture is likely to cause farmers to delay afforestation; however, that literature did not take into account the option value of timber from the harvesting decision. It makes sense to combine both decisions into one model to include both the option value of agriculture and forestry. Our results confirmed that, in most cases, option value favors agriculture, meaning that farmers will be more hesitant to adopt forestry and agroforestry than is suggested by the purely deterministic model. This is consistent with previous real options afforestation models.

We urge the reader to consider our results with some caution. Because of the quality of data and the computational necessity of simplification to be able to undertake the real options model, we have been forced to make some underlying assumptions that may not be true in a general sense. These assumptions include no variability of agricultural or forestry costs, normality of the distribution of agricultural returns and timber prices, and mean reversion. Still, our methods are robust enough that they should provide a good approximation of reality.

All in all, agroforestry and other production forestry systems may have some potential for adoption on marginal lands for farmers or landowners who feel they want to reduce risk or are not inhibited by trying non-traditional systems. These are most likely to be limited-resource farmers and landowners for whom farming is more of a lifestyle than an occupation, and plots are likely to be small. We do not see much potential for adoption of agroforestry in large areas or on land that is not marginal. Even on marginal private land, WRP is likely to continue to be the principal reforestation program. Other incentive programs would be necessary in order to promote forestry and agroforestry on marginal land.

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