

UNCERTAINTY, EMERGING BIOMASS MARKETS, AND LAND USE

by

Fanfan Weng Hallmann

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in
partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Forestry

Approved:

Gregory S. Amacher, Chair

Janaki Alavalapati

Jay Sullivan

Gwenlyn Busby

Jeffrey Alwang

May 6, 2010

Blacksburg, Virginia

Keywords: Uncertainty, Emerging biomass market, Land Use, Transaction costs, Risk-neutral,
Risk-averse, Stochastic optimization

UNCERTAINTY, EMERGING BIOMASS MARKETS, AND LAND USE

Fanfan Weng Hallmann

ABSTRACT

In this dissertation, we study the effects of emerging biomass markets on land use changes between alternatives of agricultural production, conventional timber production, and forest woody biomass production for energy use. Along with the uncertainty associated with woody biomass prices and rents, transaction costs incurred to land use play an important role in land allocation decisions and make this study distinct from other work. In Chapter 1, we introduce the background and objectives of our study. In Chapter 2, we analyze the behavior of a risk-neutral private landowner and social planner under uncertainty of woody biomass prices, assuming that there is a market emergence at some unknown time point in the future. Market emergence is characterized by a price jump and a certain timing of the price jump. Six different price jumps and five different timings of bioenergy market emergence are adopted to study their collective effects on land use change between agriculture and forestry. Chapter 3 studies this problem for a risk-averse private landowner. Two measures of relative risk aversion are used to examine how a landowner's preference may affect his or her land use decision.

In Chapter 2, we find that, for three different quality categories of land, land rents from forestry increase significantly for higher price jumps and decreases in the length of time until bioenergy market emergence. One of the most important results is concerned with the presence of transaction costs. Here, we find that these costs may require unrealistic market emergence scenarios to lead to bioenergy adoption on any large scale.

This result is even more likely with nonlinear transaction costs. Land allocation decisions in Chapter 3 are distinctly different from those in Chapter 2, due to the introduction of landowner risk aversion. In certain market emergence cases, some land units retain in agriculture entirely when the landowner is risk averse .

The Chapter 4 studies a stochastic optimization problem of land use, assuming that woody biomass rents follow a stochastic diffusion called geometric Brownian motion that is later discretized by a binomial option pricing approach. The problems in Chapters 2 and 3 assume that the landowner must make all decisions at the beginning of his or her time horizon. This

assumption is relaxed in Chapter 4. Now, the landowner is allowed to revise his or her land allocation decision among three alternatives over time as information about market emergence is collected. We observe that the different forms of transaction costs are not as significant as in Chapters 2 and 3. However, different values of volatility of forest biomass rents give rise to different land allocation decisions, especially for the land of high quality.

ACKNOWLEDGEMENTS

PhD study can be a painstaking journey but is not without great fun. In retrospect, I feel a deep gratitude to all those people who helped me get through this journey with patient advice and tremendous encouragement.

My deepest gratitude is to my advisor, Dr. Greg Amacher. I have been amazingly fortunate to have him as my advisor. The acceptance to be his student changed my life in such a good way and I appreciate it every day. I don't remember how many times I rushed into his office for help when I was struggling with courses in the first year. His patience and guidance helped me get through the language barrier and adapt to the academic demands. Progress in my research would not have been possible without his encouragement, guidance and trust. His diligence and intellect also motivated me to work harder and more efficiently. I hope that one day I can be as good an advisor to my own students as he has been to me.

I also feel blessed to have a chance to work in such a friendly department. Quite a few professors have helped me in my research. Dr. Jay Sullivan was always helpful when I needed his help on my work. Dr. Philip Radtke helped me with my data collection. Dr. Janaki Alavalapati had quite a few talks with me about my work, even though he is busy as our department head. All of my committee members including Dr. Gwenlyn Busby and Dr. Jeffrey Alwang from the department of Agricultural and Applied Economics helped me recognize my strengths and weaknesses in my study. Thank you all for your inputs. Besides the professors, I would like to thank the department secretary Sue Snow and a lot of my fellow graduate students who helped make my studies easier and more enjoyable.

I would also like to thank the US Department of Energy and the US Department of Agriculture for providing financial support for this project.

This dissertation gives me a great chance to thank my families. The love, encouragement and support from my husband have been a great driving force for me to succeed and help make this dissertation possible. As a graduate student from the department of Economics, he discussed with me problems regarding my research and motivated me all the time. I would like to thank my family in China. Without them, I would not have been able to fulfill my dream of pursuing graduate study in USA. I would also like to thank my extended family in USA. Their love and care is always appreciated. I also thank my son, Lucas, who will be born this June. He makes me stronger and more loving.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION.....	1
1.1 BACKGROUND.....	1
1.2 OBJECTIVES.....	2
CHAPTER 2. UNCERTAIN EMERGING BIOMASS MARKETS AND LAND USE FOR A RISK-NEUTRAL PRIVATE LANDOWNER.....	4
2.1 ABSTRACT.....	4
2.2 INTRODUCTION.....	5
2.3 MODELS.....	8
2.3.1 AN OPEN LOOP PROBLEM FOR A PRIVATE LANDOWNER.....	8
2.3.2 THE SOCIAL PLANNER'S PROBLEM.....	18
2.4 SIMULATION.....	22
2.5 RESULTS.....	24
2.6 DISCUSSIONS.....	28
2.7 REFERENCES.....	37
CHAPTER 3. UNCERTAIN EMERGING BIOMASS MARKETS AND LAND USE FOR A RISK-AVERSE PRIVATE LANDOWNER	41
3.1 ABSTRACT.....	41
3.2 INTRODUCTION.....	42
3.3 MODEL OF A RISK AVERSE LAND OWNER.....	43
3.4 EFFECTS OF PARAMETERS ON LAND ALLOCATION.....	47
3.4.1 EFFECT OF UNCERTAINTY, σ , ON LAND LLOCATION.....	47
3.4.2 EFFECT OF EXPECTED PRICE JUMP, δ , ON LAND LLOCATION.....	52
3.4.3 EFFECT OF EXPECTED PRICE, $\mu = (\mu_1, \mu_2)$, ON LAND LLOCATION.....	53
3.5 NUMERICAL ANALYSIS	54
3.5.1 DATA COLLECTION.....	54
3.5.2 SIMULATION ANALYSIS.....	56
3.6 CONCLUSION AND POLICY IMPLICATIONS.....	57
3.7 REFERENCES.....	64
CHAPTER 4. UNCERTAIN EMERGING BIOMASS MARKETS AND STOCHASTIC OPTIMIZATION OF LAND USE	66

4.1 ABSTRACT.....	66
4.2 INTRODUCTION.....	67
4.3 A THEORETICAL MODEL.....	70
4.4 SIMULATION ANALYSIS.....	76
4.4.1 DATA.....	76
4.4.2 SIMULATION METHOD.....	77
4.4.3 SIMULATION ANALYSIS.....	79
4.5 CONCLUSION AND POLICY IMPLICATION.....	83
4.6 REFERENCE.....	86
CHAPTER 5 CONCLUSIONS.....	90
REFERENCES.....	93
APPENDIX A DERIVATION OF EQUATION (3.9)	94
APPENDIX B STATA CODES FOR CHAPTER 2.....	95
APPENDIX C STATA CODES FOR CHAPTER 3.....	137
APPENDIX D MATLAB CODES FOR CHAPTER 4.....	200

LIST OF FIGURES

Figure 2.1: Land use with and without including transaction costs..... ..16

Figure 2.2: NPV of amenity benefits from growing loblolly pine to different potential rotation ages..... 31

Figure 4.1: The role of renewable energy in the Nation’s Energy Consumption: 2003-2007..68

LIST OF TABLES

Table 2.1: Expected NPV of land rents from forestry on low quality land with linear form Transaction Costs.....	32
Table 2.2: Expected NPV of land rents from forestry on low quality land with nonlinear transaction costs.....	32
Table 2.3: Expected NPV of land rents from forestry on average quality land with linear form transaction costs.....	33
Table 2.4: Expected NPV of land rents from forestry on average quality land with nonlinear form transaction costs.....	33
Table 2.5: Expected NPV of land rents from forestry on high quality land with linear-form transaction costs.....	34
Table 2.6: Expected NPV of land rents from forestry on high quality land with nonlinear transaction costs.....	34
Table 2.7: Effects of interest rates on landowner's expected NPV land rents and land allocation decision on average-quality land with nonlinear transaction cost.....	35
Table 2.8: Social planner's expected NPV of land rents from forestry.....	36
Table 3.1: Landowner's expected utility from forestry on land with low quality, linear form transaction cost and $\sigma = 1$	60
Table 3.2: Landowner's expected utility from forestry on land with low quality, linear form transaction cost and $\sigma = 8$	60
Table 3.3: Landowner's expected utility from forestry on land with low quality, nonlinear transaction cost and $\sigma = 1$	60
Table 3.4: Landowner's expected utility from forestry on land with low quality, nonlinear transaction cost and $\sigma = 8$	61
Table 3.5: Landowner's expected utility from forestry on land with average quality, linear form transaction cost and $\sigma = 1$	61
Table 3.6: Landowner's expected utility from forestry on land with average quality, linear form transaction cost and $\sigma = 8$	61
Table 3.7: Landowner's expected utility from forestry on land with average quality, nonlinear form transaction cost and $\sigma = 1$	62

Table 3.8: Landowner’s expected utility from forestry on land with average quality, nonlinear form transaction costs and $\sigma = 8$	62
Table 3.9: Landowner’s expected utility from forestry on land with high quality, linear form transaction costs and $\sigma = 1$	62
Table 3.10: Landowner’s expected utility from forestry on land with high quality, linear form transaction costs and $\sigma = 8$	63
Table 3.11: Landowner’s expected utility from forestry on land with high quality, nonlinear form transaction costs and $\sigma = 1$	63
Table 3.12: Landowner’s expected utility from forestry on land with high quality, nonlinear form transaction costs and $\sigma = 8$	63
Table 4.1: Net present value of land rents with and without land use change at different stopping times and $\sigma = 0.5$	81
Table 4.2: Net present value of land rents with and without land use change at different stopping times and $\sigma = 2$	83

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Renewable energy and biofuel has been a heated topic in the past decade due the rising concerns of an unstable long run supply of non-renewable fossil fuels. Volatile gasoline prices and high greenhouse gas emissions have also caused some economic growth concern in certain sectors along with environmental problems. The Kyoto protocol is one inter-governmental strategy to cope with greenhouse gas emission regarding climate change. A number of countries have established and implemented related policies and services to deal with their own concerns. For example, the United States, relying upon imported fossil oil from economically and politically volatile areas, has expressed concerns over its energy security. However, the goal of producing 36 billion gallons of renewable fuels by 2022 in the Energy Independence and Security Act of 2007 seems to be ambitious based on current demand and supply. On May 5, 2008, the EPA announced proposed rules to begin implementation of the program (Brown 2009). Of the 36 billion gallons, about 21 billion gallons are expected to come from advanced biofuels such as cellulosic and non-corn-based ethanol, of which forest biomass is supposed to play a key role. Moreover, Congress made several important revisions to the current renewable fuel standards (RFS1). The renewable fuel volume requirement for the revised annual renewable fuel standard (RFS2) at each year in the future can be accessed on EPA website¹.

Compared to other feedstock, forest biomass possesses a number of advantages. First, forest biomass production for energy use is carbon-neutral, and should not exacerbate the greenhouse gas emissions problem. Second, comparing with feedstock from the agriculture sector, bioenergy forests also give rise to public goods such as carbon sinks, improved air quality, protection of water and soil from erosion, and natural resource recreation. In addition, agricultural products can only be harvested in certain times of the year and require more storage space. Forests do not have to be harvested until needed. Third, even though the conversion technologies are still in the developmental stage, there are a number of technologies available to convert wood to fuel, including thermochemical and biochemical processes.

In the United States, several states such as Pennsylvania, Maine and Michigan have designed state level guidelines for woody biomass energy production. The policy instruments at

¹ The link for it is <http://www.epa.gov/oms/renewablefuels/420f09023.htm>.

the federal and state government level to promote wood-to-energy use in the USA are well categorized and analyzed (Aguilar et al. 2010). Europe and Asia have also advanced the development of sustainable and renewable energy sources. European countries such as the UK, Germany, The Netherlands, and Finland have similar initiatives (McKay 2006, Hoffman and Weih 2005, Junginger et al. 2008 and Malinen 2001). The recent large export of wood pellets from the USA to European countries is the result of compliance with Kyoto Protocol and the goal of producing 20 percent of electricity from renewable sources by 2020 among European Union member countries. Finally, the Chinese government also announced an area of 13.33 million hectares of forestland designed specifically for forest-based bioenergy production by 2020.

1.2 OBJECTIVES

The promotion of wood-to-energy use and the emerging bioenergy market are likely to affect landowners who can in principle provide wood-based bioenergy from their land. As markets become more fully developed in the future, we would expect changes in forest management and land use leading to more frequent harvesting of smaller diameter trees. One result may be increased establishment of forest cover on marginal agricultural land or the possibility of substitution of conventional timber land for short-rotation bioenergy dedicated tree species. However, at present the lack of well defined markets imposes some risk to a representative landowner associated with adopting woody biomass-based specific land use. Landowners also do not have perfect information about government incentives that might affect future biomass prices and returns.

In Chapter 2, we study a land use problem with varying land quality, where a risk-neutral landowner is uncertain about the timing and extent of future biomass market emergence and has different land use alternatives including agricultural production, conventional timber production, and short-rotation bioenergy dedicated tree species production. We further allow for transaction costs that may prevent conversion of land from agriculture to forest bioenergy production even when relative returns favor the establishment of these types of forests. In practice, transaction costs have been discussed as reasons why farmers are reluctant to undertake forest production on previously cleared land (Zhang 2001, van Kooten et al. 2002). Incorporating these into the analysis, we explore the optimal land allocations for the risk-neutral landowner by maximizing the expected net present value of land rents from agriculture and forestry (forestry includes

conventional timber production and short-rotation energy-dedicated biomass production). By adopting five different levels of timing of bioenergy market emergences and six different levels of increases of biomass prices, we use a simulation to study the effects of key factors mentioned above on land allocation decisions. Two different forms of transaction costs are considered in each case.

Chapter 3 extends the model in Chapter 2 to examine a land use problem for a risk-averse forest landowner. A model is built to study how a private risk-averse landowner may adjust his or her land allocation decision in the face of emerging bioenergy markets for woody biomass. Key factors of price jumps, the timing and extent of market emergence, varying land quality, and transaction costs remain in this chapter. Risk aversion means the landowner maximizes expected utility from land rents to agriculture and the two forms of forestry. Transaction costs here are directly linked to the landowner's willingness or reluctance to change land use when exposed to great market and price uncertainty. In this chapter, pure price uncertainty is studied by using a mean-preserving spread.

Chapter 4 describes a stochastic optimization model of land use for a representative landowner who is assumed to be risk-neutral. Chapters 2 and 3 assume that the landowner has to make costly land use and forest management decisions at the beginning of his or her time horizon. In Chapter 4, this assumption is relaxed and the landowner is assumed to be able to revise land use decisions based on the new information or his or her new perception of market emergence as time continues. In this model, uncertainty is captured by uncertain land rents which are expressed using a geometric Brownian motion for biomass prices. For simplicity, a binomial option pricing model is used to discretize the evolvement of uncertain land rents for bioenergy dedicated tree species. Key factors such as varying land quality and transaction costs remain in the chapter. Two specific problems are studied. One is when to stop agricultural production and begin to invest in forest biomass production for energy use. The other is the optimal land allocation between competing uses. Based on the timing of biomass market emergence, a landowner can revise his or her decision and improve land rents.

The Conclusion summarizes all of the chapters and restates the policy implications that we recommend for the landowner to ensure widespread production of biomass for energy use.

CHAPTER 2: UNCERTAIN EMERGING BIOMASS MARKETS AND LAND USE FOR A RISK-NEUTRAL PRIVATE LAND OWNER

2.1 ABSTRACT

We study a land use problem with varying land quality, where landowners are uncertain about the timing and extent of future biomass market emergence. Unlike other land use studies, we examine the importance of public goods and transaction costs that may promote or prevent conversion of land from agricultural or conventional forest production to a mix that includes forest biomass production, even when relative returns favor these types of forest establishment, through contrasting problems of a private landowner and social planner who responds to public goods. We find, among other results, that land allocated to woody biomass production increases with an increase in expected biomass price and an earlier timing of biomass market emergence. If transaction costs are high, the expected strength of market emergence must be possibly unrealistically high to encourage bioenergy land use adoption, although land quality is an important factor here. This suggests that land use change models and biomass market effects examined without transaction costs may lead to overly optimistic conclusions. Our results also suggest the importance of government policies aimed at emergence of bioenergy markets if the goal is to ensure a future supply of alternative energy.

2.2. INTRODUCTION

High greenhouse gas emissions and energy security are critical driving forces for policy discussions involving investments in alternative energy source and fuel technologies. The United States, for example, relies upon imported fossil oil from economically and politically volatile areas to a large extent. In September 2008, the top ten exporting countries, eight of which are OPEC nations, accounted for approximately 88 percent of all U.S. crude oil imports (U.S. Department of Energy EIA).

To reduce dependence on foreign oil, the US Department of Energy estimates that one billion dollars in federal funding have been invested in advancing alternative fuel sources such as biotechnology and bioenergy as of July 2007. Meanwhile, memorandums of understanding for woody biomass utilization were released jointly by the United States Department of Agriculture, Department of Energy, and Department of the Interior, and several states have adopted formal guidelines for woody biomass production for both public and private forestland, including Pennsylvania, Maine, and Michigan (Wilent 2008). Europe and Asia are also accelerating the development of sustainable and renewable energy sources. The Chinese government recently set aside 13.33 million hectares of forestland specifically for wood-based bioenergy production. The United Kingdom, Germany, the Netherlands, and Finland also have similar policies (Mckay 2006, Hoffmann et al. 2005, Junginger et al. 2008, Malinen et al. 2001). Wood-based biofuels obtained from growing forests comprise a major part of these policy initiatives.

Woody biomass-based bioenergy has a number of advantages over conventional energy sources and other new sources such as corn-based ethanol production, one of which is the possibility of sustainable wood and amenity production that forests can provide jointly with bioenergy production (Pimentel 1991, Patzek et al. 2005, Mitchell 2008, Katz 2008).² However, technologies for converting wood to energy, such as direct burning, hydrolysis and fermentation, pyrolysis, and gasification, are in the early stages of development (Malmsheimer et al. 2008). Very few, if any, well defined markets exist to any scale for forest landowners wishing to

²The broad definition of woody biomass from US Forest Service includes trees and woody plants, including limbs, tops, needles, leaves, woodland, or rangeland environment, that are by-products of forest management. In this dissertation, only short-rotation energy dedicated tree species are considered, and hybrid poplar is used as example here.

provide wood-based bioenergy products from their land. As markets become more fully developed in the future, we would expect changes in forest management and land use leading to more frequent harvesting of smaller diameter trees. One result of this may be increased establishment of forest cover on marginal agricultural land or possibly substitution of short rotation species such as hybrid poplar on land currently devoted to conventional forest production such as pine plantations grown for construction wood. However, at present the lack of markets implies a risk to a representative landowner associated with adopting woody biomass-based specific land uses. Moreover, landowners do not have perfect information about government incentives that might affect future biomass prices and returns.

In this chapter, we study a land use problem with varying land quality, where landowners are uncertain about the timing and extent of future biomass market emergence, and landowners can devote land to agricultural production, short rotation wood-based bioenergy production, and conventional forest production (pine plantations). Landowners specifically face uncertainty concerning the level and timing of government policy initiatives targeting biomass consumption and demand. Aside from these uncertainties, which have not been considered, we further extend most studies of land use by assuming landowner's transaction costs are present that may prevent conversion of land from agricultural production to bioenergy forest production even when relative returns favor these types of forest establishment. In practice, transaction costs have frequently been discussed as reasons why farmers are reluctant to undertake forest production on previously cleared land (Zhang 2001, van Kooten et al. 2002).

There has been limited work covering forest biomass production and associated land use problems in the economics literature. Phillips et al. (1995) studied conversion of degenerated agricultural land into short-rotation biomass production in Hawaii, finding that short-rotation forestry for biofuel production can be relatively more profitable. Sudha et al. (1999) analyzed the availability of land and the potential for bioenergy production with competing land uses in India, estimating that land available for biomass production is in the range of 43 to 130 million hectares once markets develop. Heaton et al. (1999) analyzed a situation with a current single land use (sheep production) and several alternative uses, including short rotation trees for energy production using a spreadsheet model comparing cash flows, finding that removal of subsidies for sheep production would cause large shifts in land use toward short rotation coppice systems for landowners seeking to maximize land rents over time. Chakravorty et al. (2008) constructed a

dynamic land allocation model to analyze clean energy production and food production from agricultural land. They found that when land is scarce, energy production gains land from farming gradually, but when land is abundant there may be a jump in the supply of clean energy. Nonetheless, they did not define or examine a specific land use form for clean energy. Finally, based on a review of biomass supply articles, Berndes et al. (2003) examined woody biomass production and the land use choices between food and energy production, concluding that the interaction between an expanding bioenergy sector and other land uses is not well explained in the literature and thus not clear so far.

Our study is different from existing work in that we formally examine the impact of various uncertainties and costs in woody biomass markets on land use decisions made by private landowners. We contrast the privately and socially optimal allocation of land between agricultural production, conventional forest production, and forest biomass production under market emergence scenarios and varying landowner preference assumptions. These results collectively are used to predict how land use will change as a result of future market emergence and policy shifts. The importance of transaction costs will also be considered. Incorporating these realities into the analysis allows a more accurate assessment of the sizes of policy instruments needed to achieve different biomass production targets. Moreover, the presence of both uncertainty and transaction costs allows a study of how landowners respond to the development of future markets based on imperfect information possessed at the time of forest establishment. There can be several years from establishment to merchantable timber production, so imperfect information problem can be a significant pitfall to bioenergy forest adoption.

In particular, we examine how a private risk neutral landowner might adjust his or her land allocation decision in the face of emerging markets for woody biomass. Returns from conventional timber production and short-rotation biomass production compete based on the technology and level of demand. The assumption of the future development of a biomass market allows for a comparison of rents from forestry biomass production as well as other land use alternatives such as agriculture and conventional timber production. Since biomass markets are now in their infancy and forestry is necessarily a long investment, the timing of any future price shifts for forestry production is very important to any private land user.

The rest of this chapter is structured as follows. First, we describe a model of land use for a private landowner and contrast it with that of a social planner. Second, we use a simulation

based on published data to analyze the impact of emerging market risk and landowner preferences on land use. Finally, we offer our conclusions and policy implications in the last section.

2.3. MODELS

2.3.1 AN OPEN LOOP PROBLEM FOR A PRIVATE LANDOWNER

In this section, a model is developed that examines how a private landowner might adjust his or her land management in the face of emerging markets for woody biomass. The assumption of the development of a biomass market allows for a comparison of rents from forestry biomass production as well as other land use alternatives such as agriculture and conventional timber production. Since biomass markets are just beginning to emerge and forestry is a long investment, the timing of any future price shifts for forestry production is critical for the landowner to make the land use decision.

The basic land use problem describes how a private landowner allocates land optimally between agricultural crop and forest production in a way that maximizes expected net present value of rents to the land. The interest is to determine how land in forest production changes in the present with anticipation of future biomass market emergence to different extents. The introduction of transaction costs relaxes the usual assumption in land use models of free and immediate land change as rents change. For example, Parks et al. (1995) analyzed cost-sharing subsidies for land conversion from agriculture to forestry to sequester carbon by establishing more trees, including a subsidy covering forest establishment cost but without transaction costs, implying that land use changes immediately as relative rents change. However, the presence of transaction costs has been found, for example, by Meshack et al. (2006) who concluded using empirical data that poor farmers have a larger burden defined as the costs incurred to attend information meetings and training in forestry practices.

We assume that a representative private forest landowner does not value amenities (public goods) produced from forest land. While these landowners certainly are known to value their own private amenities of their forests, the interesting difference in public goods in this chapter comes by comparing a social planner who values amenities to all of society from bioenergy production and conventional forest production to different extents. We also assume the possibility of a future bioenergy wood products price change motivated by a targeted government policy shift that is consistent with the aforementioned subsidies for consumption of

biomass biofuels from forest land. The reasonability of this future event is not difficult to see. First, advances in technology will likely increase supply and demand for biomass. Second, a shift of subsidies targeting different land uses may change relative land rents for any acre on a land quality continuum. The timings of these events are not known to the representative landowner at the start of his or her time horizon. Both the timing of the subsidy and its level are also unknown to the landowner when the landowner makes initial land use decisions, i.e., when he or she chooses species type and plants the trees. We will examine an open loop problem where the landowner makes costly land use decisions at the beginning of the time horizon with an expectation of future events. This is normally the assumption in forest land use since trees must be established and held for several years before they reach a merchantable size.

Suppose currently that only agricultural and conventional forest production (pine plantations) are practiced on a land quality continuum, and at time T the price of biomass jumps from p_1 to p_2 . If the bioenergy market emerges enough, then not only will conventional forest production be replaced by bioenergy forest production on some part of the land quality continuum, but also the space devoted to agricultural production and the new bioenergy forest production will not equal the pre-land use change distribution. This future time T is unknown to the landowner, and instead the landowner perceives the time of the policy shift to be \hat{T} , where $\hat{T} = \eta T_1 + \theta$, $\eta \in N$, and $0 \leq \theta \leq T_1$. η here is the number of timing periods until the emergence of biomass markets and the length of each timing period is assumed to be represented by the optimal rotation age of the conventional tree species³. T_1 is defined as the rotation age for the conventional tree species (explained in detail later). The price jump embodies the effects of a future market shift or future change in government subsidies accompanying forest bioenergy market emergence. At time zero, prices before and after the price jump are also unknown and have the following properties, respectively: $p_1 = \mu_1 + \varepsilon_1$ and $p_2 = \mu_2 + \delta + \varepsilon_2$ where, p_1 is the price for the conventional tree species (loblolly pine), p_2 is the price for the biomass price (hybrid poplar), $\mu_1 = E(p_1)$, $\mu_2 = E(p_2)$, $E(\varepsilon_1) = 0$, $E(\varepsilon_2) = 0$, $E(\varepsilon_1^2) = \sigma^2(p_1)$, and $E(\varepsilon_2^2) = \sigma^2(p_2)$. p_1 is the price before the price jump or market shift, and p_2 is the price after

³ In the simulation section, five different values of η are used to represent the possible timings of the realization of the emergence of biomass markets. The whole timing periods are long enough for the analysis.

the market shift. The disturbance errors ε_1 and ε_2 are distributed independently and identically, and δ is the price jump level, which is assumed to be positive in the following analysis.⁴

The land quality of any given land unit on the continuum, denoted q , includes a vector of characteristics such as soil and slope that are exogenous to landowner decisions and are determinants of forest and agricultural production functions. The range of land quality is normalized to be between 0 and 1, which represents minimum and maximum land qualities, respectively. Let the probability density for land quality q be $k(q)$. Following Lichtenberg (1989), let $G(q)$ then represent the cumulative distribution function of land, which represents total land area with quality of at most q . Therefore the density function, $k(q)$, is given by $k(q) = G'(q)$. Moreover, $q \in [0,1]$ implies that $G(1) - G(0) = 1$ defines the total land available for all land uses.

To ensure interior solutions of the land use problem (see Amacher et al. 2009), two conventional assumptions of relative rents on the continuum need to be made clear before proceeding. First, both agricultural crop production and forestry production (conventional timber production and short-rotation forestry biomass production) yields are assumed to increase with higher land quality. Second, agricultural crop production is assumed relatively more profitable than forest production on higher-quality land. However, forest production is relatively more profitable on low-quality land. Collectively, these assumptions suggest that even before any emerging biomass market develops with certainty, the expectant landowner may switch from agricultural crop production and conventional forestry to agricultural production and bioenergy based forest production, along with corresponding changes in the land areas devoted to these land uses. This makes sense because conventional forest production, the most common use that competes with agriculture throughout much of the U.S., is better known to the landowner than biomass production before the landowner receives information concerning future biomass markets.

⁴We assume no correlations among the prices of agricultural output, conventional timber, and woody biomass, because agricultural output is assumed to be grown for grain, and thus clearly separate it from timber production and woody biomass production. We also assume that there is no correlation between ε_1 and ε_2 , which is used purely to reduce notation. Allowing such correlations would increase notation without additional insights.

Define V_1 and V_2 as the net present value of land rents the landowner gains from forest land use on the land quality continuum before and after the price jump respectively. With the price jump in mind, V_1 is the present value of land rents from the conventional forest production before the price jump, and V_2 is the present value of land rents from bioenergy forest production after the price jump on land previously used to grow conventional forest. At any given land quality q , if the price shift is significant enough, then $V_1 < V_2$ and the landowner will only establish and grow bioenergy producing trees on land devoted to forest; otherwise bioenergy will not be established and conventional forest production will continue ad infinitum on part of the land quality continuum. Before the landowner is aware of the emergence of bioenergy market, $V_2 = 0$, or at least $V_1 > V_2$, and thus conventional forest production occurs on a subset of land qualities (following the assumptions above).

Let timber production from growing conventional forest before the price jump and bioenergy forest production from short-rotation tree species after the price jump, if significant enough to change land use, be represented by the technologies $f(T_1, q)$ and $g(T_2, q)$, respectively, where $g(T_2, q) > f(T_1, q)$ indicates the reality that short-rotation bioenergy tree species produce a great volume of woody biomass than the conventional tree species within their rotation period T_2 , where T_1 and T_2 represent the rotation ages for conventional tree species and short-rotation biomass tree species, respectively.⁵ The inclusion of q into the production function reflects the effects of land quality on production described above. Concavity of the growth functions implies that: $f_q(T_1, q) > 0$, $f_{qq}(T_1, q) < 0$, $g_q(T_2, q) > 0$, and $g_{qq}(T_2, q) < 0$.

As the landowner has some expectation of the time point of bioenergy market emergence, if the price jump is enough to change land use, then the landowner will harvest conventional trees for timber at the time point of ηT_1 , i.e., $\theta = 0$, and then establish biomass production tree species and harvest at a new rotation age T_2 and at a price of p_2 ad infinitum. Consequently, the discounted present value functions V_1 (geometric series) and V_2 are calculated as follows for a given land unit of quality q :

⁵The bioenergy tree species used in our simulation, hybrid poplar, is assumed clear-cut before a new rotation as this is the silvicultural recommendation for this species.

$$\begin{aligned}
V_1 &= \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] + e^{-rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] \\
&+ e^{-2rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] + \dots + e^{-(\eta-1)rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] \\
&= (1 + e^{-rT_1} + e^{-2rT_1} + \dots + e^{-(\eta-1)rT_1}) \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] \\
&= \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} \left[p_1 f(T_1, q) e^{-r T_1} - c_1 \right]
\end{aligned} \tag{2.1}$$

$$V_2 = \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} \left[p_2 g(T_2, q) e^{-r T_2} - c_2 \right] \tag{2.2}$$

$$\begin{aligned}
V &= V_1 + V_2 \\
&= \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} \left[p_1 f(T_1, q) e^{-r T_1} - c_1 \right] + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} \left[p_2 g(T_2, q) e^{-r T_2} - c_2 \right],
\end{aligned} \tag{2.3}$$

where c_1 and c_2 are the constant regeneration costs before and after the switch of tree species on each land unit, respectively, and r is the market interest rate. Notice that $V = V_1 + V_2$ only if $V_1 < V_2$ and forest bioenergy production is adopted after the price jump, otherwise $V = V_1$ (where the parameter η is such a large integer that $e^{-\eta r T_1}$ approaches 0) because the landowner will not establish forest bioenergy production and will continue with conventional forest production ad infinitum based on weak expected market emergence. We will examine the rest of the land use problem in this section assuming there is some scenario for which forest bioenergy production is eventually adopted, although this will be relaxed later in the simulation.

Equation (2.3) represents the landowner's net present value of land rents from all forest production before and after the woody bioenergy market develops. If we let $Z(T_1, T_2, \varphi)$ be a cost function for forest land establishment beyond the regeneration costs, then the term $[V - Z(\cdot)]$ is the profit on each land unit along the quality continuum where forest production is chosen. We should point out that transaction costs, $Z(T_1, T_2, \varphi)$, are a one-time sunk cost from land

reallocation⁶, which is assumed to depend on rotation ages T_1 and T_2 , and φ is fixed. Transaction costs result in a reluctance of the landowner to switch to a different form of production on land of quality q . For example, if rotation ages are relatively long, the landowner may not readily shift from agricultural crop production that produces annual yields. Moreover, unfamiliarity with forest production, especially forest bioenergy production, may increase the cost of adopting forest production at the margin. Either way, these effects are captured in the $Z(\cdot)$ function with $Z_{T_1} > 0$, $Z_{T_2} > 0$ and $Z_\varphi = 0$.

On land devoted to crop production, we assume that the landowner knows the input price ω and the output price p_a with certainty. The crop production function, $h(\ell, q)$, is assumed to increase with the input ℓ and land quality q , i.e., $h_\ell(\cdot) > 0$ and $h_q(\cdot) > 0$. Thus, the net present value profit function for agriculture is as follows:

$$\pi = \int_0^\infty [p_a h(\ell, q) - \omega \ell] e^{-rt} dt \quad (2.4)$$

We can predict that the landowner will not choose bioenergy forest production on any land unit if $V(\cdot) - Z(\cdot) - \pi(\cdot) < 0$ for some quality q . However, as the bioenergy market emerges and prices increase with demand shifts, we eventually would expect that $V(\cdot) - Z(\cdot) - \pi(\cdot) > 0$ for some q . Taking into consideration the assumption of relative land rents mentioned before, we know that $V_q > 0$ and $\pi_q > 0$.

We are now ready to discuss the land allocation problem in an open loop form, where the landowner must make all decisions at the beginning of the planning horizon. As such, a risk-neutral landowner will maximize the expected net present value of land rents on the heterogeneous-quality land continuum with forest bioenergy price uncertainty and an unknown price jump at a time point that the landowner perceives with some probability. This land use problem is formulated as follows,

⁶ This means that transaction costs only occur when the land use changes. The transaction costs for converting part of agricultural land to woody biomass production here are the same with converting that part of agricultural land to timber production.

$$\max_{L_f} M = E \left\{ \int_0^1 [L_f (V - Z(T_1, T_2, \varphi)) + (1 - L_f) \pi] k(q) dq \right\}, \quad (2.5)$$

where $L_f = \int_0^{q_c} k(q) dq$ and $1 - L_f = \int_{q_c}^1 k(q) dq$. All decisions are made at time zero, and recall

that total area of land is assumed normalized to one. Before continuing, we establish the first order condition of V with respect to T_1 and T_2 in order to derive the optimal rotation ages T_1^* and T_2^* for the different forest regimes (non-biomass and biomass based production). We can tell from equation (2.3) that the optimal rotations are affected by the timing and expected price jump level. We also have to solve for ℓ^* that maximizes π in equation (2.4), that is,

$$\frac{\partial \pi}{\partial \ell} = p_a h_\ell(\ell, q) - \omega = 0. \text{ This shows that for land devoted to crop production, the marginal benefit of the agriculture input is set equal to its marginal cost. Using these results we can then determine the transaction cost at the expected time of land conversion, } Z(T_1^*, T_2^*, \varphi), \text{ and (2.5) also implies that transaction costs here are a function of acreage converted because they are costs per unit of land multiplied by the units converted to forest biomass production.}$$

Using these results we can then determine the transaction cost at the expected time of land conversion, $Z(T_1^*, T_2^*, \varphi)$, and (2.5) also implies that transaction costs here are a function of acreage converted because they are costs per unit of land multiplied by the units converted to forest biomass production.

Substituting the above optimal choices into equations (2.3), (2.4), and the transaction cost function, we then obtain the indirect net present value of land rents from forestry and agriculture, and transaction costs written as: $V^* \equiv V(T_1^*, T_2^*)$, $Z^* \equiv Z(T_1^*, T_2^*, \varphi)$, and $\pi^* \equiv \pi(\ell^*)$. The problem of maximizing the net present value of land rents from all the land uses in equation (2.5) can therefore be rewritten in a more convenient form using these indirect objective functions,

$$\max_{L_f} M = E \left\{ \int_0^1 [L_f (V^* - Z^*) + (1 - L_f) \pi^*] k(q) dq \right\}, \text{ for all } 0 \leq q \leq 1 \quad (2.6)$$

In order to ensure that a unique critical quality q_c exists separating agriculture and forest production on the continuum, the two aforementioned assumptions of relative profitability can now be stated more formally:

1. $V - Z < \pi$ for $q = 1$
2. $V - Z > \pi$ for $q = 0$

Now, the first-order necessary condition for an interior solution defining the share of land devoted to forest production is given by:⁷

$$\frac{\partial M}{\partial L_f} = E(V^* - Z^*) - E(\pi^*) = 0 \quad (2.7)$$

Equation (2.7) also defines the margin on the land quality continuum where land switches from crop production to forest production. It therefore defines the critical land quality q_c^* identifying the total amount of land on the continuum allocated to forestry and agriculture, that is, $L_f^* = \int_0^{q_c^*} k(q) dq = G(q_c^*)$ and $L_a^* = 1 - L_f^* = \int_{q_c^*}^1 k(q) dq = G(1) - G(q_c^*)$, respectively.

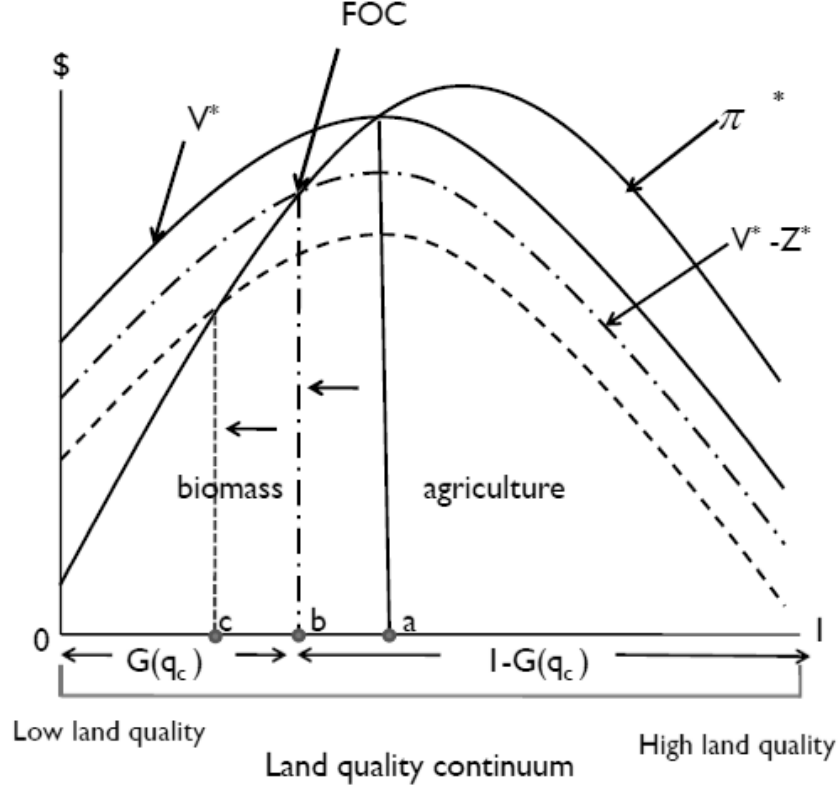
Figure 2.1 illustrates optimal land use in this model and shows how the inclusion of transaction costs affects the landowner's decisions. Point a involves no transaction costs, point b involves linear transaction costs, and point c involves nonlinear transaction costs. The point a that comes from the intersection of the optimal rent graphs $(V^* - Z^*)$ and π^* represents land allocation between forest production and agricultural production when there is no transaction cost. Point a is significantly different from the point b that results from the situation when transaction cost is introduced. The implication of the shift from a to b and further to c (where a larger value of transaction costs is adopted) is that the landowner will allocate less land to bioenergy forest production when transaction costs are accounted for, compared to the situation where transaction costs are less significant. Further, the figure shows that the adoption of bioenergy production can occur in two ways as future markets emerge, either through substitution of conventional forest production or by pushing the margin between agriculture and forest production to the right in the direction of higher land qualities. We will examine the precise significance of transaction costs and these other land use effects later in the numerical analysis.

Next we can investigate the effects of exogenous parameters on the critical land quality parameter and thus on the amount of land allocated to forestry and agriculture. The comparative statics with respect to the parameter set $\phi = (\mu_1, \mu_2, \delta, \eta, r, c2, \omega)$ are written as follows,

⁷The second order conditions for this problem can be shown to hold.

$$\frac{dL_f}{d\phi} = \frac{d \int_0^{q_c} k(q) dq}{d\phi} = k(q_c) \frac{\partial q_c}{\partial \phi} \quad (2.8)$$

Figure 2.1: Land use with and without including transaction costs



A total derivative of equation (2.8) yields the following results for critical land quality:

$$\begin{aligned} \frac{\partial q_c}{\partial \mu_1} &= -\frac{E(V_{\mu_1}^*)}{\Delta} > 0; \quad \frac{\partial q_c}{\partial \mu_2} = -\frac{E(V_{\mu_2}^*)}{\Delta} > 0; \\ \frac{\partial q_c}{\partial \delta} &= -\frac{E(V_{\delta}^*)}{\Delta} > 0; \quad \frac{\partial q_c}{\partial r} = -\frac{E(V_r^* - \pi_r^*)}{\Delta} \leq 0; \\ \frac{\partial q_c}{\partial c_2} &= -\frac{E(V_{c_2}^*)}{\Delta} < 0; \quad \frac{\partial q_c}{\partial p_a} = \frac{E(V_{p_a}^*)}{\Delta} < 0; \\ \frac{\partial q_c}{\partial \omega} &= \frac{E(V_{\omega}^*)}{\Delta} > 0; \quad \frac{\partial q_c}{\partial \eta} = -\frac{E(V_{\eta}^*)}{\Delta} < 0. \end{aligned} \quad (2.9)$$

Here, $\pi^* = \pi(\ell^*)$, and $\Delta = E(V_{q_c}^* - Z_{q_c}^* - \pi_{q_c}^*) < 0$ is the second-order sufficiency condition required for an interior solution. The numerators of the right hand sides of equations in (2.9) are defined as follows:⁸

$$E(V_{\mu_1}^*) = \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1, q) e^{-r T_1} > 0 \quad (2.10)$$

$$E(V_{\mu_2}^*) = \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2, q) e^{-r T_2} > 0 \quad (2.11)$$

$$E(V_{\delta}^*) = \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2, q) e^{-r T_2} > 0 \quad (2.12)$$

$$E(V_r^* - \pi_r^*) = E(V_r^* - \pi_r^*) \begin{matrix} \leq \\ \geq \end{matrix} 0 \quad (2.13)$$

$$E(V_{c_2}^*) = -\frac{e^{\eta r T_1}}{1 - e^{-r T_2}} < 0 \quad (2.14)$$

$$E(\pi_{p_a}^*) = h(\ell, q) \int_0^{+\infty} e^{-r t} dt > 0 \quad (2.15)$$

$$E(\pi_{\omega}^*) = -\ell \int_0^{+\infty} e^{-r t} dt < 0 \quad (2.16)$$

$$E(V_{\eta}^*) = \frac{r T_1 e^{-\eta r T_1}}{1 - e^{-r T_1}} [p_1 f(T_1, q) e^{-r T_1} - c_1] - \frac{r T_1 e^{-\eta r T_1}}{1 - e^{-r T_2}} [p_2 g(T_2, q) e^{-r T_2} - c_2] < 0 \quad (2.17)$$

These results collectively show that higher expectations of the before-the-jump price (μ_1), the after-the-jump price (μ_2), the expected price jump (δ) itself, and the price of agricultural inputs (ω) all increase the amount of land allocated to bioenergy production and decrease land allocated to agriculture, while bioenergy replaces land held in conventional forest production. Thus, forest production pushes into higher land quality and displaces some land used for crops

⁸Equation (2.17) is negative because $\frac{r T_1 e^{-\eta r T_1}}{1 - e^{-r T_1}} < \frac{r T_1 e^{-\eta r T_1}}{1 - e^{-r T_2}}$ and

$[p_1 f(T_1, q) e^{-r T_1} - c_1] < [p_2 g(T_2, q) e^{-r T_2} - c_2]$, that is, short-rotation forest production is more profitable than conventional timber production after the price change if the change is high enough, according to our model.

(the critical land quality level shifts to the right in Figure 2.1). However, the cost of forest establishment (c_2), the price of the crop output (p_a), and the number of expected time periods until a biomass market shift occurs (η) all decrease the amount of land allocated to biomass production even when it replaces some conventional forest production. This is because agricultural production is even relatively more profitable on some lower-quality land (the critical land quality level shifts to the left in Figure 2.1). The effect of a change in the interest rate on the amount of land allocated to bioenergy production remains ambiguous, and its ultimate effect depends on how it changes the relative magnitudes of optimal expected NPV rent functions for forestry and agriculture ⁹.

2.3.2 THE SOCIAL PLANNER'S PROBLEM

The social planner is assumed to value not only rents from both two forms of forest production, but also public goods such as recreation opportunities and wildlife habitat. These public goods may be ignored by private landowners, or the private landowner may value only his or her own private amenities when land use and rotation age decisions are made. The social planner's corresponding decisions should therefore differ from the private landowner that is studied in the previous sections, and the differences give an important indication of the social efficiency of encouraging bioenergy market emergence (Romero et al. 1998, Gong et al. 2005).

We use the same assumptions about bioenergy forest production, conventional forest production, and crop production as in the risk-neutral private landowner problem. It is plausible and indeed likely that the social planner places more weight on the amenity benefits from growing conventional trees for timber production than those provided from growing short-rotation tree species dedicated to energy use. This is because conventional forestry usually has longer rotation ages, which in turn supplies more public goods for ecosystem services such as protection of soil erosion, wildlife habitat, and recreation. However, the social planner still associates some public goods with bioenergy forest adoption through benefits to society of greater energy options. Let $A_1(x)$ and $A_2(x)$ be relative public goods amenity functions for

⁹ We have solved this land use problem for a risk averse landowner, and we can show that many of the results above hold under certain conditions of relative risk aversion. For example, risk-averse landowners are less willing to convert land to bioenergy forest production, either through substitution of conventional forests or agricultural land at the margin, if price uncertainty is too large. We also come to an important conclusion that bioenergy prices in an emerging market have to rise more than in the risk neutral case when transaction costs are important.

conventional forest and bioenergy forest production ¹⁰, where $A_1'(x) > A_2'(x)$ given that conventional forest and short-rotation woody bioenergy forest are planted at the same time point and x is just the variable for integration. Under the assumption that the social planner, who is also the policy maker, has imperfect foresight into the timing of future biomass market policies, we model amenity benefits before the price jump as follows:

$$\begin{aligned}
F_1^s &= \int_0^{T_1} A_1(x) e^{-rx} dx + e^{-rT_1} \int_{T_1}^{2T_1} A_1(x) e^{-rx} dx + \dots + e^{-(\eta-1)rT_1} \int_{(\eta-1)T_1}^{\eta T_1} A_1(x) e^{-rx} dx \\
&= (1 + e^{-rT_1} + \dots + e^{-(\eta-1)rT_1}) \int_0^{T_1} A_1(x) e^{-rx} dx \\
&= \frac{(1 - e^{-\eta r T_1})}{1 - e^{-rT_1}} \int_0^{T_1} A_1(x) e^{-rx} dx
\end{aligned} \tag{2.18}$$

where $A_1'(x) > 0$ for all $x < T_1$. After price jump, the net present value of amenity benefits are given by:

$$\begin{aligned}
F_2^s &= e^{-\eta r T_1} (1 + e^{-rT_2} + e^{-2rT_2} + \dots) \int_0^{T_2} A_2(x) e^{-rx} dx \\
&= \frac{e^{-\eta r T_1}}{1 - e^{-rT_2}} \int_0^{T_2} A_2(x) e^{-rx} dx
\end{aligned} \tag{2.19}$$

The present value of forest land rent is now augmented by these amenity functions at a given land quality q , so that the expected rent function for the social planner is:

$$\begin{aligned}
V^s &= V_1^s + V_2^s + F_1^s + F_2^s \\
&= \frac{1 - e^{-\eta r T_1}}{1 - e^{-rT_1}} [p_1 f(T_1, q_s) e^{-rT_1} - c_1] + \frac{e^{-\eta r T_1}}{1 - e^{-rT_2}} [p_2 g(T_2, q_s) e^{-rT_2} - c_2] \\
&\quad + \frac{1 - e^{-\eta r T_1}}{1 - e^{-rT_1}} \int_0^{T_1} A_1(x) e^{-rx} dx + \frac{e^{-\eta r T_1}}{1 - e^{-rT_2}} \int_0^{T_2} A_2(x) e^{-rx} dx
\end{aligned} \tag{2.20}$$

¹⁰ These are relative amenities for switching land from agriculture to forestry in that some agricultural production indeed produces amenity benefits.

where the superscript s is used to denote the social planner. The net present value profit function for agriculture is expressed in the same way as before, that is, $\pi = \int_0^{+\infty} [p_a h(\ell, q) - \omega \ell] e^{-rt} dt$.

The optimal rotation ages for the conventional tree species and short-rotation bioenergy dedicated tree species are now obtained from the first order condition of equation (2.20) instead of (2.1) – (2.3). As in the analysis of the last section for a representative private landowner, we assume that $p_1 = \mu_1 + \varepsilon_1$ and $p_2 = \mu_2 + \delta + \varepsilon_2$ where, $\mu_1 = E(p_1)$ and $\mu_2 = E(p_2)$, $E(\varepsilon_1) = 0$, $E(\varepsilon_2) = 0$, $E(\varepsilon_1^2) = \sigma^2(p_1)$, and $E(\varepsilon_2^2) = \sigma^2(p_2)$. p_1 is the price of the tree species before the price jump or market shift, and p_2 is the price of the tree species planted after the market shift. The disturbance errors ε_1 and ε_2 are distributed independently and identically, and δ is the price jump or price increase level. Furthermore, the assumptions about the function of land quality remain the same. From equation (2.20), we can immediately see that the number of timing periods before the bioenergy market emergence or before the price jump, η , and the expected bioenergy price level after market emergence have effects on the choice of optimal rotation ages. Different combinations of price jump and time length may yield different (possibly longer) optimal rotation ages, and different levels of these parameters will be required to favor bioenergy over conventional forest production compared to the private landowner. We will rely on a numerical analysis later to reveal the precise extent of these effects.

Using these social planner optimal rotation ages T_1^{s*} and T_2^{s*} , we can again derive the optimal transaction costs, Z^{s*} and optimal level of input in agricultural production in the same way as before. We should point out that the optimal level of agricultural inputs is not affected by the introduction of amenity values into the problem since the parameters affecting agricultural production remain the same. Finally, the assumptions of the relative profitability of land uses are needed to ensure that the uniqueness of the critical land quality, q_s^c continue to hold using the social planner's maximum NPV rents, i.e, $V^{s*} - Z^{s*} < \pi^*$ for $q = 1$ and $V^{s*} - Z^{s*} > \pi^*$ for $q = 0$.

The maximization problem is now described as one of finding the optimal land allocation choices, L_f^{s*} and L_a^{s*} to maximize the net present value of land rents from all the land uses, which is given by:

$$\max_{L_f^s} M^s = E \left\{ \int_0^1 [L_f^s (V^{s*} - Z^{s*}) + (1 - L_f) \pi^*] k(q_s) dq_s \right\} \quad \text{for all } 0 \leq q_s \leq 1 \quad (2.21)$$

Proceeding as before, obtaining an interior solution yields the critical land quality and land area devoted to the land uses at the optimal solution. Given again that the second order conditons can be shown to hold, we then examine the comparative statics of the critical land quality for the parameter set $\phi = (\mu, \delta, \eta, r, c_2, \omega)$. The results are shown as below:

$$\begin{aligned} \frac{\partial q_s^c}{\partial \mu} &= -\frac{E(V_\mu^{s*})}{\Delta} > 0; \quad \frac{\partial q_s^c}{\partial \delta} = -\frac{E(V_\delta^{s*})}{\Delta} > 0; \quad \frac{\partial q_s^c}{\partial r} = -\frac{E(V_r^{s*} - \pi_r^*)}{\Delta} \leq 0; \\ \frac{\partial q_s^c}{\partial c_2} &= -\frac{E(V_{c_2}^{s*})}{\Delta} < 0; \quad \frac{\partial q_s^c}{\partial p_a} = \frac{E(V_{p_a}^{s*})}{\Delta} < 0; \\ \frac{\partial q_s^c}{\partial \omega} &= \frac{E(\pi_\omega^*)}{\Delta} > 0; \quad \frac{\partial q_s^c}{\partial \eta} = -\frac{E(V_\eta^{s*})}{\Delta} \geq 0. \end{aligned} \quad (2.22)$$

Here, $\Delta = E(V_{q_s^c}^{s*} - Z_{q_s^c}^{s*} - \pi_{q_s^c}^*) < 0$ is the second-order sufficiency condition for optimal land allocation. In the social planner's problem, (2.22) implies that a higher expected price before the price jump (μ), the price jump itself (δ) and the agricultural input cost (ω) all increase the amount of land that the social planner allocates to bioenergy forest production. The forest establishment cost (c_2) after the price jump and the price of the agricultural output (p_a) decrease the amount the land allocated to bioenergy forest production. The effects of a change in the interest rate (r) and the number of timing periods before price jump (η) on the amount of land allocated to bioenergy forest production are ambiguous. The latter market timing result was not ambiguous for the private landowner's problem; it occurs for the social planner because longer forest rotations favor public goods, and so a faster bioenergy market emergence may not always encourage the social planner to undertake robust bioenergy forest adoption.

Comparing the other results to those from the private landowner leads to some interesting conclusions. First, optimal input levels for agricultural production are the same for both the private landowner and the social planner because we assume agricultural production produces no amenity benefits. Second, optimal rotation ages before and after the price jump are longer for the social planner. This is because the social planner responds to the decrease in amenities associated with adoption of bioenergy forest production on some subset of land units. Finally, the effects of

all parameters except η , the time length (or the number of rotations) until a biomass market shift occurs, on critical land quality and optimal land allocations are the same for both the private landowner and social planner's scenario, although their magnitudes can differ dramatically as we show in the next section.

2.4 SIMULATION

We consider loblolly pine for conventional timber production and hybrid poplar for bioenergy forest production. Hybrid poplar has long been discussed and studied by foresters as a short rotation energy producing species (Armstrong et al. 1999, Yemshanov et al. 2008). The stand-level TAUYIELD model is used to simulate yields of loblolly pine sawtimber and pulpwood at different prospective rotation ages (Amateis et al. 1995). Optimal rotation ages of loblolly pine range from 8 years to 36 years using these data for different land qualities. Loblolly pines that are less than 8 years old usually are smaller than 6-8 inches in diameter breast height and thus have little commercial value. Land quality is simulated as in other studies using site index, or the height of dominant and co-dominant trees in the stand at age 25; these correlate with both growth rate and tree mortality over time. Three different loblolly pine site indexes, 45, 60 and 75, are used to signify low, average and high land quality respectively. In all three land quality continuum, we assume that 500 trees per acre are planted and the survival rates after the first year planting are 70%, 75%, and 80%, respectively. Yield data from TAUYIELD are factor-converted into units of green tons of wood harvested (equivalent to about 2,000 pounds). Costs of growing loblolly pine are taken from Folegatti et al. (2007) and include machine planting and prescribed burning costs. Average stumpage prices of pine sawtimber and pulpwood are taken from quarterly averages reported in Timber Mart-South for the period of 2004-2007, adjusted for inflation to 2007 dollars using U.S. Bureau of Labor and Statistics calculators.

Hybrid poplar yields are obtained from the Oak Ridge Energy Crop County Level database. Three different annual yields of hybrid poplar are observed, 2.5 tons per acre per year for land of low quality ('pessimistic' yield in the database), 4.5 tons for land of average quality ('average' yield in the database) and 5.5 tons for land of high quality ('optimistic' yield in the database) at the optimal rotation age. Costs of establishment include hand planting, planting material, and herbicide equal to 230 (inflation adjusted) dollars per acre based on data in Walsh (1998).

Specific market price data for bioenergy based hybrid poplar wood have not yet been established; we assume that the initial price is 15 dollars per ton. Six price jumps are assumed which equal 100%, 200%, 300%, 400%, 500% and 600% of the initial price, that is, 30, 45, 60, 75, 90, 105 dollars per ton, respectively. From the perspective of the landowner, five different timings of market emergence are assumed, i.e. T_1^* , $2T_1^*$, $3T_1^*$, $4T_1^*$ and $5T_1^*$, where T_1^* is the optimal rotation of loblolly pine. $5T_1^*$ is at least 36 years into the future and therefore acceptable to be a maximal timing of bioenergy market emergence.

The agricultural land use is assumed to be corn for grain production. County-level yields of 2007 in Georgia, a state where loblolly pine is an economically important tree species and is in the biological range of hybrid poplar, are taken from the National Agricultural Statistics Service of United States Department of Agriculture. We choose corn for grain as the agricultural product because in the United States corn is also used to produce biofuel. Yield data for hybrid poplar from ORECC database have data for 159 counties in Georgia and NASS has provided corn yield data for 88 counties in Georgia. We only kept data for those counties growing both hybrid poplar and corn after matching the two databases.

An average price of 3.5 dollars per acre is taken from the data. The fixed cost here, assumed to be the input rate for corn production establishment, is 215 dollars. It is conventional to assume that the corn production function takes a Cobb-Douglas form, $h(l, q) = l^{0.5}s(q)$ where $s(q)$ is the maximum output in each land quality class without other input involved from the dataset and is 70, 115 and 150 bushels per acre for low, average and high land quality, respectively. According then to the first order condition derived from the net present value function of profits from agricultural production in the last section, the optimal input levels are 0.33, 0.89 and 1.51 units for land of low, average and high quality classes, respectively. Recall that all corn market parameters are assumed to be certain. This all gives net present value land rents for corn production of \$2,301.67, \$6,221.67, \$10,645 per acre on low, average, and high quality sites.

The key to solving the land allocation problem is to find the critical land quality q_c on the quality continuum. The finding of q_c will lead to the solution of the share of the land quality continuum devoted to forest production L_f and to agriculture, $1 - L_f$. Comparing the expected net present value of combined maximum land rents from conventional forest production and

bioenergy forest production to that from corn production will provide us with the critical land quality with respect to each combination of price jump and timing of market emergence. Two forms of simulated transaction costs important to these decisions are considered. One is defined as the sum of optimal rotation ages of loblolly pine and hybrid poplar, i.e. $TC = T_1^* + T_2^*$. The other is non-linear, with $TC = 200 + T_1^{*2} + T_2^{*11}$. The nonlinearity of transaction costs emphasizes that the length of the optimal rotation age of the conventional tree species (loblolly pine) could be quite critical to the landowner's willingness to change land use. If the landowner perceives a fairly long time length of time before the wood bioenergy market emerges, he or she will be less willing to shift from crop production and more willing to keep growing loblolly pine on land units devoted to forest production rather than investing and replacing this tree species with hybrid poplar, perhaps in order to gain more information, technological assistance, and policy stability before adopting bioenergy production.

2.5 RESULTS

Table 2.1 shows the expected net present value of land rents from forestry using the highest rent species as we described in the model, which in every case is bioenergy production on land with low quality and linear transaction costs. Cells to the bottom and left of the bold line are those cases where bioenergy forest is established on part of land quality continuum, while others cells are cases where agriculture is chosen. Each cell must compare to the agriculture rents to determine whether land use changes (see tables). As in all of the results here, rents are increasing in land quality as measured in the model. Although not shown in the table, in cases where the future shift in the price of biomass for energy use is small or far into the future, the landowner grows loblolly pine to a full 36 year rotation before switching all forest land to bioenergy production, but in cases where markets are expected to emerge within a rotation period and the shift in price is more than 200%, loblolly pine is grown for the shortest amount of time possible (8 years) before the landowner switches to bioenergy production. In each table, cells to the right and above of the bold border line are those where the landowner grows agricultural crops on all land, including low quality.

¹¹ Transaction costs as a positive function of T_1^* and T_2^* makes sense because if the rotation age is longer, the decision to invest in bioenergy is more irreversible.

Comparing these results to net present values from corn production on the low quality land, we see that it is always more profitable to grow forests on the lowest quality land on the right hand side of the bold border line in Table 2.1, if transaction costs are of the linear form. This is not always the case with the same combination of price jump and timing of bioenergy market emergence, however, if transaction costs are nonlinearly increasing in the optimal rotation age. For example, referring to the optimal land rents in Table 2.2, only for those cells below and to the left of the bold line through the table is it more profitable to establish bioenergy forest production on low quality land. Table 2.2 shows that market emergence must happen during the first rotation and the expected price increase cannot be less than 400% in order to encourage bioenergy forest production adoption by the private landowner. Only in cases where markets develop robustly and prices shift to very high levels will landowners adopt bioenergy when bioenergy markets are expected to develop longer than one rotation ahead. However, contrast to Table 2.2, Table 2.1 shows that even if the bioenergy markets emerge during the first rotation, with linear transaction costs (which are less than nonlinear transaction costs in Table 2.2), the landowner will choose to invest into woody bioenergy production when the price jump is not less than 200% of the initial price.

The different shapes of bold border lines in Table 2.1 and Table 2.2 demonstrate the effects of transaction costs on land use change. Clearly, the precise nature of transaction costs is critical for policy and markets as they interact importantly with the misinformation a landowner has about market emergence and the known annual returns that can be captured from agricultural land. Reducing uncertainty through government investments in bioenergy may be important, and this carries through to other land quality results as well.

On average and high quality lands, shown in Tables 2.3-2.6, we find now that the results are more pronounced. While yields are higher for forest production of both types, they are also higher for crop production. Now considerable expected market shifts are needed for bioenergy adoption, and there are fewer cells where forestry of any type is preferred since agricultural yields start to dominate. For example, at average land qualities (closest to the critical land quality margin in Figure 2.1), even if bioenergy markets emerge within one rotation, the landowner requires a very high expected price increase for linear transactions costs and a seemingly insurmountable 300% or more increase for nonlinear transaction costs in order to adopt bioenergy forest production over agricultural production; this makes it doubtful that we would see

widespread bioenergy adoption except under only the most optimistic, and possibly unrealistic, futures market emergence scenarios. This said, comparing across low to high quality sites in Tables 2.1 – 2.6, we do see that significant woody biomass based bioenergy market emergence can encourage adoption of bioenergy forest production not only through replacing conventional loblolly pine production but also through pushing the land quality margin between agriculture and forestry to higher land qualities. Without factoring in transaction costs, though, this effect would be highly misleading and overstated, as our results make clear.

We can also investigate the importance of the landowner's rate of time preference on land use decisions since this parameter had ambiguous effects in the theory. The formulation of V in the risk-neutral private landowner model suggests that the interest rate enters forest production rents in a more complicated way than it does with agriculture. On land with the same quality, expected NPV of land rents from forestry with an interest rate equal to 0.03 is larger than that with an interest rate equal to just 0.04. With other factors remaining the same and interest rates jumping to 0.04, the net present value of land rents from agriculture on low, average, and high quality land are \$1726.25, \$4666.25, and \$7983.75, respectively, which are lesser than the counterparts of the interest rate being 0.03. Table 2.7 gives an illustration of how the interest rate affects the land use decision for the landowner on land with average quality and nonlinear-form transaction costs. It is worth pointing out that a higher interest rate, 0.04, not only makes the expected NPV of rents from forestry significantly lower from those with an interest rate of 0.03, but also the expected NPV from some combinations of price jump and timing of bioenergy market emergence becomes negative. The different shapes of the bold border lines from the two subtables in Table 2.7 also indicate the different conditions for the realizations of investment in bioenergy production.

When the interest rate equals 0.03, a price jump of at least 300% of the base price for biomass is required if markets emerge in the first timing period for the landowner to invest in biomass instead of agriculture on low and average land qualities. However, if the interest rate increases to 0.04, then forestry production is not more profitable than agricultural production and now market emergence in the first rotation requires a woody biomass price jump of 500% of the initial price to make bioenergy production economically feasible.

From the above analysis, we can tell that in cases where there are greater investment opportunity costs, governments must be more involved in market emergence if the goal is

bioenergy adoption and reduced dependence on conventional energy sources. Moreover, government policy decision must account for transaction costs.

The social planner's problem is different from the private landowner as we have discussed. Some results for the social planner are similar, however, such as the effects of increasing land quality on rents, and the required expected future market scenarios that encourage bioenergy forest production by substitution of loblolly pine and pushing of the land quality margin for forest production into higher land qualities. However, these do not all happen at the same levels, because the social planner values the relative amenities to conventional and bioenergy forest production, albeit to different extents. To investigate these differences, we use an amenity function common in forest economics work (Swallow et al. 1990, Amacher et al. 2009) that takes the concave form $A = b_0 T \exp(-T/b_1)$. For loblolly pine, the parameters are $b_0 = 12$ and $b_1 = 20$, and T is replaced by T_1^* , while for hybrid poplar, we use $b_0 = 6$, $b_1 = 12$, and T is replaced by T_2^* . Figure 2.2 shows the net present value of cumulative amenity benefits from growing loblolly pine at different rotation ages ranging from 8 to 36 years, which is the result for $\int_0^{T_1} A_1(x)e^{-rx} dx$.

Table 2.7 displays rents and cut-off points for land conversion to bioenergy production for the social planner holding low, average, and high quality lands, and facing a linear form of transaction costs¹². The inclusion of amenities increases expected forest NPV rents V considerably as the table shows. Comparison of these results to those for the private landowner in Tables 2.1-2.6 shows that the social planner is more likely to prefer forest production of any kind, and bioenergy production in particular, under a larger range of biomass market emergence scenarios. On land with low quality, there is only one case with the combination of the market emergence during the first rotation and price jump being 100% of the initial price where agricultural production is favored over forestry. Otherwise, the social planner will choose to invest in forest bioenergy production instead. The reason for this significant result is that the conversion of land from agriculture to forest bioenergy production is assumed to occur on the

¹² It is debatable whether the social planner would respond to transaction costs in the same way as a private landowner, but we leave them in as our main goal is to examine the amenity valuation distinction between these landowners.

margin of agricultural land. Combining it with the assumption of relative rents between agriculture and forestry, we can tell that the social planner would favor forest bioenergy production on land of low quality. The results for land of average quality and high quality are not as significant. On land with average quality, the social planner will convert from agriculture to forest production for six cases as opposed to four cases for the private landowner. However, on land of high quality, both the private landowner and the social planner are interested in forestry investment only for a realization of the price jump equal to 600% of the initial price within the first rotation. This observation is consistent with the assumption of relative rents. For land of top quality, both decision makers choose agriculture more. This happens here even though we have structured amenities so that energy security is not as highly valued as amenities to conventional forest production due to ecosystem services; the differences would be even more in favor of bioenergy forest adoption if the social planner's energy security amenities were increased. Still, we see the pattern emerging for both landowners that, as land quality increases, the required expected market emergence can be less optimistic to guarantee bioenergy forest adoption on a wider part of the land quality continuum. Another significant difference between the private landowner and social planner is that land rents from forestry (timber production and forest bioenergy production) for the social planner are increasing with a longer timing period of the emergence of biomass markets. The explanation is that the social planner is viewed to value public goods (or amenity benefits) from growing timber production tree species and forest bioenergy production tree species to a greater extent (conventional timber production yields a lot more public goods than bioenergy of one thinks about goods such as wildlife habitat). A later realization of the emergence biomass markets will enable the social planner to gain more from amenity benefits.

2.6 DISCUSSION

We have examined how uncertain emerging biomass markets will affect land allocation for both a private forest landowner and a social planner who differ in terms of public goods valuations. Several important features are considered explicitly, such as land quality, transaction costs, and the timing and extent of future woody biomass market emergence. Complementary to the existing literature, this study illustrates the importance of including land quality into land use problems. Different land quality will affect the land allocation decision significantly even under the same expected biomass price and expected price increase. Transaction costs are an even more

important issue, and one not considered in other land use studies. We show that including these costs requires often unrealistic biomass market emergence scenarios before widespread adoption of bioenergy forest production will occur on existing land holding conventional forests and agriculture. In all cases, the timing of future biomass market emergence plays a critical role in that even with a high level of expected biomass price, the sooner that markets develop, the more profitable investment in woody biomass production will be. In forestry studies, future market uncertainty is usually modeled as an unknown price in future time periods. Our results suggest that, for land use decisions at least, the timing of market emergences or shifts can be an even more important uncertain parameter than the absolute future price level for a range of land qualities.

Numerical results for both a representative private landowner and social planner support that land allocated to woody biomass production increases with an increase in expected biomass price and an earlier timing of biomass market emergence. If transaction costs are high, the expected price jump has to be extremely high in order to make land conversion profitable. This draws into question land use change models without transaction costs and questions predictions of biomass market effects made without transaction costs in mind. Studies that ignore transaction costs will come up with much more optimistic bioenergy land use projections.

In addition, these results collectively demonstrate the challenges policy makers face in trying to ensure there is a ready supply of woody biomass available when markets finally emerge on a wide scale. There are two conventional means for encouraging bioenergy development: subsidies for its establishment (tax breaks), and reduced subsidies for agricultural production. Both of these would increase relative rents to the bioenergy forest land use and ensure, as our theoretical model shows, at least some substitution of bioenergy for conventional timber production as well as a change in the margin between agriculture and forestry in favor of forest production on land of higher qualities. It is clear that these instruments must be chosen carefully not only to compensate for relative rent differences between the competing land uses, but also to account for the transaction costs that we find are critically important to landowner decisions.

This work also reveals two other important policy options. First, the government could find ways to support increased demand for wood-based bioenergy, perhaps through incentives targeting consumption of goods using these sources. This would serve to ensure optimistic prices when markets develop that we show are important to land use decisions. Second, and perhaps

more important, the government could invest in technologies or market emergence that would ensure bioenergy products can be sold from forest land sooner rather than later. For any price, our results show that development of markets within ten to twenty years would ensure that bioenergy supply is available in time under a range of transaction costs. Delays in viable markets will not lead to widespread adoption, and this will be even more true depending on the precise magnitude of transaction costs the landowners perceive due to lack of information or simply the different type of returns obtained from rotation-based forestry compared to agricultural land use. That said, anything the government can do to remove uncertainty concerning future biomass markets is a first step in overcoming these obstacles.

This chapter assumes that agricultural production is constant over time. The constancy of output price is reasonable and fair here for the analysis of land use change from agriculture to other land use alternatives. However, price variability of agricultural products could exist and this variability could be unknown to the landowner making land use change decisions. If the variability of prices for agricultural output is considered in the analysis, we may expect the adoption of forest bioenergy to become a more favorable land use option than in the current analysis. The extent of the effect of including the price variability of agricultural product on land use change requires an extension of the above analysis, however.

In addition, the price for agricultural production could change once biomass markets emerge and there is substitution of bioenergy for crops on the land use continuum, and there may be some cases where some land of woody biomass production is converted to agricultural production if the price of agricultural output rises high enough. In our analysis, this would simply represent a more pessimistic biomass market emergence scenario since land for woody biomass production decreases.

Future work should imbed the land use problem here into a policy choice problem where the goals are to compensate for all important costs and ensure a stable flow of energy from alternative sources. Further, the open loop nature of land use could be relaxed by considering a more dynamic stochastic problem where the landowner revises information over time as biomass markets emerge. Even in this more dynamic problem, however, the same basic importance we show for transaction costs, and land quality would continue to be present. Finally, this land use problem has been solved as a one shot solution made at the beginning of the time horizon. Land

use transitions may be important as markets emerge, and this could be studied with a suitable dynamic extension of our current model.

Figure 2.2: NPV of amenity benefits from growing loblolly pine to different potential rotation ages

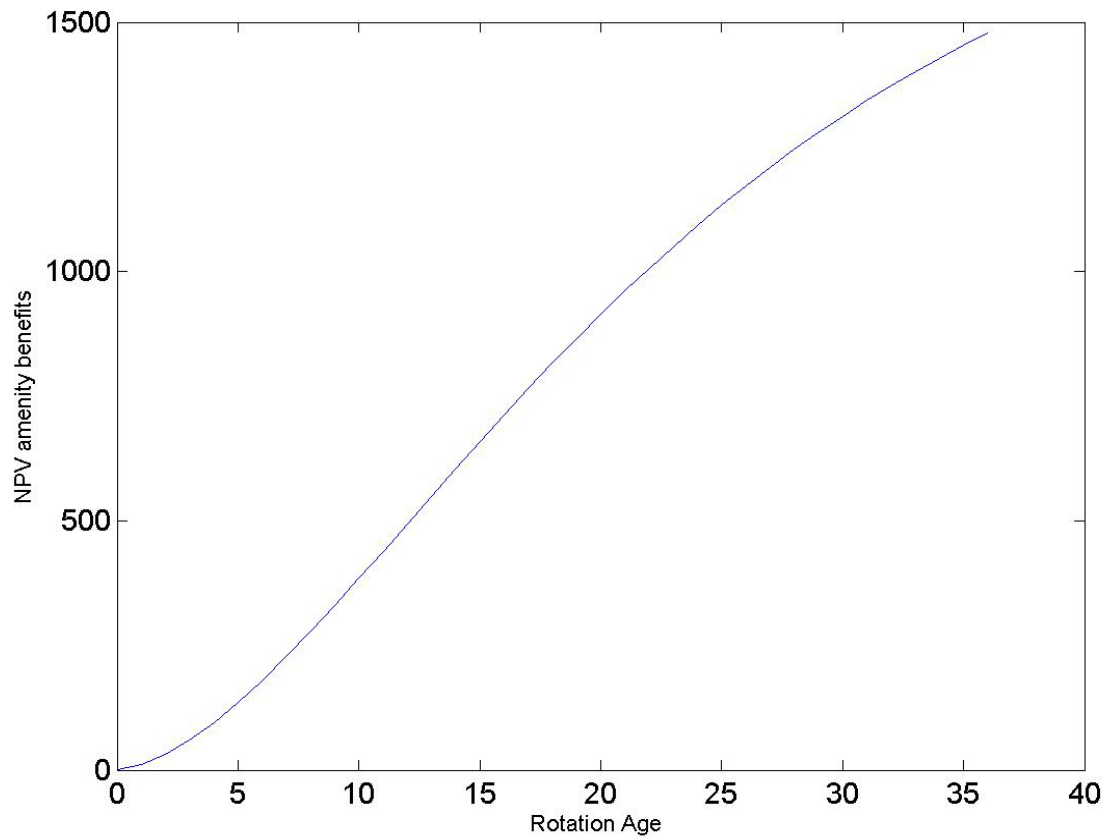


Table 2.1: Expected NPV of land rents from forestry on low quality land with linear form transaction costs

TP \ PJ	1	2	3	4	5
100%	588	325	262	241	233
200%	1497.22	915.24	457.45	131.43	239.21
300%	2406.11	1630.21	1019.86	539.74	244.43
400%	3315.01	2435.17	1582.27	982.15	510.08
500%	4223.91	3060.14	2144.68	1424.56	858.09
600%	5132.81	3775.10	2707.09	1866.97	1206.10

Note: PJ=price jump; TP= timing periods until bioenergy market emergence.

NPV of land rents from agriculture is \$2301.67.

Table 2.2 : Expected NPV of land rents from forestry on low quality land with nonlinear transaction costs

TP \ PJ	1	2	3	4	5
100%	332.32	-55.72	-360.96	-601.07	-789.95
200%	1241.22	659.24	201.45	-158.67	-491.42
300%	2150.11	1371.21	763.86	283.74	-93.93
400%	3059.01	2089.17	1326.27	726.15	254.08
500%	3967.91	2804.14	1988.68	1168.56	602.09
600%	4876.81	3591.10	2451.09	1610.97	950.10

Note: PJ=price jump; TP= timing periods until bioenergy market emergence.

NPV of land rents from agriculture is \$2301.67.

Table 2.3: Expected NPV of land rents from forestry on average quality land with linear form transaction costs

TP \ PJ	1	2	3	4	5
100%	1926.17	1352.65	1234.72	1194.67	1181.07
200%	3491.49	2509.00	1736.14	1221.13	1190.05
300%	5056.82	3740.32	2704.73	1890.11	1249.30
400%	6622.14	4971.65	3673.33	2652.03	1848.65
500%	8187.47	6202.98	4641.93	3413.96	2448.01
600%	9752.79	7434.31	5610.52	4175.88	3047.36

Note: PJ=price jump; TP = timing periods until bioenergy market emergence

NPV of land rents from agriculture is \$6221.67.

Table 2.4: Expected NPV of land rents from forestry on average quality land with nonlinear form transaction costs

TP \ PJ	1	2	3	4	5
100%	1670.17	1021.67	511.54	309.53	267.16
200%	3235.49	2253.00	1480.14	872.18	393.95
300%	4800.82	3484.32	2448.73	1634.11	993.30
400%	6366.14	4715.65	3417.33	2396.03	1592.65
500%	7931.47	5946.98	4385.93	3157.96	2192.01
600%	9496.79	7178.31	5354.52	3919.88	2791.36

Note: PJ=price jump; TP= timing periods until bioenergy market emergence.

NPV of land rents from agriculture is \$6221.67.

Table 2.5: Expected NPV of land Rents from forestry on high quality land with linear-form transaction costs

TP \ PJ	1	2	3	4	5
100%	3219.9	3037.35	2956.15	2920.02	2903.95
200%	4591.66	3549.24	3175.90	3015.55	2946.45
300%	6510.45	4923.58	3675.30	3111.08	2988.95
400%	8429.23	6432.95	4862.61	3627.34	3031.44
500%	10348.02	7942.32	6049.92	4561.32	3390.34
600%	12266.80	9451.68	7237.24	5495.29	4125.03

Note: PJ=price jump; TP= timing periods until bioenergy market emergence.

NPV of land rents from agriculture is \$10645.

Table 2.6: Expected NPV of land rents from forestry on high quality land with nonlinear transaction costs

TP \ PJ	1	2	3	4	5
100%	2441.85(22)	2205.96(24)	2109.91(25)	2065(25)	2043.79(25)
200%	4335.66(8)	3158.21(8)	2380.86(23)	2186.44(25)	2101.16(25)
300%	6254.45(8)	4667.58(8)	3419.30(8)	2437.37(8)	2158.52(25)
400%	8173.23(8)	6176.95(8)	4606.61(8)	3371.34(8)	2399.65(8)
500%	10092.02(8)	7686.32(8)	5793.92(8)	4305.32(8)	3134.34(8)
600%	12010.80(8)	9195.68(8)	6981.24(8)	5239.29(8)	3869.03(8)

Note: PJ=price jump; TP= timing periods until bioenergy market emergence.

NPV of land rents from agriculture is \$10645.

Table 2.7: Effects of interest rates on landowner's expected NPV land rents and land allocation decision on average -quality land with nonlinear transaction costs

Interest rate $r = 0.03$					
TP \ PJ	1	2	3	4	5
100%	1670.17	1021.67	511.54	309.53	267.16
200%	3235.49	2253.00	1480.14	872.18	393.95
300%	4800.82	3484.32	2448.73	1634.11	993.30
400%	6366.14	4715.65	3417.33	2396.03	1592.65
500%	7931.47	5946.98	4385.93	3157.96	2192.01
600%	9496.79	7178.31	5354.52	3919.88	2791.36
Interest rate $r = 0.04$					
TP \ PJ	1	2	3	4	5
100%	898.18	341.13	-63.38	-199.53	-219.48
200%	1943.15	1099.93	487.63	43.00	-206.85
300%	2988.11	1858.73	1038.63	443.11	10.68
400%	4033.07	2617.53	1589.63	843.223	301.22
500%	5078.04	3376.33	2140.63	1243.33	591.76
600%	6123.00	4135.13	2691.63	1643.44	882.30

Note: PJ = Price Jump, TL = timing periods until bioenergy market emergence.

NPV of land rents from agriculture with $r = 0.03$ and average land quality is \$6221.67.

NPV of land rents from agriculture with $r = 0.04$ and average land quality is \$4666.25.

Table 2.8: Social planner's expected NPV of land rents from forestry

Expected NPV Land Rents from Low- quality Land with linear transaction costs					
TP \ PJ	1	2	3	4	5
100%	2134.63(36)	2343.60 (36)	2414.57 (36)	2438.67 (36)	2446.86(36)
200%	2527.02(36)	2476.86(36)	2459.82(36)	2454.04(36)	2452.08(36)
300%	3025.98(8)	2610.11(36)	2505.08(36)	2469.41(36)	2457.29(36)
400%	3934.88(8)	3086.36(8)	2550.33(36)	2484.77(36)	2462.51(36)
500%	4843.77(8)	3801.32(8)	2981.29(8)	2500.14(36)	2467.73(36)
600%	5752.67(8)	4516.28(8)	3543.70(8)	2778.64(8)	2472.95(36)
Expected NPV Land Rents from Average- quality Land with linear transaction costs					
TP \ PJ	1	2	3	4	5
100%	3345.24(33)	3402.47(33)	3423.74(33)	3431.64(33)	3434.58(33)
200%	4133.88(28)	3698.46(30)	3533.83(32)	3473.33(32)	3450.17(32)
300%	5676.68(8)	4481.50(8)	3657.6s0(30)	3516.10(32)	3466.55(32)
400%	7242.01(8)	5712.83(8)	4509.94(8)	3563.71(8)	3482.92(32)
500%	8807.33(8)	6944.16(8)	5478.53(8)	4325.63(8)	3499.30(32)
600%	10372.65(8)	8175.49(8)	6447.13(8)	5087.56(8)	4018.08(8)
Expected NPV Land Rents from High- quality Land with linear transaction costs					
TP \ PJ	1	2	3	4	5
100%	4654.26 (29)	4889.03(29)	4987.39(29)	5028.60(29)	5045.86(29)
200%	5703.87(27)	5334.06(27)	5172.34(28)	5104.62(28)	5077.34(29)
300%	7130.31(8)	5837.24(25)	5384.3(27)	5191.90(27)	5111.97(28)
400%	9049.10(8)	7174.12(8)	5699.22(8)	5287.43(27)	5148.81(27)
500%	10967.88(8)	8683.49 (8)	6886.53(8)	5472.99(8)	5191.31(27)
600%	12886.66(8)	10192.86(8)	8073.84(8)	6406.96(8)	5233.81(27)

Note: PJ=price jump; TP= timing periods until bioenergy market emergence. NPV of AG. land rents is \$2301.67, \$6221.67 and \$10645 on low, average and high quality, respectively.

2.7 REFERENCES

Amacher, G.S., M. Ollikainen, and E. Koskela. 2009. Economics of forest resources, Cambridge: MIT Press.

Amateis, R., P. Radtke, and H. Burkhart. 1995. TAU YIELD: A stand growth and yield model for thinned and unthinned loblolly pine plantations. Loblolly Pine Growth and Res. Cooperative. Rept. No. 92. Virginia Tech, Blacksburg, Va.

Armstrong A, C. Jones, and I. Tubby. 1999. Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop. Biomass and Bioenergy 17(4): 305-314.

Berndes, G., M. Hoogwijk, and R. van den Broek (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy 25(1): 1-28.

Chakravorty, U., B., B. Magn and M. Moreax (2008). A dynamic model of food and clean energy. Journal of Economic Dynamics and Control 32(4): 1181-1203.

Energy Information Administration. U.S. Imports by Country of origin. Web 28 Sept. 2009. <
http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbb1_m.htm>

Folegatti, B.S., M.F. Smidt and M.R. Dubois (2007). Costs and cost trends for forestry practices in the South. Forest Landowner, Sep/Oct. : 11-16.

Gong, P., M. Boman, and L. Mattsson (2005). Non-timber benefits, price uncertainty and optimal harvest of an even-aged stand. Forest Policy and Economics 7(3): 283-295.

Graham R.L and L.J. Allison (1996). Oak Ridge Energy Crop County Level Database-ORECCL, Oak Ridge National Laboratory, Oak Ridge, TN.

Heaton, R. J., P. F. Randerson, and F.M.Slater (1999). The economics of growing short rotation coppice in the uplands of mid-Wales and an economic comparison with sheep production. *Biomass and Bioenergy* 17(1): 59-71.

Hoffmann, D. and M. Weih (2005). Limitations and improvement of the potential utilization of woody biomass of energy derived from short rotation woody crops in Sweden and Germany. *Biomass and Bioenergy* 28: 267-279.

Junginger, M., M. de Wit, R. Sikkema and A. Faaj (2008). International bioenergy trade in the Netherlands. *Biomass and Bioenergy* 32(8): 672-687.

Katz Solomon H. (2008). Food to fuel and the world food crisis. *Anthropology Today* 24(1): 1-3.

Lichtenberg, E. (1989). Land quality, irrigation development, and cropping patterns in the Northern High Plains. *American Journal of Agricultural Economics* 71(1): 187-194.

Malinen, J., M. Pesonen, T. Määttä and M. Kajanus. (2001). Potential harvest for wood fuels (energy wood) from logging residues and first thinnings in Southern Finland. *Biomass and Bioenergy* 20(3): 189-196.

Malmsheimer, R. W., P. Heffernan, S. Brink, D.Crandall, F. Deneke, C. Galik, E. Gee, J.A. Helms, N. McClure, M.Mortimer, S.Ruddell, M. Smith, and J.Stewart. (2008). Forest Management Solutions for Mitigating Climate Change in the United States. *Journal of Forestry* 106: 115-118.

Mckay, H. (2006). Environmental, economic, social and political drivers for increasing use of woodfuel as a renewable resource in Britain. *Biomass and Bioenergy* 30: 308-315.

Meshack, C.K., B. Ahdikari, N. Doggart, J.C. Lovett. (2006). Transaction costs of community-based forest management: empirical evidence from Tanzania. *African Journal of Ecology* 44(4): 468-477.

Mitchell, D. (2008). A note on Rising Food Prices 4682, World Bank Policy Research Working paper.

Parks, P.J. and Ian W. Hardie (1995). Least-cost forest carbon reserves: cost-effective subsidies to convert marginal agricultural land. *Land Economics* 71(1): 122-136.

Patzek Tad W. and S.-M. Anti and R. Campos and K. W. ha and J. Lee and B. Li and J. Padnick and S.-A. Yee (2005). Ethanol From Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets? *Environment, Development and Sustainability* 7(3): 319 – 336.

Phillips, V. D., W. Liu, et al. (1995). Short-rotation forestry as an alternative land use in Hawaii. *Biomass and Bioenergy* 8(4): 235-244.

Pimentel, D. (1991). Ethanol fuels: Energy security, economics, and the environment. *Journal of Agricultural and Environmental Ethics* 4(1): 1-13.

Romero, C., V. Ros, and L. Diaz-Balteiro (1998). Optimal forest rotation age when carbon captured is considered: theory and applications. *Journal of operational research society* 49(2): 121-131.

Sudha, P. and N. H. Ravindranath (1999). Land availability and biomass production potential in India. *Biomass and Bioenergy* 16(3): 207-221.

Swallow, S.K., P.J.Parks, and D.N.Wear (1990). Policy-relevant nonconvexities in the production of multiple forest benefits. *Journal of Environmental Economics and Management* 9(3): 264-280.

van Kooten, G. C., S. L. Shaikh, et al. (2002). Multigating Climate Change by Planting Trees: The Transaction Costs Trap. *Land Economics, University of Wisconsin Press.* 78: 559.

Walsh, M.E. (1998). U.S. bioenergy crop economic analysis: status and needs. *Biomass and Bioenergy* 14(4): 341-350.

Wilent, S. (2008). State Issues Guidelines for Forest Biomass Harvesting. *The Forestry Source* 13(9).

Yemshanov D and D. Mckenny, 2008. Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop *Biomass and Bioenergy* 32(3): 185-197.

Zhang, Y. (2001). Economics of transaction costs saving forestry. *Ecological Economics* 36(2): 197 – 204.

CHAPTER 3: UNCERTAIN EMERGING BIOMASS MARKETS AND LAND USE FOR A RISK-AVERSE PRIVATE LANDOWNER

3.1 ABSTRACT

This chapter examines a land use problem where a risk-averse representative landowner is uncertain about the timing and extent of future biomass market emergence. The landowner is expected to maximize his or her expected utility from land rents from agriculture and forestry. Some key factors such as varying land quality, transaction costs, the extent of price increase and the timing of biomass market emergence are incorporated into the analysis. The theoretical analysis explores the different results and possible reasons under two assumptions concerning relative risk aversion.

The simulation results show that level of risk aversion has an important influence on land allocation, and these result are significantly different findings compared to the risk-neutral model in Chapter 2. In addition, the effects of transaction costs, price increases and the timing of biomass market emergence are also studied. On land with high quality and nonlinear transaction costs, regardless of the level of risk aversion, the landowner retains all land in agriculture. All high-quality land is also allocated to agriculture when transaction cost is linear and the uncertainty level is low. A possible reason is that the landowner expects higher biomass price only under higher uncertainty levels. Generally, more low-quality land would be allocated to forestry than average-quality land. But more land will be allocated to forestry when the uncertainty level is higher.

3.2 INTRODUCTION

The applicability of forest biomass to alleviate climate change and energy dependence has advantages such as carbon storage, financial assistance, and technological support from governments and research organizations throughout the world. The growth of local and regional bioenergy markets provides a signal of a likely development of widespread woody biomass markets. Regulations and policy from federal government agencies such as the Renewable Fuel Standard (RFS) program, that was further expanded under the Energy Independence and Security Act (EISA) of 2007, and memorandums regarding development of woody biomass for energy use in several states such as Pennsylvania, Maine and Michigan, have offered a promising scenario for using woody biomass for energy production (Aguilar et al. 2010). The influence of these changes on the forest sector can be very significant since woody biomass production may affect the land use decisions of private landowners. In order to capture its effects on land use change, we present and analyze a model of land use where biomass markets are not present but there is an expectation that they will emerge at some point in the future, so that the timing and extent of emergence can affect land use decisions in the present given that trees are planted many years ahead of their merchantability.

The uncertainty of the emerging bioenergy markets introduces some risk into the landowner's decision making. This risk plays a role in land use yet it has relatively been studied sparsely in the literature. Chapter 2 studied a land use problem where future biomass markets can emerge and landowners are risk neutral. We found that the timing of market emergence is important to land use change, and that the presence of transaction costs can prevent adoption of bioenergy production in many circumstances depending on the level of uncertainty and the relative returns of alternative land uses on land units of varying qualities. Some of those results are sensitive to the fact that landowners are assumed to maximize expected net present value of returns over time. In the literature on forest landowners, there is a good reason to believe that landowners are risk averse given the extent of their financial resources. These landowners likely maximize expected utility of returns to land over time (Parks et al. 1995, Gong 1998, Gong et al. 2003, Gong et al. 2008). For land use, this is a critical assumption; because a landowner who is risk averse to changes in income is also averse to future uncertain market changes that may reduce returns on any given land unit. The majority of the formative literature in stochastic forest economics is centered on rotation age and harvesting that has and

continues to be based on risk neutral assumptions for mathematical convenience (Amacher et al. 2009, Brazee et al. 1988, Thomson 1992, and Plantinga 1998).

A model is developed in this chapter to examine how a private risk-averse landowner might adjust his or her land allocation decision in the face of emerging markets for woody biomass. Net returns from conventional timber production and short-rotation biomass production compete based on production technologies and price levels. The assumption of the development of a biomass market in the future allows for a comparison of expected utility from rents according to forestry biomass production as well as other land use alternatives such as agriculture and conventional timber production. Since biomass markets are nascent and forestry is a long-term investment, the timing of any future price shifts for forest products is very important to present decisions. How one should capture these factors in a land use analysis is a critical question for policy makers interested in eventually shifting production toward bioenergy alternatives.

3.3 MODEL OF A RISK-AVERSE LAND OWNER

We now describe how a private risk-averse landowner allocates land optimally between agricultural crop and woody biomass production in a way that maximizes the expected utility from land use on each land unit, where land units can vary in quality. The model measures a transition from a single agricultural land use to multiple land uses, as the interest is to determine how land in forest production changes with anticipation of future biomass market emergence to different extents. As in Chapter 2, the impact of transaction costs on land use decision making is critical here as well. However, in our risk averse landowner problem, the inclusion of transaction costs is directly linked to the landowner's willingness or reluctance to change land use when exposed to greater market and price uncertainty.

Assume that there is a future price change motivated by a targeted government policy shift that is consistent with subsidies for biofuel consumption from biomass or technology development. The reasonability of these future events is clear. First, advances in technologies and lower costs are likely to increase demand for biomass by processors. Second, a shift of subsidies for consumer use of fuels may change relative land rents for any acre on a land quality continuum managed by a risk-averse forest landowner. As in Chapter 2, we suppose that the timings of these two events are not known to the representative forest landowner at the start of his or her time horizon, and both the timing of a market shift and its new price level are also

assumed unknown to the landowner when the landowner makes land use decisions in the first period. We will therefore examine a problem where a risk-averse forest landowner is forced to make costly land use decisions at the beginning of his or her time horizon with an expectation of future events and uncertain future biomass markets emergence.

Suppose currently that only agricultural production is practiced on a land quality continuum, and at time T the price of biomass jumps from p_1 to p_2 . Time T is unknown to the landowner, and instead the landowner perceives this time point as \hat{T} , where $\hat{T} = \eta T_1 + \theta$, $\eta \in N$, and $0 \leq \theta \leq T_1$. η here is the number of timing periods until the emergence of biomass markets, and the length of each timing period is assumed to be represented by the optimal rotation age of the conventional tree species¹³. T_1 is defined as the rotation age for the conventional tree species. The expected price jump embodies the effects of a market shift, future dismissal of government crop subsidies, or a tax credit accompanying biomass production on forest land. Now let $\mu_1 = E(p_1)$ be the expected price of the conventional tree species and $\mu_2 = E(p_2)$ be the expected price of the short-rotation energy dedicated tree species; further assume $p_1 = \mu_1 + \sigma\varepsilon$ and $p_2 = \mu_2 + \sigma\varepsilon + \delta$. The random variable ε is mean zero and has standard deviation one, and the parameter δ signifies the level of the expected price jump after market emergence.

The positive parameter σ is interpreted as pure price uncertainty. When it increases, there is a mean-preserving spread in price, signifying increased price uncertainty from the perspective of the landowner. Timber production from growing conventional trees before the price jump and woody biomass production from short-rotation tree species after the price jump, assuming that the market emergence is enough to change land use, are represented by the technologies, $f(T_1, q)$ and $g(T_2, q)$, respectively. These two growth functions measure possible changes in technologies associated with a change in species established on each land unit after the market shifts, where $g(T_2, q) > f(T_1, q)$ for the same land quality. The time periods T_1 and T_2 are rotation ages before and after the price jump, for conventional timber and biomass

¹³ In the simulation section, five different values of η are used to represent the different possible timings of the realization of the emergence of biomass markets. The whole timing periods are long enough for the analysis.

production, respectively ¹⁴. Land quality q includes a vector of characteristics such as soil and slope that is an argument in the forest growth function and important for the landowner's decision making. The range of land quality is normalized to be between 0 and 1, which represents minimal and maximal qualities, respectively. Let the probability density function for land quality q be $k(q)$. Following Lichtenberg(1989)¹⁵, let $G(q)$ represent the distribution function of land with quality, q , thus $k(q) = G'(q)$. Moreover, $q \in [0,1]$ implies that $G(1) - G(0) = 1$ is the total land area available to the landowner. Concavity of forest growth functions implies that: $f_q(T_1, q) > 0$, $f_{qq}(T_1, q) < 0$, $g_q(T_2, q) > 0$, and $g_{qq}(T_2, q) < 0$.

As we assume that the landowner has some expectation of the time point of market emergence, the landowner will harvest conventional trees for timber at the time point of ηT_1^{th} , i.e., $\theta = 0$. Then establish the biomass production tree species and harvest it at a new rotation age T_2 and at a price p_2 ad infinitum. V_1 and V_2 represent net present value of land rents from growing conventional tree species before the price jump and short-rotation energy dedicated trees after the price jump, respectively, and are defined as follows:

$$\begin{aligned} V_1 &= \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] + e^{-rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] + \\ & e^{-2rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] + \dots + e^{-(\eta-1)rT_1} \left[p_1 f(T_1, q) e^{-rT_1} - c_1 \right] \\ &= \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} \left[p_1 f(T_1, q) e^{-r T_1} - c_1 \right] \end{aligned} \quad (3.1)$$

$$V_2 = \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} \left[p_2 g(T_2, q) e^{-r T_2} - c_2 \right], \text{ and} \quad (3.2)$$

$$V = V_1 + V_2$$

¹⁴We assume that the biomass energy dedicated tree species is clear-cut before a new rotation begins, as is usually the recommendation.

¹⁵Unlike Lichtenberg (1989), land quality q considered in this study is different in that we incorporate land's existing quality into production and illustrate how it affects profitability for each land unit.

$$= \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} \left[p_1 f(T_1, q) e^{-r T_1} - c_1 \right] + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} \left[p_2 g(T_2, q) e^{-r T_2} - c_2 \right] \quad (3.3)$$

where c_1 and c_2 are the constant regeneration costs before and after the switch of tree species on each land unit, respectively, and r is the market interest rate. Here, V is the total net present value of land rents from all forestry production on the same land unit over the landowner's time horizon. In addition, $V_2 > V_1$ has to be satisfied for the landowner to adopt energy biomass production on some land units after the price jump. We assume this is the case throughout.¹⁶

On land devoted to agricultural crop production, the landowner is assumed to know all parameters with certainty, where the input price is denoted by ω and the output price by p_a . The crop production function, $h(\ell, q)$, is monotonically increasing in the input ℓ and land quality q , and $h_\ell(\cdot) > 0$ and $h_q(\cdot) > 0$. The net present value function of land rents for agriculture on a given land unit is therefore formulated as follows:

$$\pi = \int_0^\infty [p_a h(\ell, q) - \omega \ell] e^{-rt} dt \quad (3.4)$$

As in the second chapter, we introduce transaction costs to establish the bioenergy tree species that go beyond planting costs. Let $Z(\cdot)$ be defined as this transaction costs function 'paid' at the time of establishment, which are one-time sunk costs incurred by land use change; it can be interpreted without loss as a reluctance of the landowner to switch into a different form of production. For example, if rotation ages are relatively long, the landowner may not readily shift a land unit from crop production that produces annual yields. Moreover, unfamiliarity with bioenergy dedicated forest production may increase the cost of adopting it at the margin. Under this assumption the term $(V - Z)$ is then total expected net present land rents on each land unit along the quality continuum when forest production is chosen. In order to ensure a unique solution, following Amacher et al. (2009, Chapter 2), we make two additional assumptions about the relative rents between agricultural practice and forestry: 1. $(V - Z) < \pi$ for $q < 1$; 2. $(V - Z) > \pi$ for $q = 0$. These state that forest production is relatively more profitable on lower quality land.

¹⁶ If not, then the landowner simply practices conventional timber production forever on land units devoted to forestry.

To make the property of risk aversion clear, note that the wealth of the landowner, W , is derived from agricultural crop production and forestry production on all land units, where forestry production income derives from the net benefits of conventional forest and woody biomass production. That is, $W = L_f(V - Z) + (1 - L_f)\pi$, where L_f is the share of land devoted to forest production. Let $U(\cdot)$ be a concave, continuous and differentiable von Neumann-Morgenstern utility function which satisfies $U'(W) \equiv \frac{\partial U}{\partial W} > 0$ and $U''(W) \equiv \frac{\partial^2 U}{\partial W^2} < 0$. The optimal rotation ages for conventional forestry and woody biomass forestry, T_1^* and T_2^* , are derived from finding the first order condition of $U(V)$ with respect to T_1 and T_2 . In a similar way, we derive the optimal input level of l^* by finding the first order condition of $U(\pi)$ with respect to l . Substituting the resulting optimal choices T_1^* and T_2^* into V and Z and l^* into π we arrive at an indirect utility of rent function based on maximized land use returns V^* , Z^* and π^* .

The landowner's problem is now to maximize expected utility $U(W)$ by optimizing the land allocation choice in the presence of biomass market uncertainty. This problem is given by: $\max_{L_f} E(U(W)) = E[U(L_f(V^* - Z^*) + (1 - L_f)\pi^*)]$. Now the problem can be rewritten more specifically as:

$$\max_{L_f} E(U(\hat{W})) = E[U(L_f(V^* - Z^*) + (1 - L_f)\pi^*)] \quad (3.5)$$

where $\hat{W} = L_f(V^* - Z^*) + (1 - L_f)\pi^*$ is the private landowner's maximized wealth from land use decisions when the rotation ages for conventional forestry and woody biomass forestry are chosen to be T_1^* and T_2^* , respectively. Equation (3.5) also implies that transaction costs are a function of acreage converted because it is a cost per unit of land multiplied by units converted to forest bioenergy production.

3.4 EFFECTS OF PARAMETERS ON LAND ALLOCATION

3.4.1 EFFECT OF UNCERTAINTY, σ , ON LAND ALLOCATION

We can now proceed to measure the effects of important parameters on the land allocation decision of a risk averse landowner. The first-order condition of the land allocation problem in (3.5) with respect to L_f , making use of the chain rule, is given by:

$$G = \frac{\partial E(U(\hat{W}))}{\partial L_f} = E[U'(\hat{W})(V^* - Z^* - \pi^*)] = 0 \quad (3.6)$$

where $U'(\hat{W}) \equiv U_{\hat{W}}(\cdot)$. The optimal land units allocated to forestry are denoted by $L_f = \int_0^{q_c} k(q) dq$. Letting $\phi = (\sigma, \delta, \mu)$ be a parameter vector, a total differential of (3.6) shows the relationship between these parameters and the critical land quality level, q_c , that separates agricultural production and forest production on the land quality continuum. Knowing how this critical land quality changes tells us how parameters will affect land use change.

Total differentiation of G with respect to pure price uncertainty, σ , at the optimal land allocation L_f^* generates:

$$\frac{\partial G}{\partial \sigma} + \left(\frac{\partial G}{\partial L_f^*}\right)\left(\frac{\partial L_f^*}{\partial \sigma}\right) = 0 \quad (3.7)$$

With the second-order condition holding, it is easy to come to the following conclusion:

$D = \frac{\partial G}{\partial L_f^*} < 0$. Rearranging equation (3.7) then yields:

$$\frac{\partial L_f^*}{\partial \sigma} = -D^{-1} \frac{\partial G}{\partial \sigma} = -D^{-1} \left\{ \frac{\partial E[(V^* - Z^* - \pi^*)U'(\hat{W})]}{\partial \sigma} \right\} \quad (3.8)$$

Now the fact that $-D^{-1} > 0$ implies that $\frac{\partial L_f^*}{\partial \sigma}$ has the same sign as $\frac{\partial E[(V^* - Z^* - \pi^*)U'(\hat{W})]}{\partial \sigma}$, where¹⁷,

¹⁷ See Appendix A for details of this derivation.

$$\begin{aligned}
& \frac{\partial E[(V^* - Z^* - \pi^*)U'(\hat{W})]}{\partial \sigma} \\
&= E\left\{\frac{\partial V^*}{\partial \sigma} U'(\cdot) [-\rho L_f^* (V^* - Z^* - \pi^*) / \hat{W} + 1]\right\} \\
&= \left[\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2} \right] E\{U'(\cdot) \varepsilon [-\rho L_f^* (V^* - Z^* - \pi^*) / \hat{W} + 1]\} \quad (3.9) \\
&= \left[\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2} \right] E\{U'(\cdot) \varepsilon [-\rho \Delta \hat{W} / \hat{W} + 1]\}
\end{aligned}$$

The term $\left[\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2} \right]$ is positive, and $\rho = -W \frac{U''}{U'}$ is the Arrow-Pratt coefficient of relative risk aversion, with $\rho > 0$ indicating relative risk aversion on the part of the landowner. The term in equation (3.9), $L_f^* (V^* - Z^* - W^*)$, is regarded as ΔW which is interpreted as a change in the landowner's wealth from single agricultural production on the whole land quality continuum to the mix of agriculture and forestry production after market emergence-driven land use change. The term $(\Delta \hat{W} / \hat{W})$ is thus interpreted as the percentage change in wealth due to the land use change. The following proof is used to illustrate that $E(U' \varepsilon) < 0$.

Proof: ε is I.I.D and zero mean, and thus $Cov(U', \varepsilon) = E(U' \varepsilon) - E(U')E(\varepsilon)$, $E(\varepsilon) = 0$; thus $E(U' \varepsilon) = Cov(U', \varepsilon) = Cov(U', \frac{P_1 - u_1}{\sigma}) = \frac{1}{\sigma} Cov(U', (P_1 - \mu_1)) = \frac{1}{\sigma} Cov(U', P_1)$. Therefore, the sign of $E(U' \varepsilon)$ is the same as the sign of $Cov(U', P_1)$. The sign of $Cov(U', P_1)$ can be obtained by carrying out the first order derivative of $\frac{dU'}{dP_1}$ with respect to P_1 . Therefore,

$$\frac{dU'}{dP_1} = U'' \frac{d\hat{W}}{dP_1} = U'' \frac{dV^*}{dP_1} = U'' \frac{1 - e^{-\mu r T_1}}{1 - e^{-r T_1}} e^{-r T_1} f(T_1^*, q) < 0 \text{ because } U'' < 0 \text{ and}$$

$$\frac{1 - e^{-\mu r T_1}}{1 - e^{-r T_1}} e^{-r T_1} f(T_1^*, q) > 0. \text{ Therefore, } Cov(U', P_1) < 0 \text{ and } E(U' \varepsilon) < 0. \text{ Q.E.D.}$$

We can gain further insight into the expressions $\frac{\partial E[(V^* - Z^* - \pi^*)U'(W)]}{\partial \sigma}$ and $\frac{\partial L_f^*}{\partial \sigma}$

since they have the opposite sign of $[-\rho \Delta \hat{W} / \hat{W} + 1]$. Blanchard and Fischer (1989) argues that

constant absolute risk aversion is a less plausible description of risk aversion than constant relative risk aversion even though constant absolute risk aversion sometimes is a more convenient analysis tool than constant relative risk aversion. Theoretically, we consider two cases of risk preferences for the landowner, constant relative risk aversion (CRRA) where ρ remains constant as wealth increases, and decreasing relative risk aversion (DRRA) where the landowner's risk aversion coefficient, ρ , is decreasing as wealth increases as we will explain later. It is more convenient to use CRRA in our simulation section. CRRA is expressed as

$$\rho(W) = -W \frac{U''(W)}{U'(W)}.$$

Under CRRA, we can show that $-\rho \Delta \hat{W} / \hat{W} + 1 > 0$ if $0 < \rho < (\hat{W} / \Delta \hat{W})$. In this case, when the coefficient of relative risk aversion is smaller than the relative wealth change term after the new land use is adopted, land allocated to bioenergy is a decreasing function of pure price uncertainty, $\frac{\partial L_f^*}{\partial \sigma} < 0$. This means that an increase in price uncertainty, σ , has a negative effect on land allocation to biomass production as long as the coefficient of landowner risk aversion is in the range of $(0, \hat{W} / \Delta \hat{W})$. This would be less expected if returns to bioenergy forest production were high, there was considerable land to be devoted to bioenergy, or returns to agriculture were low. Intuitively, in this case, the returns at risk for low prices are already high, and the landowner displays constant risk aversion as returns change. Thus, the landowner stands to lose relatively more under price risk and will allocate less of the land continuum to this use.

The other case, $[-\rho \Delta \hat{W} / \hat{W} + 1] < 0$, i.e. $\rho > \hat{W} / \Delta \hat{W} > 0$, is one where the relative risk aversion is higher than the relative wealth change term. Now a higher price uncertainty increases land allocated to bioenergy forest production, or $\frac{\partial L_f^*}{\partial \sigma} > 0$. In this case, we require the relative risk aversion coefficient to be in the range of $(\hat{W} / \Delta \hat{W}, \infty)$. This is more likely if the returns to agriculture are high, or less land is at risk for bioenergy forest production, meaning that the landowner's exposure to forest price uncertainty is lower.

Under constant relative risk aversion where the landowner's aversion does not change as relative income changes, the landowner will actually increase bioenergy production under higher

pure price uncertainty. This is because there is then a chance that bioenergy returns can increase under a mean preserving price spread if a higher price is observed than expected when the market emerges. The landowner can then benefit from price risk by getting a high price while wealth changes do not affect risk preferences¹⁸.

Under DRRA, an increase in wealth indicates that the forest landowner is more willing to take on risk that he may be exposed to through the wealth term, $L_f^*(V^* - Z^* - \pi^*)$ or $\Delta \hat{W}$; recall that $\frac{\partial L_f^*}{\partial \sigma}$ has the opposite sign of $[-\rho \Delta \hat{W} / \hat{W} + 1]$. There are two cases to examine for pure price uncertainty, and these depend on how a mean preserving spread in price changes wealth relative to the Arrow-Pratt risk aversion coefficients. Suppose first that we have $[-\rho \Delta \hat{W} / \hat{W} + 1] > 0$, i.e., $0 < \rho < (\hat{W} / \Delta \hat{W})$. This implies that land devoted to bioenergy forest production decreases with a mean preserving spread price increase, or $\frac{\partial L_f^*}{\partial \sigma} < 0$. The term $[-\rho \Delta \hat{W} / \hat{W}]$ is nonpositive by definition, and it becomes smaller in absolute value as relative wealth increases under DARA. If relative wealth is very high or increases to a great extent with market emergence, then ρ is very small and the landowner will decrease land allocated to bioenergy, because the potential benefits from observing a higher price with an increase in σ at the margin are lower. If wealth increases or relative wealth are not large with a change in price uncertainty, then this case is not very plausible given the likely size of ρ .

The second case for consideration is the one where: $[-\rho \Delta \hat{W} / \hat{W} + 1] < 0$, i.e. $\rho > (\hat{W} / \Delta \hat{W}) > 0$. Now, the landowner increases bioenergy forest production under an increase in a mean preserving spread in price, $\frac{\partial L_f^*}{\partial \sigma} > 0$. In this case, the landowner benefits from the possibility of observing a high price, and risk aversion is decreasing in wealth that results from

¹⁸ This is a risk aversion extension of other models such as Brazee and Mendelsohn (1988) that has shown a similar result for pure price uncertainty under risk neutrality (Amacher et al. 2009, chapters 10-11).

such a price observance. Thus, land use shifts in the direction of more land units of higher quality being devoted to bioenergy forest production.

3.4.2 EFFECT OF EXPECTED PRICE JUMP, δ , ON LAND ALLOCATION

As shown in section 3.4.1, the effect of a price jump on land allocated to forestry is given by:

$$\frac{\partial G}{\partial \delta} + \frac{\partial G}{\partial L_f^*} \frac{\partial L_f^*}{\partial \delta} = 0 \quad (3.10)$$

$$\begin{aligned} \frac{\partial L_f^*}{\partial \delta} &= -D^{-1} \frac{\partial G}{\partial \delta} \\ &= -D^{-1} E \left[U''(\cdot) L_f^* \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} (V^* - Z^* - \pi^*) + U'(\cdot) \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} \right] \\ &= -D^{-1} E \left\{ U'(\cdot) \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} \left[L_f^* (V^* - Z^* - \pi^*) + 1 \right] \right\} \\ &= -D^{-1} E \left\{ U'(\cdot) \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} \left[\frac{-W U''(\cdot) - \Delta W}{U'(\cdot)} \frac{1}{W} \right] + 1 \right\} \\ &= -D^{-1} E \left\{ U'(\cdot) \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} \left[-\rho \frac{\Delta W}{W} + 1 \right] \right\} \end{aligned} \quad (3.11)$$

The above equation shows that the sign of $\frac{\partial L_f^*}{\partial \delta}$ is determined by the sign of

$$\left[-\rho \frac{\Delta W}{W} + 1 \right] \text{ because both } E \left[U'(\cdot) \frac{e^{-\eta T_1^*}}{1 - e^{-r T_2^*}} g(T_2^*, q) e^{-r T_2^*} \right] \text{ and } (-D^{-1}) \text{ are positive. Under}$$

constant relative risk aversion, the relative risk aversion coefficient ρ is positive. When

$\rho < \frac{W}{\Delta W}$, we can derive that $\frac{\partial L_f^*}{\partial \delta} > 0$. We can tell that this case is more likely to occur for a

risk-averse landowner. This implies, as expected, that for a landowner with a lower risk tolerance, a higher expected price jump leads to a positive effect on land allocated to woody biomass production. The larger the expected price jump, the more land will be allocated to forest

bioenergy production. However, when $\rho > \frac{W}{\Delta W}$, i.e. a landowner has a very high risk aversion, a higher price jump will lead to less land allocated to forest bioenergy production.

3.4.3 EFFECT OF EXPECTED PRICES, $\mu = (\mu_1, \mu_2)$, ON LAND ALLOCATION

Using the same procedures as above, the effect of expected prices, μ , on land allocation can be derived from equation (3.12) below:

$$\frac{\partial G}{\partial \mu} + \frac{\partial G}{\partial L_f^*} \frac{\partial L_f^*}{\partial \mu} = 0 \quad (3.12)$$

Rearranging equation (3.12), the effect of expected price μ on the land allocation decision

is given by: $\frac{\partial L_f^*}{\partial \mu} = -D^{-1} \frac{\partial G}{\partial \mu}$. Obviously, $\frac{\partial L_f^*}{\partial \mu}$ has the same sign as $\frac{\partial G}{\partial \mu}$ with

$G = E[U'(\hat{W})(V^* - Z^* - \pi^*)] = 0$. Now we obtain $\frac{\partial G}{\partial \mu}$ as follows.

$$\begin{aligned} \frac{\partial G}{\partial \mu_1} &= \frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} E\{[U'[-\rho \Delta \hat{W} / \hat{W} + 1]]\} \\ \frac{\partial G}{\partial \mu_2} &= \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2} E\{[U'[-\rho \Delta \hat{W} / \hat{W} + 1]]\} \end{aligned} \quad (3.13)$$

Under CRRA we are unable to sign equations in (3.13) without analyzing specific conditions. with $\rho > 0$ and $U' > 0$ signifying a risk-aversion preference, we have either that

$(-\rho \Delta \hat{W} / \hat{W} + 1) > 0$ i.e. $0 < \rho < (\hat{W} / \Delta \hat{W})$ which implies $\frac{\partial L_f^*}{\partial \mu} > 0$, or $(-\rho \Delta \hat{W} / \hat{W} + 1) < 0$ i.e.

$\rho > (\hat{W} / \Delta \hat{W}) > 0$ which implies that $\frac{\partial L_f^*}{\partial \mu} < 0$, because $[\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1}]$ and

$[\frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2}]$ are both positive. The first case, where the marginal increase in returns is

positive, is one where land allocated to bioenergy forest production increases, while the other is a case where at the margin the price level after market emergence is not enough to increase relative returns thereby leading to a decrease in land allocated to bioenergy. These two different situations are fitting here, because with a lower level of uncertainty and the same expected price,

the landowner will invest in forest bioenergy production more readily than the case with higher uncertainty associated with the price of the short-rotation bioenergy dedicated tree species.

3.5 NUMERICAL ANALYSIS

3.5.1 DATA COLLECTION

Loblolly pine and hybrid poplar are considered for conventional timber production and bioenergy woody biomass production, respectively. Loblolly pine is a conventional tree species with a longer rotation age in the southeastern US. Hybrid poplar has been studied as a short-rotation energy production forest species (Armstrong et al. 1999, Yemshanov et al. 2008). The stand-level TAUYIELD model is adopted to obtain yields of loblolly pine sawtimber and pulpwood for potential rotation ages ranging from 8 years to 36 years (Amateis et al. 1995). According to the guidebook for TAUYIELD model, loblolly pines that are less than 8 years old are considered to have little commercial value.

In this model, three different indexes are chosen to simulate different land qualities, or more specifically, a site index of 45 is used for land of low quality, 60 for land of average quality, and 75 for land of high quality. We also assume 500 trees per acre for planting, and for the above three different land quality classes, the survival rates of trees after the first year are assumed to be 70%, 75% and 80%, respectively. Data from TAUYIELD are also factor-converted into units of green tons of wood harvested. Folegatti et al. (2007) reports the costs of establishing loblolly pine; these are assumed to include machine planting and prescribed burning. Stumpage prices of pine sawtimber and pulpwood are taken from quarterly averages reported by Timber Mart-South during the period of 2004-2007. These are adjusted for inflation to 2007 dollars using the U.S. Bureau of Labor and Statistics calculator.

Yields of hybrid poplar are taken from the Oak Ridge Energy Crop County Level database (ORECCL). Annual yields are observed to be 2.5 tons per acre for land of low quality (pessimistic yield in the database), 4.5 tons for land of average quality, and 5.5 tons for land of high quality (optimistic yield in the database). Costs of stand establishment including hand planting, planting materials, and herbicide are taken from Walsh (1998) and are also inflation adjusted.

Markets for bioenergy-based hybrid poplar have not yet been established on a large scale, and therefore specific prices of hybrid poplar are not available. With the assistance of Timber Mart-South, the price of woody biomass from hybrid poplar is initially assumed to be 15 dollars

per ton. In addition, six different levels of price jumps are assumed. They are 30, 45, 60, 75, 90, and 105 dollars per green ton, respectively. Following Chapter 2, we further assume that the landowner has a perspective of the timing of market emergence, Five levels of timing are assumed. That is, T_1^* , $2T_1^*$, $3T_1^*$, $4T_1^*$ and $5T_1^*$, where T_1^* is the optimal rotation age of loblolly pine. The longest timing is accepted to be the maximum timing of bioenergy market emergence.

Two forms of simulated transaction cost functions are considered as in Chapter 2. One is a linear form defined as the sum of optimal rotation ages of loblolly pine and hybrid poplar, i.e., $TC = T_1^* + T_2^*$, which means that the optimal rotation ages of loblolly pine and hybrid poplar have equivalent impacts, when the landowner considers a change in land use. It is because the longer the rotation age is in either tree species, the more uncertainty the investment may embody. The other transaction cost is non-linear with $TC = 200 + T_1^{*2} + T_2^*$ ¹⁹. The nonlinearity of transaction costs emphasizes that the length of the optimal rotation age of the conventional tree species could be more significant to the landowner's willingness to switch land use. Both forms of transaction costs are sensitive because the landowner makes decisions at the beginning of the time horizon without knowing the exact timing. The rotation age is an important and easier indicator when he or she makes the land use change decision. If the timing of woody bioenergy market emergence is too far away, the landowner may not be willing to change land use from crop production, or he or she may just keep growing conventional tree species rather than investing in hybrid poplar.

Corn for grain is taken to represent agricultural production. County-level yields of 2007 in Georgia, a state where loblolly pine is an economically important tree species and is in the biological range of hybrid poplar, are taken from the National Agricultural Statistics Service of the United States Department of Agriculture. We choose corn for grain as the agricultural product because in the United States corn is also used to produce biofuel. Yield data for hybrid poplar from ORECC database have data for 159 counties in Georgia and NASS has provided corn yield data for 88 counties in Georgia. We only kept data for those counties growing both hybrid poplar and corn after matching the two databases. The maximum annual yields for land

¹⁹ Transaction costs as a positive function of T_1^* and T_2^* makes sense because if the rotation age is longer, the decision to invest in bioenergy is more irreversible.

with low, average and high quality are 50, 115 and 150 bushels per acre, respectively. The average price equals 3.5 dollars per bushel. The fixed cost for corn production establishment is 215 dollars, which is supposed to be the input rate for corn production. It is conventional to assume that the corn production function takes a Cobb-Douglas form, $h(l, q) = l^{0.5} s(q)$, where $s(q)$ is annual yield as just described. Recall that all corn market parameters are assumed to be certain. By the first order condition derived from the net present value function of profits from agricultural production in the last section, the optimal input levels are 0.33, 0.89 and 1.51 units for a land unit of low, average and high quality classes, respectively. The factors in agriculture are constant, therefore it is more simple to calculate the expected utilities from agriculture. These utilities are 774.14, 873.58 and 927.28 units for a land unit with low, average and high qualities, respectively.

3.5.2 SIMULATION ANALYSIS

A log utility function is taken to represent CRRA, $U(W) = 100 \log(W)$. Tables 3.1 to 3.12 display the landowner's expected utility from forestry on land with low, average and high quality, with two forms of transaction costs and two different values of the uncertainty level governed by σ ad infinitum. Table 3.1 and Table 3.2 show results for land with low quality and linear-form transaction costs. The difference between them is introduced by the different uncertainty level, $\sigma = 1$ and $\sigma = 8$ for Table 3.1 and Table 3.2, respectively. Under price uncertainty, income or wealth to the landowner is higher when the transaction cost is linear and bioenergy production is preferred on land with low quality. Compared to the results from the risk-neutral landowner in Chapter 2, these results show the effects of the landowner's risk preference on land use change. Compared to the landowner's utility from agriculture on land of low quality (774.14), forestry in general is preferred in fewer cases in Tables 3.3 and 3.4 because the nonlinear transaction costs cancel the benefits from forestry to a larger extent. As a consequence, with the inclusion of nonlinear transaction costs, the landowner yields some land of low quality to agriculture. In Table 3.3 and Table 3.4, the cells below or to the left side of the bold border lines are cases that are more profitable to agriculture. The results suggest that the magnitude of transaction costs is again an important factor in land use change decisions. A large transaction cost could arise if the landowner perceives that bioenergy markets will not develop soon.

Tables 3.5 to 3.8 present the results from the land of average quality, showing that both forestry and agriculture have distinctly higher yields. The landowner gains 873.58 units of expected utility from agricultural production on average quality land. From the bold border lines in each table, we can tell immediately that agricultural production dominates. Forestry production is preferred only when the market develops in the first timing period, that is, in the very near future. The price jump also has to be very high. In Table 3.5, at least a 500% increase of the initial price is needed where only linear transaction costs are considered. If transaction costs are any higher, then all land stays in agriculture and there is never any land use change (see Table 3.7). The landowner can be wealthier if more price risk is involved as in Table 3.6. But large transaction costs can change the land use result comparing Table 3.6 and Table 3.8; the latter shows there will be no land use change at all.

Tables 3.1-3.4 and Tables 3.5-3.8 show that land quality affects land use change significantly. With higher land quality, bioenergy gains favor only through a quicker realization of bioenergy market emergence and smaller transaction costs. The relative wealth changes before and after the market emergence is also decreasing among the cells throughout the table.

The results from Tables 3.9-3.12 show the domination of agriculture over forestry. As in Tables 3.9 and 3.12, the realization of bioenergy markets won't lead to biomass forest establishment despite any price and timing of bioenergy market emergence, based on the relative rents between agriculture and forestry.

3.6 CONCLUSION AND POLICY IMPLICATIONS

In this study, we extend the risk-neutral model of Chapter 2 to incorporate a landowner risk-aversion preference. Several important features associated with land use change are considered, such as land quality, timing of woody bioenergy market emergence and a price jump. The risk aversion extension is important to the literature on bioenergy production and land use change because the results are quite different, and there is growing evidence that forest landowners have some risk aversion. Comparing within and among tables, the land quality, timing of woody bioenergy market emergence, and the price jump all play critical roles in land use change. The landowner's expected utility from forestry increases with higher land quality, faster realization of woody bioenergy, and larger price increases. As in Chapter 2, the timing of the market emergence may be the most critical factor because the relative change of expected utility is higher with earlier emergence than the change that comes from price jumps.

This offers insight into adopting policies to encourage development of woody bioenergy production. As other markets, the establishment of woody bioenergy markets requires institutional incentives. Competitiveness between woody bioenergy production and agricultural production demands a fair competing platform, i.e. either by removing existing subsidies to the agricultural production or offering cost reduction program to bioenergy consumers. The result also suggests that more efficient conversion technologies are needed to compete with conventional energy sources and corresponding subsidies to the consumption of renewable energy from woody biomass are needed.

Comparing the results from risk-averse and risk-neutral models, we come to the conclusion that under the same land quality, risk aversion causes less land allocation to bioenergy production even when different transaction costs and uncertainty levels are corrected for. Both linear-form transaction costs and nonlinear-form transaction costs are only a reference. As to which form is most reasonable and the extent to which they occur, we can only say that they may be contingent on the landowner's specific preferences and different scenarios of incentives from governments. Moreover, different geographic regions have different markets and prices. Local governments and agencies should also seek to improve information landowners have about woody bioenergy demand, as this decreases uncertainty and alleviates the effects of risk aversion on land use change and bioenergy forest adoption.

In addition, note that the constancy of price for agricultural output is reasonable and fair here for the analysis of land use change from agriculture to other land use alternatives. However, the price variability of agricultural products could exist and be unknown to the landowner. If the variability of prices for agricultural output is incorporated into the analysis, we may expect the adoption of forest bioenergy to become a more favorable land use option in that the landowner is assumed to be risk averse. The extent of the effect of including the price variability of agricultural product on land use change requires a specific analysis. In addition, the price for the agricultural crop could change as substitution between biomass and crop land occurs on the land use continuum, and there may be some cases where some land of woody biomass production is converted to agricultural production if the price of agricultural output rises high enough. This scenario simply represents a more pessimistic biomass market emergence case in our model and we would expect land for woody biomass production to decrease.

We have considered cases of risk-neutral and risk-averse preferences. Extending the analysis to explore the land use transition in a more dynamic manner is necessary to really understand how uncertain biomass market emergence affects land use. In a more dynamic setting, the open-loop nature of the modeling in this chapter and Chapter 2 can be relaxed while retaining important features such as land quality, timing of market emergence, and price jumps.

Table 3.1: Landowner’s expected utility from forestry on land with low quality, linear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	708.66	637.72	565.22	488.66	506.61
200%	738.19	670.91	602.97	519.53	493.89
300%	758.05	691.84	626.46	556.72	486.99
400%	777.65	710.51	647.12	582.76	491.53
500%	793.04	727.32	664.74	603.12	528.19
600%	807.51	742.04	678.65	618.20	550.65

Note: TP= timing periods until bioenergy markets emerge; PJ= price jump.

Expected discounted utility from agriculture is 774.14.

Table 3.2: Landowner’s expected utility from forestry on land with low quality, linear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	749.68	681.30	644.6	610.76	590.49
200%	773.67	714.37	664.15	630.86	595.26
300%	774.91	717.96	668.82	635.80	603.97
400%	798.01	731.92	686.08	652.09	621.40
500%	810.28	751.28	706.11	670.08	640.44
600%	828.84	769.94	717.71	679.49	648.95

Note: Expected discounted utility from agriculture is 774.14.

Table 3.3: Landowner’s expected utility from forestry on land with low quality, nonlinear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	631.68	570.55	494.04	-	-
200%	667.92	606.40	559.44	479.14	-
300%	694.66	636.19	595.44	541.18	390.61
400%	727.08	657.26	613.43	576.86	519.30
500%	753.00	675.61	632.55	601.34	547.69
600%	774.70	690.89	647.97	619.73	576.31

Note: Expected discounted utility from agriculture is 774.14.

Table 3.4: Landowner's expected utility from forestry on land with low quality, nonlinear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	635.96	617.76	575.81	513.09	-
200%	722.77	640.92	595.93	543.55	483.68
300%	721.46	661.72	616.94	553.34	486.88
400%	760.59	684.58	624.25	578.78	521.09
500%	778.73	698.60	652.19	627.22	575.19
600%	804.25	703.53	660.56	643.17	597.59

Note: Expected discounted utility from agriculture is 774.14.

Table 3.5: Landowner's expected utility from forestry on land with average quality, linear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	803.56	760.67	728.81	702.99	680.25
200%	825.18	780.31	744.99	717.27	694.45
300%	840.00	792.78	755.35	726.51	703.22
400%	855.85	806.02	767.25	736.93	712.76
500%	868.54	817.30	776.55	744.98	719.90
600%	880.54	829.12	786.84	753.77	727.41

Note: Expected discounted utility from agriculture is 873.58.

Table 3.6: Landowner's expected utility from forestry on land with average quality, linear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	832.96	785.30	760.55	741.65	729.37
200%	853.97	811.25	778.57	755.55	742.22
300%	852.26	808.51	775.12	752.98	740.06
400%	872.56	822.25	790.53	766.90	751.21
500%	882.90	832.14	797.15	772.39	754.61
600%	900.29	852.61	815.36	787.38	766.01

Note: Expected discounted utility from agriculture is 873.58.

Table 3.7: Landowner's expected utility from forestry on land with average quality, nonlinear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	772.42	703.95	653.07	606.51	547.58
200%	800.95	734.75	676.67	628.12	586.47
300%	819.35	752.74	691.52	647.19	605.36
400%	838.41	771.74	706.14	664.01	617.61
500%	853.32	786.45	719.94	675.94	634.82
600%	867.67	802.28	737.33	687.33	645.52

Note: Expected discounted utility from agriculture is 873.58.

Table 3.8: Landowner's expected utility from forestry on land with average quality, nonlinear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	810.33	747.75	713.02	685.35	660.47
200%	836.66	781.54	735.01	698.94	679.11
300%	834.41	776.66	728.60	699.07	676.09
400%	857.95	795.95	753.14	720.03	693.80
500%	869.85	806.08	756.71	717.44	690.44
600%	889.62	833.08	784.81	746.65	717.21

Note: Expected discounted utility from agriculture is 873.58.

Table 3.9: Landowner's expected utility from forestry on land with high quality, linear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	841.24	814.41	796.15	782.20	770.65
200%	860.26	829.27	807.15	790.77	778.81
300%	873.03	838.73	814.56	797.27	783.81
400%	886.94	849.81	823.55	804.52	790.00
500%	898.43	858.67	830.07	809.38	793.83
600%	910.05	868.84	838.43	816.46	800.02

Note: Expected discounted utility from agriculture is 927.28

Table 3.10: Landowner's expected utility from forestry on land with high quality, linear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	865.69	838.34	825.13	815.18	807.17
200%	887.62	857.66	836.66	821.50	811.41
300%	884.95	853.32	833.18	821.53	812.47
400%	901.90	867.29	846.77	832.19	821.25
500%	911.62	872.99	848.63	831.31	818.40
600%	929.6	892.36	865.77	847.03	833.33

Note: Expected discounted utility from agriculture is 927.28.

Table 3.11: Landowner's expected utility from forestry on land with high quality, nonlinear form transaction costs and $\sigma = 1$

TP \ PJ	1	2	3	4	5
100%	822.21	789.30	766.50	748.99	734
200%	844.67	807.08	779.66	759.34	743.53
300%	859.27	818.18	788.69	767.41	750.77
400%	874.94	831.33	799.33	776.05	758.29
500%	887.74	841.54	806.85	781.55	762.88
600%	900.58	853.25	816.74	790.06	770.20

Note: Expected discounted utility from agriculture is 927.28.

Table 3.12: Landowner's expected utility from forestry on land with high quality, nonlinear form transaction costs and $\sigma = 8$

TP \ PJ	1	2	3	4	5
100%	850.69	819.85	804.50	792.88	783.35
200%	876.06	841.58	817.08	799.41	788.08
300%	872.90	835.98	813.73	800.25	789.66
400%	891.56	852.75	829.13	812.39	799.83
500%	902.26	858.86	830.64	810.57	796.13
600%	921.97	880.60	850.36	829.00	813.45

Note: Expected discounted utility from agriculture is 927.28.

3.7 REFERENCES

Aguilar, F.X. and A. Saunders. 2010. Policy instruments promoting wood-to-energy uses in the continental United States. *Journal of Forestry* 108(3):132-140.

Amacher, G.S., M. Ollikainen, and E. Koskela. 2009. *Economics of forest resources*, Cambridge: MIT Press.

Amateis, R., P. Radtke, and H. Burkhart. 1995. TAUYIELD: A stand growth and yield model for thinned and unthinned loblolly pine plantations. *Loblolly Pine Growth and Res. Cooperative. Rept. No. 92*. Virginia Tech, Blacksburg, Va.

Armstrong A, C. Jones, and I.Tubby. 1999. Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop. *Biomass and Bioenergy* 17(4): 305-314.

Blanchard, O.J. and Fischer, S. 1989. *Lectures on Macroeconomics*, Cambridge: MIT Press.

Braze, R. and M. Robert. 1988. Timber Harvesting with Fluctuating Prices. *Forest Science* (34): 359-372.

Energy Information Administration. U.S. Imports by Country of origin. Web 28 Sept. 2009. < http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_m.htm> (accessed on Jan.2010)

Folegatti. B.S., M.F.Smidt and M.R.Dubois (2007). Costs and Cost Trends for Forestry Practices in the South. *Forest Landowner*, Sep/Oct. : 11-16.

Gong, P. (1998). Risk Preferences and Adaptive Harvest Policies for Even-Aged Stand Management. *Forest Science* (44): 496-506.

Gong, P. and Löfgren, K. G.(2003). Risk-aversion and the Short-Run Supply of Timber. *Forest Science* (49):647-656.

Gong, P. and K.G. Löfgren. (2008). Impact of *Risk Aversion* on the Optimal Rotation with Stochastic Price. *Natural Resource Modeling* 21: 385–415

Graham R.L and L.J. Allison (1996). Oak Ridge Energy Crop County Level Database-ORECCL, Oak Ridge National Laboratory, Oak Ridge, TN.

Lichtenberg, E. (1989). Land quality, Irrigation Development, and Cropping Patterns in the Northern High Plains. *American Journal of Agricultural Economics* 71(1): 187-194.

Parks. P.J. and Ian W. Hardie (1995). Least-Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land. *Land Economics* 71(1): 122-136.

Plantinga, A.J. (1998). The Optimal Timber Rotation: An Option Value Approach. *Forest Science* (44):192-202.

Thomson, T.A.(1992). Optimal Forest Rotation When Stumpage Prices Follow a Diffusion Process. *Land Economics* 68(3): 329-342.

Walsh, M.E. (1998). U.S. Bioenergy Crop Economic Analysis: Status and Needs. *Biomass and Bioenergy* 14(4): 341-350.

Yemshanov D and D. Mckenny, 2008. Effects of Spacing and Cutting Cycle on the Yield of Poplar Grown as an Energy Crop *Biomass and Bioenergy* 32(3): 185-197.

Chapter 4: A DYNAMIC LAND USE PROBLEM UNDER STOCHASTIC WOODY BIOMASS MARKETS

4.1 ABSTRACT

In this chapter, we examine a land use problem when the landowner no longer has to make a costly land use change decision at the beginning of his or her time horizon. Instead, the landowner is able to revise his or her decision over time based on the arrival of new information, or new perceptions of forest biomass rents. The uncertainty of forest bioenergy markets is governed by the evolution of forest biomass rents that follow a stochastic diffusion process defined as geometric Brownian motion calibrated using a binomial option pricing assumption. Such a process is important in specifying drift and volatility in biomass rents that follow from unknown market emergence.

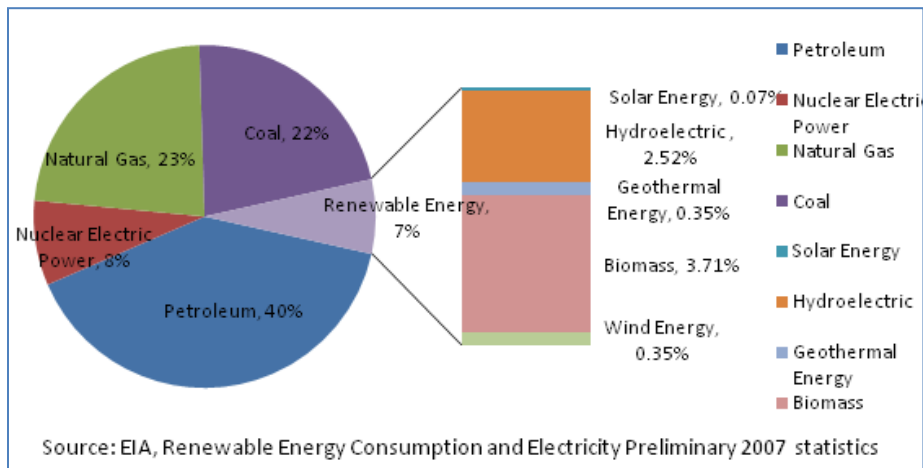
Several key factors for land use changes in Chapters 2 and 3 are retained. A stochastic optimization model is constructed to solve two problems. One is when to stop agriculture and begin to invest in hybrid poplar for energy production. The other is the optimal land allocation between the alternatives. The two problems are correlated and assumed solved at the same time. The simulation analysis shows that the results due to volatility are significantly different than price uncertainty in previous chapters. For example, a volatility $\sigma = 0.5$ signifies a rather high probability of an upward movement of future forest biomass rents and therefore a higher NPV of land rents with the land use switch compared to the NPV of agriculture on the infinite time horizon. In addition, more land units are allocated to hybrid poplar after 37 years than in the case when volatility is higher.

4.2 INTRODUCTION

Volatile gasoline prices and high greenhouse gas (GHG) emissions have stirred ongoing worldwide debates concerning the development of biotechnology and bioenergy. Energy security is a related driving force for policy discussions involving investments in alternate fuel technologies. The United States, for example, relies upon imported fossil oil from economically and politically volatile areas. Wood-based biofuels, obtained from growing forests, are considered an important part of alternative fuels. Based on the data collected from the US Department of Energy, an estimated 1 billion dollars in federal funding has already been invested in advancing biotechnology and bioenergy as of July 2007. A memorandum for woody biomass utilization released jointly by The United States Department of Agriculture, Department of Energy, and Department of the Interior has facilitated the research and application of woody biomass. Guidelines for woody biomass energy production have also been released for both state and private forestland in several states such as Pennsylvania, Maine, and Michigan. (Wilent 2008).

Figure 4.1 shows the momentum that biomass appears to have among renewable energy sources in the United States. Europe and Asia both have also been advancing the development of sustainable and renewable energy sources. The Chinese government recently announced an area of 13.33 million hectares of forestland designated specifically for forest-based bioenergy production by 2020. European countries such as the UK, Germany, Netherlands and Finland also have similar policy initiatives (Mckay 2006, Hoffman and Weih 2005, Junginger et al. 2008 and Malinen 2001).

Figure 4.1: The role of renewable energy in the Nation's Energy Consumption: 2003-2007



Woody biomass as an energy source has several advantages over conventional fossil fuels and other energy feedstock sources such as corn-based and sugarcane-based biomass. First, a number of tree species can be grown specifically as feedstocks for bioenergy production, and a number of conversion technologies such as direct combustion, thermo-chemical conversion, and biochemical conversion are already available (EPA 2007). Second, woody-biomass-oriented forestry may also give rise to public goods benefits such as carbon sinks and improved air quality, protection of water and soil from erosion, and natural resource recreation. Third, energy based forest management can create a new income source for landowners and another source of tax revenues for governments. Finally, bioenergy production from woody biomass may not result in the problems such as the food price crisis for which corn-based and sugarcane-based biomass have already been blamed, and water and soil erosion which results to a greater extent from corn-based ethanol production (OECD 1984, Mitchell 2008, and Katz 2008, Pimentel 1991 and Patzek et al. 2004).

Though woody biomass industries are in the early stages of development, and at present there are few well developed markets for forest landowners wishing to provide wood-based fuel supplies, there will likely be emerging future biomass markets on a large scale given that there are already some regional markets, and efforts are continuing to reduce transportation and storage costs. Once markets develop and woody biomass is cost effective, we would expect changes in forest management and land use leading to more frequent establishment and harvesting of smaller diameter trees. The result may also be increased establishment of forest cover on marginal agricultural land.

Given the discussion thus far and the long-term nature of forest investments, there is much uncertainty a landowner has about future biomass prices. In the forest economics literature, there has been a growing body of research dealing with price uncertainty and a forest landowner's optimal rotation and harvesting decisions (Amacher et al. 2009, Brazee et al. 1988, Clarke et al. 1989, Morck et al. 1989, Koskela 1989, Thomson 1992, Brazee et al. 2000, Lu et al. 2003, Motoh 2004, Gong et al. 2005 and Chladná 2007). Work on land use with respect to uncertainty is less frequently studied, but one example is Schatzki (2003), who modeled land use conversion under uncertainty using an option-value approach. The land use threshold model incorporated uncertainty in returns and sunk costs. In this model, the before-conversion and after-conversion stages both assume there is only one production choice. A conversion threshold is then solved to determine whether to convert from agriculture to forestry or not. Although not specifically a land use problem, Tahvonen and Markku (2006) applied both random walk and mean reversion stochastic processes to characterize timber price uncertainty in a model that allowed for multiple age classes on any land unit. They then analyzed the effects of including planting costs and risk aversion on rotation periods.

The literature has several other examples where stochastic processes have been introduced into forest decision making. In most cases, prices of forest products, e.g. timber, non-timber amenity and forest revenues, are assumed to evolve according to geometric Brownian process or mean-reversion. For example, Conrad (1997) used geometric Brownian motion to represent the evolution of non-timber amenity value in an option-value analysis of when to harvest an old-growth forest. Chladná (2007) applied mean-reversion to study optimal rotations with uncertain carbon and harvest prices. In Yoshimoto (2002), a stochastic dynamic model was constructed to examine forest stand management, specifically, optimal harvest timing under log price uncertainty. He assumed geometric Brownian process to capture uncertainty in future log price. Results from his one-stage and two-stage dynamic programming algorithm reveal different conclusions from Faustmann results due to the introduction of an option of abandoning forest management. The finding is that optimal harvest timing under stochastic log prices was delayed when a price level was too low to maintain forest management. However, a binary timing problem was studied concerning whether to "keep" or "discontinue" current single-rotation forestry. Ohnishi (2003) is another example of the application of geometric Brownian processes for price to an optimal stopping harvest problem.

The purpose in this chapter is to examine a private landowner who must optimize his or her land use allocation under uncertainty of a future biomass price and associated returns, where uncertainty in woody biomass prices follows from the fact that the biomass market is in an emerging stage. The woody biomass price and thus returns to the bioenergy land use are assumed to follow geometric Brownian motion, for reasons that will be discussed later.

This chapter is organized as follows. In the next section, a modified stopping problem incorporating stochastic dynamics and land use decisions over time is developed. In the third section, a stochastic dynamic simulation will be conducted. The last section will include conclusions and policy implications.

4.3 A THEORETICAL MODEL

The problem of land use change is inspired by uncertainty in future woody biomass prices associated with an emerging biomass market. The landowner is assumed to maximize his or her expected net present value of returns to land by optimizing land allocation between agriculture and forestry. The extension we make of this land use problem to existing optimal stopping problems follows from Lichtenberg (1989), utilizing the introduction of land quality into a land use problem. Woody biomass investment is partly irreversible, and sometimes it may be optimal to wait for more information to arrive before establishing this form of land use. This makes the problem of a forest landowner similar to an option value problem, where the option value is introduced in each period as a premium that measures the opportunity cost of investing now and forgoing the option to delay investment until more information is revealed (Dixit et al. 1994, and Plantinga 1997).

Our model is based on land rents to outline how a landowner optimizes land use over time between agricultural and woody biomass production when the biomass price follows geometric Brownian motion. Biomass production comes from short-rotation tree species such as hybrid poplar, which is different from timber production from conventional tree species such as loblolly pine. Suppose that land quality is represented by the scalar q ranging from 0 to 1; 0 and 1 indicates the minimum and maximum land quality, respectively. To simplify the analysis, the total areage of land is assumed normalized to one. The amount of land with quality q is then denoted by $G(q) = \int_0^q k(q) dq$ where $k(q)$ is the probability density function of q and $G(q)$ indicates the amount of land with quality at most q with $G'(q) = k(q)$.

Before proceeding to establish the model, we make several assumptions about relative land rents between agriculture and forestry (both timber production and woody biomass production) that are standard in land use problems: 1. Returns to all land uses are increasing in land quality, 2. Agriculture is more profitable on land with higher quality, while forestry production, i.e. either timber production or biomass production, is more profitable on land of lower qualities. These assumptions guarantee unique solutions when they exist. They also suggest that at present a landowner should allocate the land to agricultural crop production on land with superior land quality and timber production on land with inferior land quality. Should there be no emerging biomass market, the landowner will simply allocate land on the continuum between agricultural crop production and conventional timber production to maximize his or her expected net present value. However, when the landowner has imperfect foresight that at some point of time a biomass market will emerge and make woody biomass production more profitable than timber production, there are then two questions the landowner faces: First, without knowledge of the exact time of development in the biomass market, the landowner must decide when to stop timber production and invest in woody biomass. This is a modified optimal stopping problem. Second, the landowner must decide how much land should be allocated to timber production before the land use shift or stopping time, and the land allocations among woody biomass production, conventional timber production and agricultural crop production after the land use shift.

We suppose that, before the land use shift, the amounts of land that are allocated to timber production and crop production, i.e. the initial proportions of land on the continuum, are denoted as \bar{L}_f and \bar{L}_a , respectively. After the land use shift, the amounts of land allocated to woody biomass production, timber production, and crop production are \tilde{L}_b , \tilde{L}_f and \tilde{L}_a , respectively, where the subscripts f , a , and b denote timber production, agricultural production, and short-rotation biomass production, respectively.

Agricultural production parameters are assumed to be known, i.e. the unit price of output p_a , and the constant wage, ω , are known to the landowner. The labor input ℓ is assumed to be the only input used for agricultural production. Agricultural output is represented by the technology, $h(\ell, q)$. Therefore, the net benefits on each land unit from agriculture are given by:

$$R_a = \int_0^{\infty} [p_a h(\ell, q) - \omega \ell] e^{-rt} dt \quad (4.1)$$

where agricultural production $h(\ell, q)$ is concave, with $h_\ell(\ell, q) > 0$, $h_{\ell\ell}(\ell, q) < 0$, and $h_q(\ell, q) > 0$.

The optimal level of the input, ℓ^* , is obtained by solving the first-order condition of equation (4.1): $p_a f(\ell, q) - \omega = 0$.

For conventional timber production, we suppose that the unit price of output p_f , the total regeneration cost, c_1 , and the optimal rotation age T_1 , are given. The conventional timber production function is then $f(T_1, q)$ with $f_{T_1} > 0$ and $f_q > 0$. Therefore, the net present value returns per land unit from timber production is represented by:

$$R_f = \frac{p_f f(T_1, q) e^{-rT_1} - c_1}{1 - e^{-rT_1}} \quad (4.2)$$

This represents the capitalized value when the land unit is devoted to timber production in perpetuity (e.g., see Amacher et al. 2009). The initial proportion of the land quality continuum devoted to timber production \overline{L}_f is then obtained by maximizing the net present value of land as follows.

$$V = \max_{\overline{L}_f} \int_0^1 [\overline{L}_f R_f + (1 - \overline{L}_f) R_a] k(q) dq \quad (4.3)$$

The necessary condition is given by:

$$\frac{\partial V}{\partial \overline{L}_f} = R_f^* - R_a^* = 0 \quad (4.4)$$

Equation (4.4) defines the critical land quality q^c that divides the land continuum into agriculture and conventional timber production, and thus the optimal initial land allocations are obtained as follows:

$$\begin{aligned} \hat{L}_f^* &= \int_0^{q^c} k(q) dq, \\ \hat{L}_a^* &= \int_{q^c}^1 k(q) dq \end{aligned} \quad (4.5)$$

Provided that there is no emerging biomass market, the land allocation derived above would be a permanent choice the landowner makes to maximize rents from the land. However, an emerging biomass market may make woody biomass production more profitable than timber

production at some point of time if prices are high enough for biomass production. As a consequence, at some point in time in the future t , the initial land allocation between forestry and agriculture will change to \tilde{L}_b (woody biomass), \tilde{L}_f (conventional timber) and \tilde{L}_a (agricultural crop), as the landowner adopts biomass and agriculture on a part of the land continuum²⁰. Due to the uncertainty in the timing of biomass market emergence, the solutions of \tilde{L}_b^* , \tilde{L}_f^* , and \tilde{L}_a^* will be different from \hat{L}_f^* and \hat{L}_a^* .

Transaction costs variable Z is introduced here to indicate the landowner's reluctance to switch to a different form of production on land with quality q . Z is assumed to be a constant serving as a "cushion" for the landowner to consider whether the investment is financially feasible. This means that the investment value after the land use switch should exceed the investment value before the land use switch including the transaction costs as a deduction item. In the simulation part, the importance of Z will be fully examined.

Unknown biomass prices can be introduced in a number of ways. We assume that there is a known stochastic process governing fluctuations in this price. Let the biomass price at time t , p_b , follow geometric Brownian motion so that at any point in time,

$$p_b = \alpha p_b dt + \sigma p_b dZ \quad (4.6)$$

where α and σ are the drift and volatility of the process, respectively, and dZ is the increment of a standard Wiener process such that $dZ = \varepsilon_t \sqrt{dt}$, where $E(\varepsilon_t) = 0$ and $Var(\varepsilon_t) = 1$. The geometric Brownian motion assumption, with increasing drift, is reasonable here in that the supply of land is inelastic and thus rents to land use could in fact increase without bound over time as the drift increases²¹. It is more convenient to work with land rents, R_b , which is a continuous function of the biomass price. There is no explicit functional form for the land rents from growing woody biomass for energy use. Thus it is reasonable to use the net present value of

²⁰We are assuming that the landowner switches from conventional timber production to biomass production on some land with relative low quality. This is reasonable in the absence of non-timber amenities because we are assuming that biomass production will become relatively more profitable than conventional timber production if the biomass market prices are high enough.

²¹ This property of ever increasing drift is usually stated as a weakness to using geometric Brownian motion to describe prices.

land rents deriving from conventional timber production just as we did in equation (4.2). To be more specific, the initial land rents from woody biomass production are given by

$R_b = \frac{P_b g(T_2, q) e^{-rT_2} - C_2}{1 - e^{-rT_2}}$. The fact that it is a monotonic continuous function of woody

biomass price, P_b , it implies that R_b also follows a geometric Brownian process given by:

$$dR_b = \alpha R_b dt + \sigma R_b dZ. \quad (4.7)$$

The drift and the volatility, α and σ in (4.7) are the same as assumed in the stochastic process for the woody biomass price, P_b . This is because we assume the rotation age for biomass is known and equal to T_2 . The biomass production function is represented by $g(T_2, q)$. The regeneration cost is set to be a constant C_2 . Meanwhile, we proceed with the same technology for crop production as we did in Chapters 2 and 3. R_a remains the same as in earlier chapters.

In order to solve the landowner's problem with an accessible method, the two-state option pricing model (binomial option pricing model) is taken to numerically discretize the evolution of R_b described by equation (4.7) into an upward or downward movement through time. Suppose R_b starts at R_b in the first state. In next state, it will either rise to $u \times R_b$ (an upward state) or fall to $d \times R_b$ (a downward state). The probabilities for an upward move and a downward move are denoted by q and $(1 - q)$, respectively. As $\Delta t \rightarrow 0$, the following binomial option pricing model will converge to equation (4.7) (Cox et al. 1979):

$$u = e^{\sigma\sqrt{\Delta t}} \quad (4.8)$$

$$d = \frac{1}{u} = e^{-\sigma\sqrt{\Delta t}} \quad (4.9)$$

$$q = \frac{e^{\mu\Delta t} - d}{u - d} \quad (4.10)$$

The time point of the land use switch from the initial land allocation to the mixed land use investment in agricultural crop, conventional tree species and woody biomass for energy will require deciding on when to 'kill the option'. Here the option is that the landowner retains the initial land use to the next period. The landowner evaluates whether to invest at time t and change land use on the continuum, versus keeping the option open to establish biomass production later and keep initial land use for another period. If the landowner kills the option to

continue at time t , then a new optimal land allocation for agricultural crop, conventional tree species and short-rotation woody crops is solved. Specifically, we need to solve for $\tilde{L}_a^*(t)$, $\tilde{L}_f^*(t)$, and $\tilde{L}_b^*(t)$ defined above.

Including all of these features, a modified optimal stopping problem where the following objective functional is maximized is established. Equation (4.11) represents total land rent before time t , where $R_a(t_1)$ and $R_f(t_1)$ are land rents on the unit land continuum from agricultural production and conventional timber production before time t , respectively, if the forestry is relative more profitable on some land unit.

$$\pi_t = \bar{L}_a R_a(t_1) + \bar{L}_f R_f(t_1) \quad (4.11)$$

The total land rents after the land use switch is given by,

$$V_t = \tilde{L}_a R_a(t_2) + \tilde{L}_f R_f(t_2) + \tilde{L}_b R_b(t_2) - Z \quad (4.12)$$

where $R_a(t_2)$, $R_f(t_2)$, and $R_b(t_2)$ are land rents on the unit land continuum from agricultural production, conventional timber production and short-rotation woody crop production after time t . Transaction costs Z is included as a general term to reflect the landowner's willness or reluctance to switch the land use. In order to differentiate the land rents before and after the switch, we use t_1 and t_2 in equations (4.11) and (4.12) to clear any confusion.

A modified stopping problem consistent with equations (4.11) and (4.12) can be written compactly as one of solving the following simple Bellman equation:

$$M(V_t) = \max \left\{ E(\pi_t + V_t); \frac{E[M(V_{t+1} + \pi_{t+1})]}{1+r} \right\} \quad (4.13)$$

The LHS of equation (4.13) is the value function at time t , while the RHS is the value function for the next instant in time. The uncertain biomass revenues are included in V_t and V_{t+1} . The first term on the RHS of equation (4.13) is the payoff if the landowner invests some of his or her land in forest biomass production for bioenergy and adjusts land use at time t . The second term on the RHS of equation (4.13) is the discounted value from not changing the land use at the current period and waiting for another period. Equation (4.13) is different from the conventional stopping problem found in the literature. Both terms on the RHS include the uncertainty of the biomass revenues. Its counterpart of partial differential equation cannot be derived directly.

Thus, Equations (4.8)-(4.10) are particularly helpful to find the solutions here. The constraints on the land allocation variables will be explained in the next section.

4.4 SIMULATION ANALYSIS

4.4.1 DATA

As mentioned before, loblolly pine and hybrid poplar are considered as tree species for conventional timber production and bioenergy forest production, respectively. Loblolly pine is a typical tree species in the Southeast US. Hybrid poplar has long been discussed and studied as a short rotation tree species for energy production by professionals and academicians (Armstrong et al. 1999, Yemshanov et al. 2008). The stand-level TAUYIELD model is used to simulate yields of loblolly pine sawtimber and pulpwood at different rotation ages (Amateis et al. 1995). The optimal rotation age ranges from 8 to 36 years using the data for different land qualities. Usually loblolly pines that are less than 8 years old are around 6 to 8 inches in diameter at breast height, and thus have little commercial value for timber production. Land quality is simulated based on site index or the height of dominant and co-dominant tree in the stand at age 25; those correlate with both growth rate and tree mortality over time. Three different loblolly pine site indexes, 45, 60, and 75 are used to denote low, average and high land quality, respectively. In all three land quality continuums, we assume that 500 trees per acre are planted and the survival rates after the first year planting are 70%, 75%, and 80%, respectively. In the theoretical section, land quality is assumed to be continuous; but we discretize the land quality in the simulation process to simplify the problem.

Yield data from TAUYIELD are factor-converted into units of green tons of wood harvested (equivalent to about 2,000 pounds). Costs of growing loblolly pine are taken from Folegatti et al. (2007) and include machine planting and prescribed burning. They are adjusted for inflation to the base year of 2009. Average stumpage prices of pine sawtimber and pulpwood are taken from quarterly averages reported in Timber Mart-South during the periods of 2004 to 2007 and the year of 2009, adjusted for inflation to 2009 dollars using the annual average consumer purchasing index (CPI) data from U.S. Bureau of Labor and Statistics.

Hybrid poplar yields data are obtained from the Oak Ridge Energy Crop County Level database (ORECC). Three different annual yields are observed, 2.5 tons per acre per year for land of low quality ('pessimistic' yield in the database), 4.5 tons for land of average quality ('average yield' in the database) and 5.5 tons for land of high quality ('optimistic' yield in the

database) at the optimal rotation age, which is fixed to be 7 years in ORECC research. Costs of establishment including hand planting, planting materials, and herbicide equal 263 dollars (inflation adjusted using the base year of 2009) per acre based on the study results from the University of Minnesota.

Specific market price data for bioenergy-based hybrid poplar wood have not yet been established; it is initially assumed to be 60 dollars per ton. The timing of the emergence of woody biomass markets is unknown.

Corn for grain production is adopted as the agricultural practice. County-level yields from the year of 2007 in Georgia, a state where loblolly pine is an economically important tree species and is in the biological range of growing hybrid poplar, are taken from the National Agricultural and Statistics Service of the United States Department of Agriculture. We choose corn for grain as the agricultural product because in the United States corn is also used to produce biofuel. Yield data for hybrid poplar was taken from the ORECC database have data for 159 counties in Georgia and NASS has provided corn yield data for 88 counties in Georgia. We only kept the data for those counties growing both hybrid poplar and corn after matching the two databases. The fixed cost for corn production here, assumed to be the input rate for corn production establishment, is 215 dollars. It is conventional to assume that the corn production function takes a Cobb-Douglas form, $h(l, q) = l^{0.5}s(q)$. $s(q)$ is the maximum output in each land quality class without other inputs involved and is 70, 115 and 150 bushels per acre per year for the land of low, average, and high quality, respectively. Deriving from the first order condition of the net present value function of agricultural profits in the last section, the optimal input levels are 0.33, 0.89 and 1.51 units for the land of low, average, and high quality, respectively.

4.4.2 SIMULATION METHOD

The stochastic problem in our study (4.13) cannot be solved using the ordinary derivative method. A backward recursive procedure is adopted instead. However, different from other stochastic optimal stopping problems, the model in our study is designed to solve two problems: one is optimal land allocation, and the other is the optimal “stopping” decision, that is, when to invest in bioenergy dedicated tree species production.

The procedures for the land use allocation decision and optimal stopping problems are designed as follows:

First, the decision for the stopping problem can be derived by the following steps.

Step 0: Initiation

Predefine transaction costs Z (which serves as a cut-off line): two different values of transaction costs Z are assumed, 10% and 20% of the establishment costs of the hybrid poplar.

End time: $t = T$;

The interval setup: $0 \leq \tilde{L}_b \leq 1, 0 \leq \tilde{L}_f \leq 0.5, \tilde{L}_b + \tilde{L}_f \leq 1$ and $\tilde{L}_a + \tilde{L}_f + \tilde{L}_b = 1$;

Calculate $E(\pi_T + V_T)$ and $E[(\pi_\infty)]$. The former is the total expected land rents on the time horizon, and the landowner is assumed to switch land use at the end time, T , if it happens. The latter term is the total expected land rents assuming that the landowner does not switch land use and remains with the original land use ad infinitum. Now we compare the difference between two terms, $D = E(\pi_T + V_T) - E(\pi_\infty)$, with the transaction costs Z . If $D > Z$, the investment at time T can be regarded as financially feasible. If $D < Z$, the investment at time T should not be considered as a good alternative and land remains the original land use. This means that the landowner should either practice agriculture on the whole land quality continuum or have a mixed land use with agricultural production and conventional timber production. At this point, the optimal land allocation can also be determined.

Step 1: Iteration

$t = T - 1$; calculate and compare $E(\pi_t + V_t)$ and $\frac{E[M(V_T + \pi_T)]}{1+r}$.

Step 2: If $D < Z$, go to Step 1; if $D > Z$ and $\tilde{L}_b(t) - \tilde{L}_b(t-1) < 0.001$, go to Step 3.

Step 3: With the constraints on the land allocation variables, we can find the optimal solutions, \tilde{L}_a^* , \tilde{L}_f^* and \tilde{L}_b^* , that maximize $M(V_t)$ and terminate the procedure at the optimal stopping time t^* . Based on the time point of stopping and relative land rents from the alternatives, the optimal land allocation may not remain the same as the initial allocation.

To verify the assumptions of $0 \leq \tilde{L}_f \leq 1$ and $\tilde{L}_b + \tilde{L}_f \leq 1$, we need to recall the assumptions of relative rents in the previous sections, that is, agricultural production is more profitable on land with higher qualities. Therefore, the land allocated to forestry should be not more than that to agriculture on a varying land quality continuum.

4.4.3 SIMULATION ANALYSIS

For simulation programming, we discretize land into three categories, low, average, and high site qualities, based on the output data collected for agricultural crop, timber production and hybrid poplar. It is therefore theoretically consistent to examine how the land in each category is allocated between different alternatives before and after the emergence of the woody biomass market.

The results for the land use allocation before the emergence of bioenergy markets are clear. For corn production, with all the factors constant, the net present values of land rents during the landowner's whole time horizon (infinite sequences of rotations) are \$2,326, \$6,278, and \$10,683 for the land with low, average and high quality, respectively. Even when we assume a maximum 40 years before the emergence of bioenergy dedicated biomass markets and land use changes, these rents are \$1,625, \$4,388 and \$7,465, respectively. The maximal net present values of land rents from planting loblolly pine during the whole time horizon are \$536.80 (rotation age of 36), \$1,568 (rotation age of 32), and \$3,275 (rotation age of 27) on land with low, average and high quality, respectively. With these results, we can infer that before bioenergy market emergence, loblolly pine will not be chosen as a land use on the land quality continuum. The most robust explanation is the imperfection of data available for this study. County-level data on corn production are collected from USDA, and the quality of land is basically categorized by maximum yields. However, the data on loblolly pine are based on TAUYIELD predictions while the quality of land depends on the site index assumptions. As a consequence, this situation very likely results in the possibility that the quality of land used for agricultural yields does not match the site indices chosen for forestry. Our model is particularly useful for a case study where data are specified regionally.

The above results also show that, in our case, for any possible realization of timing for bioenergy market emergence, we only need to be concerned about the land allocation decision between corn production and hybrid poplar over time. Noting that in other cases with higher forestry output, i.e., the alternative of growing conventional timber production is not irrelevant, the land allocation decision after the emergence of biomass markets should be considered among agricultural corn production, loblolly pine production, and bioenergy dedicated hybrid poplar production.

Now we need to consider the situation after the emergence of bioenergy markets. In this study, we assume the drift of the woody biomass returns is, $\alpha = 0.5$, while the volatility, σ , can take on two different values, 0.5 and 2, to denote the range of woody biomass price and revenue uncertainty, as well as the relative high and low probabilities of future prices and biomass revenues with an upward movement. Using the method proposed by Cox et al. (1979), the probability of an upward movement for woody biomass revenues in the next time period is 1 when $\sigma = 0.5$, and 0.2 when $\sigma = 2$, respectively. The results show that a low volatility in current woody biomass revenues is associated with a higher probability of an upward movement of biomass revenues in the next period, and a high volatility may indicate a downward movement in the next period. We take two possible volatilities to examine their effects on the land allocation decision and optimal stopping timing.

First we consider $\sigma = 0.5$. For the end time, $T = 40$, on land of low quality, the net present value of land rents from agriculture on the whole time horizon, $E(\pi_\infty)$, is \$2,326. Assume that the landowner decides to invest in woody biomass production for energy use at this time point. Comparing the discounted land rents from growing hybrid poplar and agricultural corn production to the end time, we find that the former is significantly larger than the latter. Therefore, land of low quality will be allocated to hybrid poplar production. Furthermore, the sum of land rents before the switch (agricultural corn production) and land rents after the switch (hybrid poplar production), \$6,801, is higher than the net present value of land rents from agricultural corn production on the whole time horizon, \$2,326. Therefore, at the end time, if the landowner has not changed his or her land use, it is still better to switch at that time, even after taking into account both forms of transaction costs.

For land with average quality, using the same method, we find that the land is still allocated to hybrid poplar production. The sum of land rents before the switch (agricultural corn production) and land rents after the switch (hybrid poplar production) is \$9,563, and it is much larger than the expected net present value of land rents from agriculture on the infinite time horizon, \$6,278. The same result occurs with the land of high quality. Specifically, the total expected land rents are \$20,861 if the landowner switches the land use. The total expected NPV of land rents from corn production on an infinite time horizon here are \$10,683.

The explanation to this land use change result and its accompanying significant land rents change is that we take a low value of volatility, $\sigma = 0.5$. As analyzed before, it denotes a high

probability of an upward movement of biomass revenues which surpasses the land rents from agriculture to a great extent.

Backward recursion yields results presented in the table below.

Table 4.1: Expected net present value of land rents with and without land use change at different stopping times and $\sigma = 0.5$ ²²

Time Rents	Switch Time t	40	39	38	37	36	35
Expected rents from low quality land (\$)	With land use change	6,801	4,743	3,486	2,714	2,326	2,326
	Without land use change	2,326	2,326	2,326	2,326	2,326	2,326
Expected rents from average quality land (\$)	With land use change	9,563	7,469	6,175	5,364	6,278	6,278
	Without land use change	6,278	6,278	6,278	6,278	6,278	6,278
Expected rents from high quality land (\$)	With land use change	20,861	15,492	12,194	10,683	10,683	10,683
	Without land use change	10,683	10,683	10,683	10,683	10,683	10,683

In Table 4.1, we compare the land rents with and without the land use change for each land quality class. We come to the conclusion that, on land of low quality it is better for the landowner to switch the land use not later than the 36th year, where during the 35th and 36th years, the land use change won't cause a large change to land rents. On land of average quality, it is better for the landowner to switch the land use after 39 year, since before that year the expected NPV of land rents from agriculture with an infinite horizon is larger than that occurring from

²² Without land use change means that the landowner keeps agricultural production ad infinitum.

land use change. On land of high quality, it is better for the landowner to switch land use after the 37th year due to the much higher land rents afforded by land use change.

Second, consider a higher biomass rent volatility of $\sigma = 2$. Recall that a higher volatility results in a lower possibility of an upward movement of biomass returns over time. Comparing Table 4.2 to Table 4.1, we find some interesting differences. The overall expected NPV of land rents with land use change is significantly lower than that in Table 4.1 for which volatility is lower at $\sigma = 0.5$. On land of high quality, land remains in agriculture and there is no land use change. On land of average quality, any land use change can only make the landowner worse off. On land of low quality, the landowner won't be worse off for any land use change, and he or she will be slightly better off if land use change takes place after the 38th year. These results differ significantly from the scenario of $\sigma = 0.5$. Intuitively, with a long time horizon, the landowner prefers to change land use only when the uncertainty of land rents from biomass production for energy use is low. A lower volatility of biomass rents also denotes a higher possibility of an upward movement of biomass returns, which increases incentives for biomass investment according to the results across Tables 4.1 and 4.2.

Table 4.2: Expected net present value of land rents with and without land use change at different stopping times and $\sigma = 2$ ²³

Time Rents	Switch Time t	40	39	38	37
Expected rents from low quality land (\$)	With land use change	2,595	2,595	2,326	2,326
	Without land use change	2,326	2,326	2,326	2,326
Expected rents from AVR quality land (\$)	With land use change	5,321	5,321	6,278 ²⁴	6,278
	Without land use change	6,278	6,278	6,278	6,278
Expected rents from high quality land (\$)	With land use change	10,683	10,683	10,683	10,683
	Without land use change	10,683	10,683	10,683	10,683

4.5 CONCLUSION AND POLICY IMPLICATION

In this chapter, we have extended Chapters 2 and 3 to examine a landowner decision problem with stochastic optimization of land use under future emergence of bioenergy-based forest biomass markets. Several important factors associated with land use change such as land quality, timing of the emergence of bioenergy markets, transaction costs, and price increase all remain in this chapter. However, we incorporate the last three factors in a different way here. For the timing of the emergence of bioenergy markets, the timing interval is no longer based on the rotation but is measured as a stochastic evolution process over an interval of one year.

²³ Without land use change means that the landowner keeps agricultural production ad infinitum.

²⁴ This is a special case where agriculture dominates hybrid poplar production and no land use change occurs.

Transaction costs here are regarded as a general deduction item to total expected NPV of land rents after land use changes. Surprisingly, it does not affect the land use much, possibly because the two levels of transaction costs that we used are only 10% and 20% of the establishment costs of hybrid poplar. Price increases here over time are represented by an upward movement of forest biomass returns across time. Its extent depends on the level of volatility in the stochastic process. In order to measure its effects, two different values of volatility of forest biomass returns are considered. The effects of land quality on land use change is evident, especially comparing between the land of low and high quality.

The results in this chapter suggest several points to consider. First, a more precise definition of transaction costs is required. This will provide a better land use change framework for the landowner and other stakeholders. Second, more technologies and techniques are needed to measure the land quality in each study area. Third, more policy instruments may be needed to hasten the development of bioenergy market if this is the ultimate goal of the government. So far the recommendations have only been removing or decreasing existing subsidies to agriculture or offering cost-reduction program to bioenergy consumption.

Comparing what we found in Chapters 2 and 3, this chapter relaxes the assumption that the landowner has to make a costly land use change at the beginning of his or her time horizon. The stochastic optimization of land use presumes that the landowner can make land use change decisions based on new information that arises and his or her perception of the movement of forest biomass rents in future periods. Unlike Chapters 2 and 3, and consistent with theoretical analysis, the results of this chapter show conversion of some land quality classes entirely to hybrid poplar, based on the value of the volatility of forest biomass rents. On some land units, it is always better to keep land in agriculture and no bioenergy will be adopted. It is critical, based on our results, for any government or related agency to provide the landowner with the latest information on forest biomass to decrease uncertainty and improve the landowner's perception of forest biomass rents, if the goal is an earlier land use change.

In addition, we assume that agricultural production, particularly its output price, is constant. However, the price variability of agricultural products could exist and could be a variable that evolves over time for the landowner. If the variability of prices for agricultural output is incorporated into the analysis, we may expect the adoption of forest bioenergy to become a relatively more favorable land use option. In addition, the price for agricultural

production could change once biomass markets emerge, and there may be some cases where some land of woody biomass production is converted to agricultural production if the price of agricultural output rises high enough. This is a more pessimistic biomass market emergence scenario since land for woody biomass production decreases.

4.6 REFERENCES:

Amacher, G.S., M. Ollikainen, and E. Koskela. 2009. Economics of forest resources, Cambridge: MIT Press.

Amateis, R., P. Radtke, and H. Burkhart. 1995. TAU YIELD: A stand growth and yield model for thinned and unthinned loblolly pine plantations. Loblolly Pine Growth and Res. Cooperative. Rept. No. 92. Virginia Tech, Blacksburg, Va.

Armstrong A, C. Jones, and I. Tubby. 1999. Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop. Biomass and Bioenergy 17(4): 305-314.

Braze, R. and R. Mendelsohn (1988). Timber Harvesting with Fluctuating Prices. Forest Science (34): 359-372.

Chladná, Z. (2007). Determination of Optimal Rotation Period under Stochastic Wood and Carbon Prices. Forest Policy and Economics 9(8):1031-1045.

Clarke, H.R. and W.J. Reed (1989). The Tree-cutting Problem in a Stochastic Environment: The Case of Age-dependent Growth. Journal of Economic Dynamics and Control 13(4):569-595.

Consumer Price Index Detailed Report Tables for the years from 2004 to 2007 and the year of 2009, http://www.bls.gov/cpi/cpi_dr.htm, Bureau of Labor Statistics.

Conrad, J.M. (1997) On the Option Value of Old-growth Forest. Ecological Economics 22(2): 97-102.

Cox J. C., Stephen A. Ross, and Mark Rubinstein. Option Pricing: A simplified Approach. Journal of Financial Economics, 7(3): 229-263, 1979.

Dixit, R.K. and R.S. Pindyck. 1994. Investment under Uncertainty. Princeton University Press.

Energy Information Administration. U.S. Imports by Country of origin. Web 28 Sept. 2009. <
http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbbl_m.htm>

Wilent, S. (2008). State Issues Guidelines for Forest Biomass Harvesting. *The Forestry Source* 13(9).

Folegatti, B.S., M.F.Smidt and M.R.Dubois (2007). Costs and cost trends for forestry practices in the South. *Forest Landowner*, Sep/Oct. : 11-16.

Gong, P., M. Boman, and L. Mattsson (2005). Non-timber benefits, price uncertainty and optimal harvest of an even-aged stand. *Forest Policy and Economics* 7(3): 283-295.

Koskela, E. (1989). Forest Taxation and Timber Supply Under Price Uncertainty: Perfect Capital Markets. *Forest Science* (35):137-159.

Lu, F. and P.Gong (2003). Optimal Stocking Level and Final Harvest Age with Stochastic Prices. *Journal of Forest Economics* 9(2):119-136.

Mckay, H. (2008). Environmental, economic, social and political drivers for increasing use of woodfuel as a renewable resource in Britain. *Biomass and Bioenergy* 30. 308-315.

Hoffmann, D. and M. Weih (2005). Limitations and improvement of the potential utilization of woody biomass of energy derived from short rotation woody crops in sweden and Germany. *Biomass and Bioenergy* 28: 267-279.

Junginger, M., M. de Wit, R. Sikkema and A. Faaj (2008). International bioenergy trade in the Netherlands. *Biomass and Bioenergy* 32(8): 672-687.

Katz, S. H. (2008). Food to fuel and the world food crisis. *Anthropology Today* 24(1): 1-3.

Lichtenberg, E. (1989). *Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains*. Blackwell Publishing Limited.

Mitchell, D. (2008). A note on Rising Food Prices 4682, World Bank Policy Research Working paper.

Motoh, T. (2004). Optimal Natural Resources Management under Uncertainty with Catastrophic Risk. *Energy Economics* 26(3):487-499.

Ohnishi, M.(2003). An optimal stopping problem for a geometric Brownian motion with Poissonian jumps. *Mathematical and Computer Modeling* (38): 1381–1390.

Patzek Tad W. and S.-M. Anti and R. Campos and K. W. ha and J. Lee and B. Li and J. Padnick and S.-A. Yee (2005). Ethanol From Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets? *Environment, Development and Sustainability* 7(3): 319 – 336.

Pimentel, D. (1991). Ethanol fuels: Energy security, economics, and the environment. *Journal of Agricultural and Environmental Ethics* 4(1): 1-13.

Plantinga, A.J. (1998). The Optimal Timber Rotation: An Option Value Approach. *Forest Science* (44): 192-202.

Tahvonen, O. and M. Kallio (2006). Optimal Harvesting of Forest Age Classes under Price Uncertainty and Risk Aversion. *Natural Resource Modelling* 19(4): 557-585.

Thomson, T. A.(1992). Optimal Forest Rotation When Stumpage Prices Follow a Diffusion Process. *Land Economics* 68(3): 329-342.

Schatzki, T. (2003). Options, Uncertainty and Sunk Costs: an Empirical Analysis of Land Use Change. *Journal of Environmental Economics and Management* 46(1): 86-105.

U.S. Energy Consumption by Energy Source 2003-2007, EIA, Renewable Energy Consumption and Electricity Preliminary 2007 Statistics.

1998 Establishment and Maintenance Costs of hybrid poplar, <http://www.hybridpoplar.org/EMCosts.htm>, Growing Hybrid Poplars as a Crop, University of Minnesota, 1998 (accessed Oct. 2009).

Yemshanov D and D. Mckenny, 2008. Effects of spacing and cutting cycle on the yield of poplar grown as an energy crop *Biomass and Bioenergy* 32(3): 185-197.

Yoshimoto, A. and I. Shaji (1998). Searching for an Optimal Rotation Age for Forest Stand Management under Stochastic Log Prices. *European Journal of Operational Research* 105: 100-112.

CHAPTER 5: CONCLUSIONS

The purpose of this dissertation is to study land allocation decisions for a private landowner who faces various degrees of uncertainty about the emergence of bioenergy markets. The overall objective is to determine how emerging markets stimulate land use in the present, and to assess how policy instruments are important in inducing land use change that helps to establish a long term biomass bioenergy market.

We take three steps to achieve a complete analysis. First, in Chapter 2 we study the problem with a risk-neutral private landowner who is expected to maximize his or her net present value of expected land rents from different land use alternatives. This landowner faces an open loop problem where decisions must be made at the beginning of the time horizon. Both the timing and extent of bioenergy market emergence are examined. The collective effects of several key factors to land use are examined, including varying land quality, transaction costs, and future bioenergy demand shifts. Possible alternative and competing land uses include conventional timber production, short-rotation bioenergy dedicated woody biomass production, and agriculture all of which are chosen on a land quality continuum. In a simulation, uncertainty concerning future biomass market demand is captured using six different timings of market emergence and five different price increase levels. The results show that the net present value of expected land rents from biomass adoption on the land quality continuum increase with a higher price increase or price jump, and that the expected price shift appears more important to ensuring bioenergy land use adoption than the length of time the landowner expects to wait until market emergence. Perhaps the most important variable in land use decisions with emerging markets for the risk neutral landowner is transaction costs that can prevent land use change even when relative expected returns favor it. In many cases, the presence of transaction costs mean that unrealistic scenarios for biomass emergence may be needed before land use shifts toward short rotation bioenergy crops. In contrast, in Chapter 2 we also study a land use problem for a risk-neutral social planner who is assumed to value public goods from forest establishment. The net present value of expected land rents is distinctly larger for the social planners than for a private landowner, and in this scenario, more land is allocated to bioenergy if that crop provides public goods that are valued by the social planner.

In Chapter 3 we study the problem of Chapter 2 but assume that the private landowner displays a risk aversion preference over unknown parameters related to market emergence. The

risk-averse private landowner, supported by a growing body of work in the literature, maximizes his or her expected utility when making land use decisions. Both constant relative risk aversion and decreasing relative risk aversion are examined, and in this chapter pure price uncertainty is examined as a mean preserving spread in prices. Higher risk aversion results in more land allocated to bioenergy for all land quality levels. The explanation for this result is that the landowner can expect a higher forest biomass price when pure uncertainty (the price variance) is higher. However, comparing the results to the risk-neutral landowner and controlling for other factors such as transaction costs, generally less land is allocated to bioenergy for all land quality classes when the landowner is risk averse. Thus, bioenergy adoption is less likely if the forest sector is composed of risk averse landowners, implying that it is important to empirically investigate risk aversion in future studies of forest landowners if the goal is to determine whether bioenergy production will be adopted ahead of market emergence.

Chapters 2 and 3 restrict the land use problem to an open-loop approach, which means that the landowner has to make a costly land allocation decision at the beginning of his or her time horizon. In Chapter 4, this key assumption is relaxed, and instead the landowner is able to revise his or her decision based on the arrival of new information about biomass market emergence through time. To study this problem a stochastic optimization problem is applied, where the uncertainty of the emerging forest bioenergy markets is captured by the uncertain evolution of forest biomass rents for any land quality level. Geometric Brownian motion is used to represent this evolution. In the simulation results, the ending time is assumed to be 40 years, and before land use changes agriculture is expected to dominate forest rents on all land qualities. Using backward recursion, the land allocation decision is then solved as an optimal stopping problem. The results show that when the volatility of forest biomass rents is relatively high on land of high quality, the landowner will not consider a land use change during any time. On land of average quality, agriculture continues to dominate forestry in most time periods. However, the landowner will not be worse off if he or she invests in bioenergy use after the 37th year on land of low quality. At a lower level of volatility, a much higher probability of an upward movement of forest biomass rents is expected. In this scenario, land rents from forest biomass production are higher over time than with the lower volatility level, and now on high quality land the landowner will be much better off investing in forest biomass after the 37th year. For land of average quality, the landowner is better off with a land use switch at the 39th year. On

land of low quality, the landowner will be better off if he or she decides to invest in forest bioenergy after the 35th year.

Of all the key factors analyzed in Chapters 2, 3 and 4, transaction costs, a measurement of landowner's reluctance to change land use due to the uncertainty of the emergence of woody biomass markets, are the most important factor to decision making. This is despite the fact that transaction costs are usually not addressed in the literature on forest land use. The results in this dissertation show that transaction costs are important in almost every scenario of land use change. Further, the presence of these costs if significant suggest that forest biomass adoption by forest landowners will either not occur or will occur far out into the future. In many cases, if transaction costs are significant the required scale and timing of bioenergy market emergence will be unrealistically optimistic.

The results in this dissertation can help guide policy. The critical issues governments must know before forming a bioenergy policy are the extent to which landowners are risk averse, and the ways in which they update information over time. Reducing uncertainty is very important to ensuring bioenergy adoption, and anything the government can do to remove this uncertainty will lead to earlier and stronger land use change in favor of woody biomass. Another important target for government policy instruments is land quality. Our results appear quite sensitive to this parameter across all landowner types and decision making problems presented here. Finally, the government can reduce transactions costs through active information dissemination programs or an approach that encourages clear development of markets should the goal be to move toward biomass based biofuels.

REFERENCES

Brown, H.D. . “Goodnight, John Boy”: What Forest Landowners Can Learn From Farm Policy.
Forest Landowner. Nov/DEC 2009, 16-17.

APPENDIX A

Derivation of equation (3.9)

$$\begin{aligned}
& \frac{\partial E[(V^* - Z^* - \pi^*)U'(\hat{W})]}{\partial \sigma} \\
&= E[U'(\hat{W}) \frac{\partial(V^* - Z^* - \pi^*)}{\partial \sigma} + U''(\hat{W}) \frac{\partial \hat{W}}{\partial \sigma} (V^* - Z^* - \pi^*)] \\
&= E[U'(\cdot) \frac{\partial V^*}{\partial \sigma} + U''(\cdot) \frac{\partial(L_f V^*)}{\partial \sigma} (V^* - Z^* - \pi^*)] \\
&= E[\frac{\partial V^*}{\partial \sigma} (U'(\cdot) + U''(\cdot)L_f (V^* - Z^* - \pi^*))] \\
&= E\{\frac{\partial V^*}{\partial \sigma} U'(\cdot) [1 + (-1) \frac{-\hat{W} U''(\cdot)}{U'(\cdot)} L_f (V^* - Z^* - \pi^*) / \hat{W}]\} \\
&= E\{\frac{\partial V^*}{\partial \sigma} U'(\cdot) [-\rho L_f^* (V^* - Z^* - \pi^*) / \hat{W} + 1]\} \\
&= [\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2}] E\{U'(\cdot) \varepsilon [-\rho L_f^* (V^* - Z^* - \pi^*) / \hat{W} + 1]\} \\
&= [\frac{1 - e^{-\eta r T_1}}{1 - e^{-r T_1}} f(T_1^*, q) e^{-r T_1} + \frac{e^{-\eta r T_1}}{1 - e^{-r T_2}} g(T_2^*, q) e^{-r T_2}] E\{U'(\cdot) \varepsilon [-\rho \Delta \hat{W} / \hat{W} + 1]\}
\end{aligned}$$

$\Delta \hat{W} = L_f^* (V^* - Z^* - \pi^*)$ is proved here:

Original maximal wealth from agriculture before any land use change is denoted by W_1 .

Maximal wealth from all land uses after land use change is denoted by W_2 .

$$W_1 = L_f^* \pi^* + (1 - L_f^*) \pi^*$$

$$W_2 = L_f^* (V^* - Z^*) + (1 - L_f^*) \pi^* \quad \text{Q.E.D.}$$

$$\Delta W = W_2 - W_1 = L_f^* (V^* - Z^* - \pi^*)$$

APPENDIX B

STATA code for Chapter 2

```
/*the followings is for loblolly pine*/
gen pr_p_pulp=6.60
gen pr_sawtimber=39.17

gen Cost1=267.64
gen r1=0.03

gen T1=_n+7

/*low land quality*/

gen V1_11=0
gen V1_12=0
gen V1_13=0
gen V1_14=0
gen V1_15=0

replace V1_11=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_12=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_13=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_14=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_15=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)

/* median land quality*/
g V1_21=0
g V1_22=0
g V1_23=0
g V1_24=0
g V1_25=0
```



```

replace V1_21=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_22=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_23=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_24=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_25=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)

```

```

/* high land quality */

```

```

gen V1_31=0
gen V1_32=0
gen V1_33=0
gen V1_34=0
gen V1_35=0
replace V1_31=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_32=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_33=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_34=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_35=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)

```

```

/*the following is for hybrid poplar*/

```

```

gen T2=7
gen Cost2=230
gen Z1=T1+T2
gen Z2=T1^2+T2

```

```

gen pop_low=18
gen pop_median=31
gen pop_high=38

gen pr_pop=15.00
gen pr_pop1=(1+1.00)*pr_pop
gen pr_pop2=(1+2.00)*pr_pop
gen pr_pop3=(1+3.00)*pr_pop
gen pr_pop4=(1+4.00)*pr_pop
gen pr_pop5=(1+5.00)*pr_pop
gen pr_pop6=(1+6.00)*pr_pop

/* situation with low land quality when the price is 100% increase and the
time length until a biomass market shift occurs takes
1,2,3,4,5,respectively.*/

gen V2_111=0
gen V2_112=0
gen V2_113=0
gen V2_114=0
gen V2_115=0

replace V2_111=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-r1*T2)-
Cost2)
replace V2_112=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_113=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_114=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_115=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)

gen V_111=V1_11+V2_111

```

```

gen V_112=V1_12+V2_112
gen V_113=V1_13+V2_113
gen V_114=V1_14+V2_114
gen V_115=V1_15+V2_115
gen Vnet1111=V_111-Z1
gen Vnet1112=V_112-Z1
gen Vnet1113=V_113-Z1
gen Vnet1114=V_114-Z1
gen Vnet1115=V_115-Z1

```

```

gen Vnet2111=V_111-Z2
gen Vnet2112=V_112-Z2
gen Vnet2113=V_113-Z2
gen Vnet2114=V_114-Z2
gen Vnet2115=V_115-Z2

```

```

/*low land quality with 200% price increase */

```

```

gen V2_121=0
gen V2_122=0
gen V2_123=0
gen V2_124=0
gen V2_125=0

```

```

replace V2_121=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-r1*T2)-
Cost2)
replace V2_122=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_123=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_124=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_125=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)

```

```
gen V_121=V1_11+V2_121
gen V_122=V1_12+V2_122
gen V_123=V1_13+V2_123
gen V_124=V1_14+V2_124
gen V_125=V1_15+V2_125
```

```
gen Vnet1121=V_121-Z1
gen Vnet1122=V_122-Z1
gen Vnet1123=V_123-Z1
gen Vnet1124=V_124-Z1
gen Vnet1125=V_125-Z1
```

```
gen Vnet2121=V_121-Z2
gen Vnet2122=V_122-Z2
gen Vnet2123=V_123-Z2
gen Vnet2124=V_124-Z2
gen Vnet2125=V_125-Z2
```

```
/*low land quality with 300% price increase.*/
```

```
gen V2_131=0
gen V2_132=0
gen V2_133=0
gen V2_134=0
gen V2_135=0
```

```
replace V2_131=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-r1*T2)-
Cost2)
```

```
replace V2_132=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_133=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_134=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_135=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
```

```
gen V_131=V1_11+V2_131
gen V_132=V1_12+V2_132
gen V_133=V1_13+V2_133
gen V_134=V1_14+V2_134
gen V_135=V1_15+V2_135
```

```
gen Vnet1131=V_131-Z1
gen Vnet1132=V_132-Z1
gen Vnet1133=V_133-Z1
gen Vnet1134=V_134-Z1
gen Vnet1135=V_135-Z1
```

```
gen Vnet2131=V_131-Z2
gen Vnet2132=V_132-Z2
gen Vnet2133=V_133-Z2
gen Vnet2134=V_134-Z2
gen Vnet2135=V_135-Z2
```

```
/*low land quality with 400% price increase*/
```

```
gen V2_141=0
gen V2_142=0
gen V2_143=0
gen V2_144=0
gen V2_145=0
```

```
replace V2_141=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-r1*T2)-
Cost2)
```

```
replace V2_142=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_143=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_144=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
```

```
replace V2_145=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
```

```
gen V_141=V1_11+V2_141
gen V_142=V1_12+V2_142
gen V_143=V1_13+V2_143
gen V_144=V1_14+V2_144
gen V_145=V1_15+V2_145
```

```
gen Vnet1141=V_141-Z1
gen Vnet1142=V_142-Z1
gen Vnet1143=V_143-Z1
gen Vnet1144=V_144-Z1
gen Vnet1145=V_145-Z1
```

```
gen Vnet2141=V_141-Z2
gen Vnet2142=V_142-Z2
gen Vnet2143=V_143-Z2
gen Vnet2144=V_144-Z2
gen Vnet2145=V_145-Z2
```

```
/* low land quality with 500% price increase*/
```

```
gen V2_151=0
gen V2_152=0
gen V2_153=0
gen V2_154=0
gen V2_155=0
```

```
replace V2_151=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-r1*T2)-
Cost2)
```

```
replace V2_152=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
```

```

replace V2_153=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
replace V2_154=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
replace V2_155=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)

```

```

gen V_151=V1_11+V2_151
gen V_152=V1_12+V2_152
gen V_153=V1_13+V2_153
gen V_154=V1_14+V2_154
gen V_155=V1_15+V2_155

```

```

gen Vnet1151=V_151-Z1
gen Vnet1152=V_152-Z1
gen Vnet1153=V_153-Z1
gen Vnet1154=V_154-Z1
gen Vnet1155=V_155-Z1

```

```

gen Vnet2151=V_151-Z2
gen Vnet2152=V_152-Z2
gen Vnet2153=V_153-Z2
gen Vnet2154=V_154-Z2
gen Vnet2155=V_155-Z2

```

```

/* low land quality with 600% price increase */

```

```

gen V2_161=0
gen V2_162=0
gen V2_163=0
gen V2_164=0
gen V2_165=0

```

```

replace V2_161=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-r1*T2)-
Cost2)

```

```

replace V2_162=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_163=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_164=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_165=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)

```

```

gen V_161=V1_11+V2_161
gen V_162=V1_12+V2_162
gen V_163=V1_13+V2_163
gen V_164=V1_14+V2_164
gen V_165=V1_15+V2_165

```

```

gen Vnet1161=V_161-Z1
gen Vnet1162=V_162-Z1
gen Vnet1163=V_163-Z1
gen Vnet1164=V_164-Z1
gen Vnet1165=V_165-Z1

```

```

gen Vnet2161=V_161-Z2
gen Vnet2162=V_162-Z2
gen Vnet2163=V_163-Z2
gen Vnet2164=V_164-Z2
gen Vnet2165=V_165-Z2

```

```

/*median land quality with 100% price increase*/

```

```

gen V2_211=0
gen V2_212=0
gen V2_213=0
gen V2_214=0
gen V2_215=0

```

```

replace V2_211=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-
r1*T2)-Cost2)

```



```

replace V2_212=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-
r1*T2)-Cost2)
replace V2_213=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-
r1*T2)-Cost2)
replace V2_214=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-
r1*T2)-Cost2)
replace V2_215=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-
r1*T2)-Cost2)

gen V_211=V1_21+V2_211
gen V_212=V1_22+V2_212
gen V_213=V1_23+V2_213
gen V_214=V1_24+V2_214
gen V_215=V1_25+V2_215

gen Vnet1211=V_211-Z1
gen Vnet1212=V_212-Z1
gen Vnet1213=V_213-Z1
gen Vnet1214=V_214-Z1
gen Vnet1215=V_215-Z1

gen Vnet2211=V_211-Z2
gen Vnet2212=V_212-Z2
gen Vnet2213=V_213-Z2
gen Vnet2214=V_214-Z2
gen Vnet2215=V_215-Z2

/* median land quality with 200% price increase */
gen V2_221=0
gen V2_222=0
gen V2_223=0
gen V2_224=0
gen V2_225=0

replace V2_221=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_222=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)

```

```

replace V2_223=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_224=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_225=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)

gen V_221=V1_21+V2_221
gen V_222=V1_22+V2_222
gen V_223=V1_23+V2_223
gen V_224=V1_24+V2_224
gen V_225=V1_25+V2_225

gen Vnet1221=V_221-Z1
gen Vnet1222=V_222-Z1
gen Vnet1223=V_223-Z1
gen Vnet1224=V_224-Z1
gen Vnet1225=V_225-Z1

gen Vnet2221=V_221-Z2
gen Vnet2222=V_222-Z2
gen Vnet2223=V_223-Z2
gen Vnet2224=V_224-Z2
gen Vnet2225=V_225-Z2

/* median land quality with 300% price increase*/
gen V2_231=0
gen V2_232=0
gen V2_233=0
gen V2_234=0
gen V2_235=0
replace V2_231=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_232=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_233=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)

```

```

replace V2_234=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_235=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)

gen V_231=V1_21+V2_231
gen V_232=V1_22+V2_232
gen V_233=V1_23+V2_233
gen V_234=V1_24+V2_234
gen V_235=V1_25+V2_235

gen Vnet1231=V_231-Z1
gen Vnet1232=V_232-Z1
gen Vnet1233=V_233-Z1
gen Vnet1234=V_234-Z1
gen Vnet1235=V_235-Z1

gen Vnet2231=V_231-Z2
gen Vnet2232=V_232-Z2
gen Vnet2233=V_233-Z2
gen Vnet2234=V_234-Z2
gen Vnet2235=V_235-Z2

/* median land quality with 400% price increase*/
gen V2_241=0
gen V2_242=0
gen V2_243=0
gen V2_244=0
gen V2_245=0
replace V2_241=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_242=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_243=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_244=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)

```

```
replace V2_245=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
```

```
gen V_241=V1_21+V2_241
```

```
gen V_242=V1_22+V2_242
```

```
gen V_243=V1_23+V2_243
```

```
gen V_244=V1_24+V2_244
```

```
gen V_245=V1_25+V2_245
```

```
gen Vnet1241=V_241-Z1
```

```
gen Vnet1242=V_242-Z1
```

```
gen Vnet1243=V_243-Z1
```

```
gen Vnet1244=V_244-Z1
```

```
gen Vnet1245=V_245-Z1
```

```
gen Vnet2241=V_241-Z2
```

```
gen Vnet2242=V_242-Z2
```

```
gen Vnet2243=V_243-Z2
```

```
gen Vnet2244=V_244-Z2
```

```
gen Vnet2245=V_245-Z2
```

```
/* median land quality with 500% price increase*/
```

```
gen V2_251=0
```

```
gen V2_252=0
```

```
gen V2_253=0
```

```
gen V2_254=0
```

```
gen V2_255=0
```

```
replace V2_251=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
```

```
replace V2_252=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
```

```
replace V2_253=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
```

```
replace V2_254=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
```

```
replace V2_255=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
```

```

gen V_251=V1_21+V2_251
gen V_252=V1_22+V2_252
gen V_253=V1_23+V2_253
gen V_254=V1_24+V2_254
gen V_255=V1_25+V2_255

gen Vnet1251=V_251-Z1
gen Vnet1252=V_252-Z1
gen Vnet1253=V_253-Z1
gen Vnet1254=V_254-Z1
gen Vnet1255=V_255-Z1

gen Vnet2251=V_251-Z2
gen Vnet2252=V_252-Z2
gen Vnet2253=V_253-Z2
gen Vnet2254=V_254-Z2
gen Vnet2255=V_255-Z2

/* median land quality with 600% price increase */
gen V2_261=0
gen V2_262=0
gen V2_263=0
gen V2_264=0
gen V2_265=0

replace V2_261=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_262=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_263=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_264=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_265=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)

gen V_261=V1_21+V2_261

```

```

gen V_262=V1_22+V2_262
gen V_263=V1_23+V2_263
gen V_264=V1_24+V2_264
gen V_265=V1_25+V2_265

gen Vnet1261=V_261-Z1
gen Vnet1262=V_262-Z1
gen Vnet1263=V_263-Z1
gen Vnet1264=V_264-Z1
gen Vnet1265=V_265-Z1

gen Vnet2261=V_261-Z2
gen Vnet2262=V_262-Z2
gen Vnet2263=V_263-Z2
gen Vnet2264=V_264-Z2
gen Vnet2265=V_265-Z2

/* high land quality with 100% price increase */

gen V2_311=0
gen V2_312=0
gen V2_313=0
gen V2_314=0
gen V2_315=0

replace V2_311=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-r1*T2)-
Cost2)
replace V2_312=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_313=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_314=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_315=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)

gen V_311=V1_31+V2_311

```

```

gen V_312=V1_32+V2_312
gen V_313=V1_33+V2_313
gen V_314=V1_34+V2_314
gen V_315=V1_35+V2_315

gen Vnet1311=V_311-Z1
gen Vnet1312=V_312-Z1
gen Vnet1313=V_313-Z1
gen Vnet1314=V_314-Z1
gen Vnet1315=V_315-Z1

gen Vnet2311=V_311-Z2
gen Vnet2312=V_312-Z2
gen Vnet2313=V_313-Z2
gen Vnet2314=V_314-Z2
gen Vnet2315=V_315-Z2

/* high land quality with 200% price increase */

gen V2_321=0
gen V2_322=0
gen V2_323=0
gen V2_324=0
gen V2_325=0

replace V2_321=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-r1*T2)-
Cost2)
replace V2_322=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_323=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_324=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_325=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)

gen V_321=V1_31+V2_321
gen V_322=V1_32+V2_322

```

```

gen V_323=V1_33+V2_323
gen V_324=V1_34+V2_324
gen V_325=V1_35+V2_325

gen Vnet1321=V_321-Z1
gen Vnet1322=V_322-Z1
gen Vnet1323=V_323-Z1
gen Vnet1324=V_324-Z1
gen Vnet1325=V_325-Z1

gen Vnet2321=V_321-Z2
gen Vnet2322=V_322-Z2
gen Vnet2323=V_323-Z2
gen Vnet2324=V_324-Z2
gen Vnet2325=V_325-Z2
/* high land quality with 300% price increase */

gen V2_331=0
gen V2_332=0
gen V2_333=0
gen V2_334=0
gen V2_335=0

replace V2_331=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-r1*T2)-
Cost2)
replace V2_332=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_333=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_334=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_335=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)

gen V_331=V1_31+V2_331
gen V_332=V1_32+V2_332
gen V_333=V1_33+V2_333

```



```

gen V_334=V1_34+V2_334
gen V_335=V1_35+V2_335

gen Vnet1331=V_331-Z1
gen Vnet1332=V_332-Z1
gen Vnet1333=V_333-Z1
gen Vnet1334=V_334-Z1
gen Vnet1335=V_335-Z1

gen Vnet2331=V_331-Z2
gen Vnet2332=V_332-Z2
gen Vnet2333=V_333-Z2
gen Vnet2334=V_334-Z2
gen Vnet2335=V_335-Z2
/* high land quality with 400% price increase */

gen V2_341=0
gen V2_342=0
gen V2_343=0
gen V2_344=0
gen V2_345=0

replace V2_341=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-r1*T2)-
Cost2)
replace V2_342=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_343=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_344=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_345=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)

gen V_341=V1_31+V2_341
gen V_342=V1_32+V2_342
gen V_343=V1_33+V2_343
gen V_344=V1_34+V2_344

```

```

gen V_345=V1_35+V2_345

gen Vnet1341=V_341-Z1
gen Vnet1342=V_342-Z1
gen Vnet1343=V_343-Z1
gen Vnet1344=V_344-Z1
gen Vnet1345=V_345-Z1

gen Vnet2341=V_341-Z2
gen Vnet2342=V_342-Z2
gen Vnet2343=V_343-Z2
gen Vnet2344=V_344-Z2
gen Vnet2345=V_345-Z2

/* high land quality with 500% price increase */

gen V2_351=0
gen V2_352=0
gen V2_353=0
gen V2_354=0
gen V2_355=0

replace V2_351=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-r1*T2)-
Cost2)
replace V2_352=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_353=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_354=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_355=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)

gen V_351=V1_31+V2_351
gen V_352=V1_32+V2_352
gen V_353=V1_33+V2_353
gen V_354=V1_34+V2_354
gen V_355=V1_35+V2_355

```

```

gen Vnet1351=V_351-Z1
gen Vnet1352=V_352-Z1
gen Vnet1353=V_353-Z1
gen Vnet1354=V_354-Z1
gen Vnet1355=V_355-Z1

gen Vnet2351=V_351-Z2
gen Vnet2352=V_352-Z2
gen Vnet2353=V_353-Z2
gen Vnet2354=V_354-Z2
gen Vnet2355=V_355-Z2

/* high land quality with 600% price increase */
gen V2_361=0
gen V2_362=0
gen V2_363=0
gen V2_364=0
gen V2_365=0

replace V2_361=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-r1*T2)-
Cost2)
replace V2_362=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)
replace V2_363=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)
replace V2_364=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)
replace V2_365=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)

gen V_361=V1_31+V2_361
gen V_362=V1_32+V2_362
gen V_363=V1_33+V2_363
gen V_364=V1_34+V2_364
gen V_365=V1_35+V2_365

gen Vnet1361=V_361-Z1
gen Vnet1362=V_362-Z1

```

```

gen Vnet1363=V_363-Z1
gen Vnet1364=V_364-Z1
gen Vnet1365=V_365-Z1

gen Vnet2361=V_361-Z2
gen Vnet2362=V_362-Z2
gen Vnet2363=V_363-Z2
gen Vnet2364=V_364-Z2
gen Vnet2365=V_365-Z2

/* the following is for agricultural corn production*/
gen cornyield_low=70
gen cornyield_avrg=115
gen cornyield_high=150

gen pr_corn=3.5

gen corncost_fixed=215

gen labor_low=0.33
gen labor_avrg=0.89
gen labor_high=1.51

/* corn price is based on dollars per bushel in real term and yield are per
bushel */

gen pf_corn_low=(1/r1)*(pr_corn*cornyield_low-(corncost_fixed*labor_low))
gen pf_corn_avrg=(1/r1)*(pr_corn*cornyield_avrg-(corncost_fixed*labor_avrg))
gen pf_corn_high=(1/r1)*(pr_corn*cornyield_high-(corncost_fixed*labor_high))

*** STATA code for social planner problem
/*the followings is for loblolly pine*/

```

```

gen pr_p_pulp=6.60
gen pr_sawtimber=39.17

gen Cost1=267.64
gen r1=0.03

gen T1=_n+7

/*low land quality*/

gen V1_11=0
gen V1_12=0
gen V1_13=0
gen V1_14=0
gen V1_15=0

replace V1_11=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_12=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_13=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_14=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)
replace V1_15=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulplow+pr_sawtimber*psawlow)-Cost1)

/* median land quality*/
g V1_21=0
g V1_22=0
g V1_23=0
g V1_24=0
g V1_25=0
replace V1_21=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_22=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)

```

```

replace V1_23=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_24=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)
replace V1_25=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulpavrg+pr_sawtimber*psawavrg)-Cost1)

```

```

/* high land quality */

```

```

gen V1_31=0
gen V1_32=0
gen V1_33=0
gen V1_34=0
gen V1_35=0
replace V1_31=((1-exp(-r1*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_32=((1-exp(-r1*2*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_33=((1-exp(-r1*3*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_34=((1-exp(-r1*4*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)
replace V1_35=((1-exp(-r1*5*T1))/(1-exp(-r1*T1)))*(exp(-
r1*T1)*(pr_p_pulp*ppulphigh+pr_sawtimber*psawhigh)-Cost1)

```

```

/*the following is for hybrid poplar*/

```

```

gen T2=7
gen Cost2=230
gen Z1=T1+T2
gen Z2=T1^2+T2

```

```

gen pop_low=18
gen pop_median=32
gen pop_high=39

gen pr_pop=15.00
gen pr_pop1=(1+1.00)*pr_pop
gen pr_pop2=(1+2.00)*pr_pop
gen pr_pop3=(1+3.00)*pr_pop
gen pr_pop4=(1+4.00)*pr_pop
gen pr_pop5=(1+5.00)*pr_pop
gen pr_pop6=(1+6.00)*pr_pop

/*social planner's problem, amenity included */
/* for loblolly pine */
gen b0=12
gen b1=20
gen lob_ame=0
replace lob_ame=b0*T1*exp(-T1/b1)
gen lob_ame_stock1=0
gen lob_ame_stock2=0
gen lob_ame_stock3=0
gen lob_ame_stock4=0
gen lob_ame_stock5=0

replace lob_ame_stock1=(-b0/(r1+1/b1)*exp(-
T1*(r1+1/b1))*(T1+1/(r1+1/b1))+b0/((r1+1/b1)^2))*(1-exp(-r1*T1))/(1-exp(-
r1*T1))
replace lob_ame_stock2=(-b0/(r1+1/b1)*exp(-
T1*(r1+1/b1))*(T1+1/(r1+1/b1))+b0/((r1+1/b1)^2))*(1-exp(-r1*2*T1))/(1-exp(-
r1*T1))
replace lob_ame_stock3=(-b0/(r1+1/b1)*exp(-
T1*(r1+1/b1))*(T1+1/(r1+1/b1))+b0/((r1+1/b1)^2))*(1-exp(-r1*3*T1))/(1-exp(-
r1*T1))

```

```

replace lob_ame_stock4=(-b0/(r1+1/b1)*exp(-
T1*(r1+1/b1))*(T1+1/(r1+1/b1))+b0/((r1+1/b1)^2))*(1-exp(-r1*4*T1))/(1-exp(-
r1*T1))
replace lob_ame_stock5=(-b0/(r1+1/b1)*exp(-
T1*(r1+1/b1))*(T1+1/(r1+1/b1))+b0/((r1+1/b1)^2))*(1-exp(-r1*5*T1))/(1-exp(-
r1*T1))

/*for hybrid poplar */

gen b3=6
gen b4=12
gen pop_ame=b3*T2*exp(-T2/b4)

gen pop_ame_stock1=(-b3/(r1+1/b4)*exp(-
T2*(r1+1/b4))*(T2+1/(r1+1/b4))+b3/((r1+1/b4)^2))*(exp(-r1*T1))/(1-exp(-
r1*T2))
gen pop_ame_stock2=(-b3/(r1+1/b4)*exp(-
T2*(r1+1/b4))*(T2+1/(r1+1/b4))+b3/((r1+1/b4)^2))*(exp(-r1*2*T1))/(1-exp(-
r1*T2))
gen pop_ame_stock3=(-b3/(r1+1/b4)*exp(-
T2*(r1+1/b4))*(T2+1/(r1+1/b4))+b3/((r1+1/b4)^2))*(exp(-r1*3*T1))/(1-exp(-
r1*T2))
gen pop_ame_stock4=(-b3/(r1+1/b4)*exp(-
T2*(r1+1/b4))*(T2+1/(r1+1/b4))+b3/((r1+1/b4)^2))*(exp(-r1*4*T1))/(1-exp(-
r1*T2))
gen pop_ame_stock5=(-b3/(r1+1/b4)*exp(-
T2*(r1+1/b4))*(T2+1/(r1+1/b4))+b3/((r1+1/b4)^2))*(exp(-r1*5*T1))/(1-exp(-
r1*T2))

/* situation with low land quality when the price is 100% increase and the
time length until a biomass market shift occurs takes
1,2,3,4,5,respectively.*/

gen V2_111=0
gen V2_112=0
gen V2_113=0
gen V2_114=0
gen V2_115=0

```



```

replace V2_111=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-r1*T2)-
Cost2)
replace V2_112=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_113=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_114=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)
replace V2_115=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_low*exp(-
r1*T2)-Cost2)

```

```

gen V_111=V1_11+V2_111+lob_ame_stock1+pop_ame_stock1
gen V_112=V1_12+V2_112+lob_ame_stock2+pop_ame_stock2
gen V_113=V1_13+V2_113+lob_ame_stock3+pop_ame_stock3
gen V_114=V1_14+V2_114+lob_ame_stock4+pop_ame_stock4
gen V_115=V1_15+V2_115+lob_ame_stock5+pop_ame_stock5
gen Vnet1111=V_111-Z1
gen Vnet1112=V_112-Z1
gen Vnet1113=V_113-Z1
gen Vnet1114=V_114-Z1
gen Vnet1115=V_115-Z1

```

```

gen Vnet2111=V_111-Z2
gen Vnet2112=V_112-Z2
gen Vnet2113=V_113-Z2
gen Vnet2114=V_114-Z2
gen Vnet2115=V_115-Z2

```

```

/*low land quality with 200% price increase */

```

```

gen V2_121=0
gen V2_122=0
gen V2_123=0

```

```

gen V2_124=0
gen V2_125=0

replace V2_121=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-r1*T2)-
Cost2)
replace V2_122=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_123=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_124=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)
replace V2_125=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_low*exp(-
r1*T2)-Cost2)

gen V_121=V1_11+V2_121+lob_ame_stock1+pop_ame_stock1
gen V_122=V1_12+V2_122+lob_ame_stock2+pop_ame_stock2
gen V_123=V1_13+V2_123+lob_ame_stock3+pop_ame_stock3
gen V_124=V1_14+V2_124+lob_ame_stock4+pop_ame_stock4
gen V_125=V1_15+V2_125+lob_ame_stock5+pop_ame_stock5

gen Vnet1121=V_121-Z1
gen Vnet1122=V_122-Z1
gen Vnet1123=V_123-Z1
gen Vnet1124=V_124-Z1
gen Vnet1125=V_125-Z1

gen Vnet2121=V_121-Z2
gen Vnet2122=V_122-Z2
gen Vnet2123=V_123-Z2
gen Vnet2124=V_124-Z2
gen Vnet2125=V_125-Z2

/*low land quality with 300% price increase.*/
gen V2_131=0
gen V2_132=0
gen V2_133=0

```

```

gen V2_134=0
gen V2_135=0

replace V2_131=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-r1*T2)-
Cost2)
replace V2_132=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
replace V2_133=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
replace V2_134=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)
replace V2_135=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_low*exp(-
r1*T2)-Cost2)

gen V_131=V1_11+V2_131+lob_ame_stock1+pop_ame_stock1
gen V_132=V1_12+V2_132+lob_ame_stock2+pop_ame_stock2
gen V_133=V1_13+V2_133+lob_ame_stock3+pop_ame_stock3
gen V_134=V1_14+V2_134+lob_ame_stock4+pop_ame_stock4
gen V_135=V1_15+V2_135+lob_ame_stock5+pop_ame_stock5

gen Vnet1131=V_131-Z1
gen Vnet1132=V_132-Z1
gen Vnet1133=V_133-Z1
gen Vnet1134=V_134-Z1
gen Vnet1135=V_135-Z1

gen Vnet2131=V_131-Z2
gen Vnet2132=V_132-Z2
gen Vnet2133=V_133-Z2
gen Vnet2134=V_134-Z2
gen Vnet2135=V_135-Z2

/*low land quality with 400% price increase*/

gen V2_141=0

```

```

gen V2_142=0
gen V2_143=0
gen V2_144=0
gen V2_145=0

replace V2_141=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-r1*T2)-
Cost2)
replace V2_142=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
replace V2_143=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
replace V2_144=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)
replace V2_145=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_low*exp(-
r1*T2)-Cost2)

gen V_141=V1_11+V2_141+lob_ame_stock1+pop_ame_stock1
gen V_142=V1_12+V2_142+lob_ame_stock2+pop_ame_stock2
gen V_143=V1_13+V2_143+lob_ame_stock3+pop_ame_stock3
gen V_144=V1_14+V2_144+lob_ame_stock4+pop_ame_stock4
gen V_145=V1_15+V2_145+lob_ame_stock5+pop_ame_stock5

gen Vnet1141=V_141-Z1
gen Vnet1142=V_142-Z1
gen Vnet1143=V_143-Z1
gen Vnet1144=V_144-Z1
gen Vnet1145=V_145-Z1

gen Vnet2141=V_141-Z2
gen Vnet2142=V_142-Z2
gen Vnet2143=V_143-Z2
gen Vnet2144=V_144-Z2
gen Vnet2145=V_145-Z2

```

```

/* low land quality with 500% price increase*/
gen V2_151=0
gen V2_152=0
gen V2_153=0
gen V2_154=0
gen V2_155=0

replace V2_151=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-r1*T2)-
Cost2)
replace V2_152=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
replace V2_153=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
replace V2_154=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)
replace V2_155=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_low*exp(-
r1*T2)-Cost2)

gen V_151=V1_11+V2_151+lob_ame_stock1+pop_ame_stock1
gen V_152=V1_12+V2_152+lob_ame_stock2+pop_ame_stock2
gen V_153=V1_13+V2_153+lob_ame_stock3+pop_ame_stock3
gen V_154=V1_14+V2_154+lob_ame_stock4+pop_ame_stock4
gen V_155=V1_15+V2_155+lob_ame_stock5+pop_ame_stock5

gen Vnet1151=V_151-Z1
gen Vnet1152=V_152-Z1
gen Vnet1153=V_153-Z1
gen Vnet1154=V_154-Z1
gen Vnet1155=V_155-Z1

gen Vnet2151=V_151-Z2
gen Vnet2152=V_152-Z2
gen Vnet2153=V_153-Z2
gen Vnet2154=V_154-Z2
gen Vnet2155=V_155-Z2

```

```

/* low land quality with 600% price increase */
gen V2_161=0
gen V2_162=0
gen V2_163=0
gen V2_164=0
gen V2_165=0

replace V2_161=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-r1*T2)-
Cost2)
replace V2_162=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_163=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_164=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)
replace V2_165=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_low*exp(-
r1*T2)-Cost2)

gen V_161=V1_11+V2_161+lob_ame_stock1+pop_ame_stock1
gen V_162=V1_12+V2_162+lob_ame_stock2+pop_ame_stock2
gen V_163=V1_13+V2_163+lob_ame_stock3+pop_ame_stock3
gen V_164=V1_14+V2_164+lob_ame_stock4+pop_ame_stock4
gen V_165=V1_15+V2_165+lob_ame_stock5+pop_ame_stock5

gen Vnet1161=V_161-Z1
gen Vnet1162=V_162-Z1
gen Vnet1163=V_163-Z1
gen Vnet1164=V_164-Z1
gen Vnet1165=V_165-Z1

gen Vnet2161=V_161-Z2
gen Vnet2162=V_162-Z2
gen Vnet2163=V_163-Z2
gen Vnet2164=V_164-Z2

```

```
gen Vnet2165=V_165-Z2
```

```
/*median land quality with 100% price increase*/
```

```
gen V2_211=0
```

```
gen V2_212=0
```

```
gen V2_213=0
```

```
gen V2_214=0
```

```
gen V2_215=0
```

```
replace V2_211=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-r1*T2)-Cost2)
```

```
replace V2_212=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-r1*T2)-Cost2)
```

```
replace V2_213=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-r1*T2)-Cost2)
```

```
replace V2_214=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-r1*T2)-Cost2)
```

```
replace V2_215=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_median*exp(-r1*T2)-Cost2)
```

```
gen V_211=V1_21+V2_211+lob_ame_stock1+pop_ame_stock1
```

```
gen V_212=V1_22+V2_212+lob_ame_stock2+pop_ame_stock2
```

```
gen V_213=V1_23+V2_213+lob_ame_stock3+pop_ame_stock3
```

```
gen V_214=V1_24+V2_214+lob_ame_stock4+pop_ame_stock4
```

```
gen V_215=V1_25+V2_215+lob_ame_stock5+pop_ame_stock5
```

```
gen Vnet1211=V_211-Z1
```

```
gen Vnet1212=V_212-Z1
```

```
gen Vnet1213=V_213-Z1
```

```
gen Vnet1214=V_214-Z1
```

```
gen Vnet1215=V_215-Z1
```

```
gen Vnet2211=V_211-Z2
```

```
gen Vnet2212=V_212-Z2
```

```
gen Vnet2213=V_213-Z2
```

```
gen Vnet2214=V_214-Z2
```

```

gen Vnet2215=V_215-Z2

/* median land quality with 200% price increase */
gen V2_221=0
gen V2_222=0
gen V2_223=0
gen V2_224=0
gen V2_225=0

replace V2_221=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_222=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_223=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_224=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)
replace V2_225=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_median*exp(-
r1*T2)-Cost2)

gen V_221=V1_21+V2_221+lob_ame_stock1+pop_ame_stock1
gen V_222=V1_22+V2_222+lob_ame_stock2+pop_ame_stock2
gen V_223=V1_23+V2_223+lob_ame_stock3+pop_ame_stock3
gen V_224=V1_24+V2_224+lob_ame_stock4+pop_ame_stock4
gen V_225=V1_25+V2_225+lob_ame_stock5+pop_ame_stock5

gen Vnet1221=V_221-Z1
gen Vnet1222=V_222-Z1
gen Vnet1223=V_223-Z1
gen Vnet1224=V_224-Z1
gen Vnet1225=V_225-Z1

gen Vnet2221=V_221-Z2
gen Vnet2222=V_222-Z2
gen Vnet2223=V_223-Z2
gen Vnet2224=V_224-Z2
gen Vnet2225=V_225-Z2

```



```

/* median land quality with 300% price increase*/
gen V2_231=0
gen V2_232=0
gen V2_233=0
gen V2_234=0
gen V2_235=0
replace V2_231=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_232=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_233=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_234=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)
replace V2_235=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_median*exp(-
r1*T2)-Cost2)

gen V_231=V1_21+V2_231+lob_ame_stock1+pop_ame_stock1
gen V_232=V1_22+V2_232+lob_ame_stock2+pop_ame_stock2
gen V_233=V1_23+V2_233+lob_ame_stock3+pop_ame_stock3
gen V_234=V1_24+V2_234+lob_ame_stock4+pop_ame_stock4
gen V_235=V1_25+V2_235+lob_ame_stock5+pop_ame_stock5

gen Vnet1231=V_231-Z1
gen Vnet1232=V_232-Z1
gen Vnet1233=V_233-Z1
gen Vnet1234=V_234-Z1
gen Vnet1235=V_235-Z1

gen Vnet2231=V_231-Z2
gen Vnet2232=V_232-Z2
gen Vnet2233=V_233-Z2
gen Vnet2234=V_234-Z2
gen Vnet2235=V_235-Z2

/* median land quality with 400% price increase*/
gen V2_241=0

```

```

gen V2_242=0
gen V2_243=0
gen V2_244=0
gen V2_245=0
replace V2_241=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_242=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_243=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_244=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)
replace V2_245=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_median*exp(-
r1*T2)-Cost2)

```

```

gen V_241=V1_21+V2_241+lob_ame_stock1+pop_ame_stock1
gen V_242=V1_22+V2_242+lob_ame_stock2+pop_ame_stock2
gen V_243=V1_23+V2_243+lob_ame_stock3+pop_ame_stock3
gen V_244=V1_24+V2_244+lob_ame_stock4+pop_ame_stock4
gen V_245=V1_25+V2_245+lob_ame_stock5+pop_ame_stock5

```

```

gen Vnet1241=V_241-Z1
gen Vnet1242=V_242-Z1
gen Vnet1243=V_243-Z1
gen Vnet1244=V_244-Z1
gen Vnet1245=V_245-Z1

```

```

gen Vnet2241=V_241-Z2
gen Vnet2242=V_242-Z2
gen Vnet2243=V_243-Z2
gen Vnet2244=V_244-Z2
gen Vnet2245=V_245-Z2

```

```

/* median land quality with 500% price increase*/
gen V2_251=0
gen V2_252=0
gen V2_253=0

```

```

gen V2_254=0
gen V2_255=0
replace V2_251=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
replace V2_252=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
replace V2_253=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
replace V2_254=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)
replace V2_255=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_median*exp(-
r1*T2)-Cost2)

gen V_251=V1_21+V2_251+lob_ame_stock1+pop_ame_stock1
gen V_252=V1_22+V2_252+lob_ame_stock2+pop_ame_stock2
gen V_253=V1_23+V2_253+lob_ame_stock3+pop_ame_stock3
gen V_254=V1_24+V2_254+lob_ame_stock4+pop_ame_stock4
gen V_255=V1_25+V2_255+lob_ame_stock5+pop_ame_stock5

gen Vnet1251=V_251-Z1
gen Vnet1252=V_252-Z1
gen Vnet1253=V_253-Z1
gen Vnet1254=V_254-Z1
gen Vnet1255=V_255-Z1

gen Vnet2251=V_251-Z2
gen Vnet2252=V_252-Z2
gen Vnet2253=V_253-Z2
gen Vnet2254=V_254-Z2
gen Vnet2255=V_255-Z2

/* median land quality with 600% price increase */
gen V2_261=0
gen V2_262=0
gen V2_263=0
gen V2_264=0
gen V2_265=0

```

```

replace V2_261=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_262=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_263=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_264=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)
replace V2_265=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_median*exp(-
r1*T2)-Cost2)

gen V_261=V1_21+V2_261+lob_ame_stock1+pop_ame_stock1
gen V_262=V1_22+V2_262+lob_ame_stock2+pop_ame_stock2
gen V_263=V1_23+V2_263+lob_ame_stock3+pop_ame_stock3
gen V_264=V1_24+V2_264+lob_ame_stock4+pop_ame_stock4
gen V_265=V1_25+V2_265+lob_ame_stock5+pop_ame_stock5

gen Vnet1261=V_261-Z1
gen Vnet1262=V_262-Z1
gen Vnet1263=V_263-Z1
gen Vnet1264=V_264-Z1
gen Vnet1265=V_265-Z1

gen Vnet2261=V_261-Z2
gen Vnet2262=V_262-Z2
gen Vnet2263=V_263-Z2
gen Vnet2264=V_264-Z2
gen Vnet2265=V_265-Z2

/* high land quality with 100% price increase */

gen V2_311=0
gen V2_312=0
gen V2_313=0
gen V2_314=0
gen V2_315=0

```

```

replace V2_311=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-r1*T2)-
Cost2)
replace V2_312=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_313=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_314=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)
replace V2_315=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop1*pop_high*exp(-
r1*T2)-Cost2)

gen V_311=V1_31+V2_311+lob_ame_stock1+pop_ame_stock1
gen V_312=V1_32+V2_312+lob_ame_stock2+pop_ame_stock2
gen V_313=V1_33+V2_313+lob_ame_stock3+pop_ame_stock3
gen V_314=V1_34+V2_314+lob_ame_stock4+pop_ame_stock4
gen V_315=V1_35+V2_315+lob_ame_stock5+pop_ame_stock5

gen Vnet1311=V_311-Z1
gen Vnet1312=V_312-Z1
gen Vnet1313=V_313-Z1
gen Vnet1314=V_314-Z1
gen Vnet1315=V_315-Z1

gen Vnet2311=V_311-Z2
gen Vnet2312=V_312-Z2
gen Vnet2313=V_313-Z2
gen Vnet2314=V_314-Z2
gen Vnet2315=V_315-Z2

/* high land quality with 200% price increase */

gen V2_321=0
gen V2_322=0
gen V2_323=0
gen V2_324=0
gen V2_325=0

```

```

replace V2_321=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-r1*T2)-
Cost2)
replace V2_322=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_323=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_324=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)
replace V2_325=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop2*pop_high*exp(-
r1*T2)-Cost2)

gen V_321=V1_31+V2_321+lob_ame_stock1+pop_ame_stock1
gen V_322=V1_32+V2_322+lob_ame_stock2+pop_ame_stock2
gen V_323=V1_33+V2_323+lob_ame_stock3+pop_ame_stock3
gen V_324=V1_34+V2_324+lob_ame_stock4+pop_ame_stock4
gen V_325=V1_35+V2_325+lob_ame_stock5+pop_ame_stock5

gen Vnet1321=V_321-Z1
gen Vnet1322=V_322-Z1
gen Vnet1323=V_323-Z1
gen Vnet1324=V_324-Z1
gen Vnet1325=V_325-Z1

gen Vnet2321=V_321-Z2
gen Vnet2322=V_322-Z2
gen Vnet2323=V_323-Z2
gen Vnet2324=V_324-Z2
gen Vnet2325=V_325-Z2
/* high land quality with 300% price increase */

gen V2_331=0
gen V2_332=0
gen V2_333=0
gen V2_334=0
gen V2_335=0

replace V2_331=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-r1*T2)-
Cost2)

```

```

replace V2_332=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_333=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_334=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)
replace V2_335=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop3*pop_high*exp(-
r1*T2)-Cost2)

gen V_331=V1_31+V2_331+lob_ame_stock1+pop_ame_stock1
gen V_332=V1_32+V2_332+lob_ame_stock2+pop_ame_stock2
gen V_333=V1_33+V2_333+lob_ame_stock3+pop_ame_stock3
gen V_334=V1_34+V2_334+lob_ame_stock4+pop_ame_stock4
gen V_335=V1_35+V2_335+lob_ame_stock5+pop_ame_stock5

gen Vnet1331=V_331-Z1
gen Vnet1332=V_332-Z1
gen Vnet1333=V_333-Z1
gen Vnet1334=V_334-Z1
gen Vnet1335=V_335-Z1

gen Vnet2331=V_331-Z2
gen Vnet2332=V_332-Z2
gen Vnet2333=V_333-Z2
gen Vnet2334=V_334-Z2
gen Vnet2335=V_335-Z2
/* high land quality with 400% price increase */

gen V2_341=0
gen V2_342=0
gen V2_343=0
gen V2_344=0
gen V2_345=0

replace V2_341=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-r1*T2)-
Cost2)

```

```

replace V2_342=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_343=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_344=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)
replace V2_345=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop4*pop_high*exp(-
r1*T2)-Cost2)

gen V_341=V1_31+V2_341+lob_ame_stock1+pop_ame_stock1
gen V_342=V1_32+V2_342+lob_ame_stock2+pop_ame_stock2
gen V_343=V1_33+V2_343+lob_ame_stock3+pop_ame_stock3
gen V_344=V1_34+V2_344+lob_ame_stock4+pop_ame_stock4
gen V_345=V1_35+V2_345+lob_ame_stock5+pop_ame_stock5

gen Vnet1341=V_341-Z1
gen Vnet1342=V_342-Z1
gen Vnet1343=V_343-Z1
gen Vnet1344=V_344-Z1
gen Vnet1345=V_345-Z1

gen Vnet2341=V_341-Z2
gen Vnet2342=V_342-Z2
gen Vnet2343=V_343-Z2
gen Vnet2344=V_344-Z2
gen Vnet2345=V_345-Z2
/* high land quality with 500% price increase */

gen V2_351=0
gen V2_352=0
gen V2_353=0
gen V2_354=0
gen V2_355=0

replace V2_351=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-r1*T2)-
Cost2)

```



```

replace V2_352=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_353=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_354=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)
replace V2_355=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop5*pop_high*exp(-
r1*T2)-Cost2)

gen V_351=V1_31+V2_351+lob_ame_stock1+pop_ame_stock1
gen V_352=V1_32+V2_352+lob_ame_stock2+pop_ame_stock2
gen V_353=V1_33+V2_353+lob_ame_stock3+pop_ame_stock3
gen V_354=V1_34+V2_354+lob_ame_stock4+pop_ame_stock4
gen V_355=V1_35+V2_355+lob_ame_stock5+pop_ame_stock5

gen Vnet1351=V_351-Z1
gen Vnet1352=V_352-Z1
gen Vnet1353=V_353-Z1
gen Vnet1354=V_354-Z1
gen Vnet1355=V_355-Z1

gen Vnet2351=V_351-Z2
gen Vnet2352=V_352-Z2
gen Vnet2353=V_353-Z2
gen Vnet2354=V_354-Z2
gen Vnet2355=V_355-Z2

/* high land quality with 600% price increase */
gen V2_361=0
gen V2_362=0
gen V2_363=0
gen V2_364=0
gen V2_365=0

replace V2_361=((exp(-r1*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-r1*T2)-
Cost2)
replace V2_362=((exp(-r1*2*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)

```

```

replace V2_363=((exp(-r1*3*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)
replace V2_364=((exp(-r1*4*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)
replace V2_365=((exp(-r1*5*T1))/(1-exp(-r1*T2)))*(pr_pop6*pop_high*exp(-
r1*T2)-Cost2)

gen V_361=V1_31+V2_361+lob_ame_stock1+pop_ame_stock1
gen V_362=V1_32+V2_362+lob_ame_stock2+pop_ame_stock2
gen V_363=V1_33+V2_363+lob_ame_stock3+pop_ame_stock3
gen V_364=V1_34+V2_364+lob_ame_stock4+pop_ame_stock4
gen V_365=V1_35+V2_365+lob_ame_stock5+pop_ame_stock5

gen Vnet1361=V_361-Z1
gen Vnet1362=V_362-Z1
gen Vnet1363=V_363-Z1
gen Vnet1364=V_364-Z1
gen Vnet1365=V_365-Z1

gen Vnet2361=V_361-Z2
gen Vnet2362=V_362-Z2
gen Vnet2363=V_363-Z2
gen Vnet2364=V_364-Z2
gen Vnet2365=V_365-Z2

```

APPENDIX C

STATA code for Chapter 3

```

***LOW, SIGMA=,LINEAR
***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=1

gen prjump1=30
gen prjump2=40

```

```

gen prjump3=50
gen prjump4=60
gen prjump5=70
gen prjump6=80

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3
gen pr1_jump4=15+sgm*invnormal(uniform()+prjump4
gen pr1_jump5=15+sgm*invnormal(uniform()+prjump5

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

```

```

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18
gen TC=T1+T2
***TC is transaction cost, and it is linear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {

```

```

sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC

```

```
gen U22`n'=100*ln(V22`n')
}
```

```
gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}
```

```
forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}
```

```
gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}
```

```
forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}
```

```
gen means7=0
forvalues n=1/29 {
```

```

sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

```

```
sum means1 means2 means3 means4 means5 means6 means7 means8 means9
```

LOW, SIGMA=1, NONLINEAR

.....•

```
***ppulplow and psawlow are yields of loblolly pine on low land quality.so  
are ppulpavrg and psawavrg on avrg land***
```

```
set seed 2009
```

```
set obs 29
```

```
gen sgm=0
```

```
replace sgm=1
```

```
gen prjump1=30
```

```
gen prjump2=40
```

```
gen prjump3=50
```

```
gen pr1_saw=39.17+sgm*invnormal(uniform())
```

```
gen pr1_pulp=6.60+sgm*invnormal(uniform())
```

```
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
```

```
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
```

```
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3
```

```
***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and  
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
```

```
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
```

```
pr1_jump1/2/3 are for hybrid poplar****
```

```
replace pr1_saw=0 if pr1_saw<0
```

```
replace pr1_pulp=0 if pr1_pulp<0
```

```
replace pr1_jump1=0 if pr1_jump1<0
```

```
replace pr1_jump2=0 if pr1_jump2<0
```

```
replace pr1_jump3=0 if pr1_jump3<0
```

```
forvalues n = 1/29 {
```



```

gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18
gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulpflow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

***V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0

```

```

forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

```

```

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

*****LOW, SIGMA=8, LINEAR

clear

set memory 5m
use "C:\Users\Fanfan\Documents\dissertation\Dissertation1\stata
data\loblollypine TAUYIELDold.dta", clear
***ppulp low and psaw low are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=8

gen prjump1=30
gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2

```

```

gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected
price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {

```

```

gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)
gen U11`n'=100*ln(V11`n')
}

```

```

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)
gen U12`n'=100*ln(V12`n')
}

```

```

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)
gen U13`n'=100*ln(V13`n')
}

```

```

gen means3=0
forvalues n=1/29 {
sum U13`n'

```

```

scalar g3`n`=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n`=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n`=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {

```



```

gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)
gen U33`n'=100*ln(V33`n')
}

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

*****LOW, SIGMA=8, NONLINEAR

clear

set memory 5m
use "C:\Users\Fanfan\Documents\dissertation\Dissertation1\stata
data\loblollypine TAUYIELDold.dta", clear
*****ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=8

```

```
gen prjump1=30
gen prjump2=40
gen prjump3=50
```

```
gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3
```

```
***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected
price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****
```

```
replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0
```

```
forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}
```

```
gen T1=_n+7
gen T2=7
```

```
gen Cost1=267.64
gen Cost2=230
```

```

gen r=0.03
gen poplow=18
gen TC=T1+T2
***TC is transaction cost, and it is linear here***

***poplow is yielded of hybrid poplar on land with low quality over 7 years
(rotation age)***

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
}

```

```

replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

```

```

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)

```

```
replace means7=g7`n' in `n'
}
```

```
forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}
```

```
gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}
```

```
forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}
```

```
gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}
```

```
forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}
```

```
sum means1 means2 means3 means4 means5 means6 means7 means8 means9
```

******average quality land, sigma=1, linear**

.....

****ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land****

set seed 2009

set obs 29

gen sgm=0

replace sgm=1

gen prjump1=30

gen prjump2=40

gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())

gen pr1_pulp=6.60+sgm*invnormal(uniform())

gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1

gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2

gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***

***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0

replace pr1_pulp=0 if pr1_pulp<0

replace pr1_jump1=0 if pr1_jump1<0

replace pr1_jump2=0 if pr1_jump2<0

replace pr1_jump3=0 if pr1_jump3<0


```

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18
gen TC=T1+T2
***TC is transaction cost, and it is linear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'

```

```

scalar g1`n`=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n`=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n`=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

```

```

}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

gen means9=0

```

```

forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

```

```

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

```

```
sum means1 means2 means3 means4 means5 means6 means7 means8 means9
```

*****AVRG, SIGMA=1 AND NONLINEAR

.....

***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***

```

set seed 2009
set obs 29
gen sgm=0
replace sgm=1

```

```

gen prjump1=30
gen prjump2=40
gen prjump3=50

```

```

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

```

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

```

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0

```

```

replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=32
***needs to be revised for each level of land. poplow is yiled of hybrid
poplar on land with average quality over 7 years (rotation age)****

gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulpflow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

***V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

```

```

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {

```

```

gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

```

```

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

```

```

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'

```



```

scalar g6`n`=r(mean)
replace means6=g6`n' in `n'
}

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n`=r(mean)
replace means7=g7`n' in `n'
}

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n`=r(mean)
replace means8=g8`n' in `n'
}

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

}

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

```

*******AVRG, SIGMA=8, LINEAR**

.....

```

***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=8

gen prjump1=30
gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

```

39.17 and 6.60 dollars per acre is expected price for pine sawtimber and pine pulpwood. 15 dollars per acre is expected price for hybrid poplar
pr1_saw is the price for sawtimber and pr1_pulp is for pulpwood, and pr1_jump1/2/3 are for hybrid poplar*

```
replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0
```

```
forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}
```

```
gen T1=_n+7
gen T2=7
```

```
gen Cost1=267.64
gen Cost2=230
```

```
gen r=0.03
gen poplow=18
gen TC=T1+T2
```

TC is transaction cost, and it is linear here*

poplow is yiled of hybrid poplar on land with low quality over 7 years (rotation age)*

```
forvalues n = 1/29 {
```

```

gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

```

****V is the net present value of land rents from forestry including conventional timber and woody biomass production net of transaction costs****

```

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

```

```

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

```

```

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {

```

```

gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

gen means8=0
forvalues n=1/29 {
sum U32`n'

```

```

scalar g8`n`=r(mean)
replace means8=g8`n' in `n'
}

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n`=r(mean)
replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n`=round(means`n')
}

```

```
sum means1 means2 means3 means4 means5 means6 means7 means8 means9
```

*******AVRG, SIGMA=8, NONLINEAR**

.....

***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***

```

set seed 2009
set obs 29
gen sgm=0
replace sgm=8

```

```
gen prjump1=30
```

```

gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18

```



```

gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here***

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)***

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

***V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs***

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {

```

```

sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

```

```

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

```

```

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

```

******* HIGH, SIGMA=1, LINEAR**

.....

```

***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=8

gen prjump1=30
gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

```

```

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=18
gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

```

```

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {

```

```

gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

```

```

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

```

```

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```



```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

```

```

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

***** HIGH, SIGMA=1, NONLINEAR
***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=1

gen prjump1=30
gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]

```

```

gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=39
gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulpflow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {

```

```

sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC

```

```

gen U31`n'=100*ln(V31`n')
}

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

```

```

forvalues n=1/9{
gen roundmeans`n`=round(means`n')
}

```

```

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

```

******HIGH, SIGMA=8, LINEAR**

.....

***ppulplow and psawlow are yields of loblolly pine on low land quality.so
are ppulpavrg and psawavrg on avrg land***

```

set seed 2009
set obs 29
gen sgm=0
replace sgm=8

```

```

gen prjump1=30
gen prjump2=40
gen prjump3=50

```

```

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

```

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

```

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

```

```

forvalues n = 1/29 {

```

```

gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=39
gen TC=T1+T2
***TC is transaction cost, and it is linear here***

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)***

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulpflow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'
scalar g1`n'=r(mean)
replace means1=g1`n' in `n'
}

```



```

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n'=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n'=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

gen means4=0
forvalues n=1/29 {

```

```

sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

forvalues n = 1/29 {

```

```

gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```

```

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
}

```

```

replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

```

***HIGH, SIGMA=8, NONLINEAR

```

.....
***ppulp and psaw are yields of loblolly pine on low land quality.so
are ppulpavg and psawavg on avrg land***
set seed 2009
set obs 29
gen sgm=0
replace sgm=8

gen prjump1=30
gen prjump2=40
gen prjump3=50

gen pr1_saw=39.17+sgm*invnormal(uniform())
gen pr1_pulp=6.60+sgm*invnormal(uniform())
gen pr1_jump1=15+sgm*invnormal(uniform()+prjump1
gen pr1_jump2=15+sgm*invnormal(uniform()+prjump2
gen pr1_jump3=15+sgm*invnormal(uniform()+prjump3

***39.17 and 6.60 dollars per acre is expected price for pine sawtimber and
pine pulpwood. 15 dollars per acre is expected price for hybrid poplar***
***pr1_saw is the price for sawtimer and pr1_pulp is for pulpwood, and
pr1_jump1/2/3 are for hybrid poplar****

replace pr1_saw=0 if pr1_saw<0
replace pr1_pulp=0 if pr1_pulp<0
replace pr1_jump1=0 if pr1_jump1<0
replace pr1_jump2=0 if pr1_jump2<0
replace pr1_jump3=0 if pr1_jump3<0

```

```

forvalues n = 1/29 {
gen pr1_saw`n' = pr1_saw[`n' ]
gen pr1_pulp`n' =pr1_pulp[`n' ]
gen pr1_jump1`n' =pr1_jump1[`n' ]
gen pr1_jump2`n' =pr1_jump2[`n' ]
gen pr1_jump3`n' =pr1_jump3[`n' ]
}

gen T1=_n+7
gen T2=7

gen Cost1=267.64
gen Cost2=230

gen r=0.03
gen poplow=39
gen TC=T1^2+T2
***TC is transaction cost, and it is nonlinear here****

***poplow is yiled of hybrid poplar on land with low quality over 7 years
(rotation age)****

forvalues n = 1/29 {
gen V11`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump1`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U11`n'=100*ln(V11`n')
}

****V is the net present value of land rents from forestry including
conventional timber and woody biomass production net of transaction costs****

gen means1=0
forvalues n=1/29 {
sum U11`n'

```

```

scalar g1`n`=r(mean)
replace means1=g1`n' in `n'
}

forvalues n = 1/29 {
gen V12`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U12`n'=100*ln(V12`n')
}

gen means2=0
forvalues n=1/29 {
sum U12`n'
scalar g2`n`=r(mean)
replace means2=g2`n' in `n'
}

forvalues n = 1/29 {
gen V13`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump1`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U13`n'=100*ln(V13`n')
}

gen means3=0
forvalues n=1/29 {
sum U13`n'
scalar g3`n`=r(mean)
replace means3=g3`n' in `n'
}

forvalues n = 1/29 {
gen V21`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump2`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U21`n'=100*ln(V21`n')
}

```

```

}

gen means4=0
forvalues n=1/29 {
sum U21`n'
scalar g4`n'=r(mean)
replace means4=g4`n' in `n'
}

forvalues n = 1/29 {
gen V22`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U22`n'=100*ln(V22`n')
}

gen means5=0
forvalues n=1/29 {
sum U22`n'
scalar g5`n'=r(mean)
replace means5=g5`n' in `n'
}

forvalues n = 1/29 {
gen V23`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump2`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U23`n'=100*ln(V23`n')
}

gen means6=0
forvalues n=1/29 {
sum U23`n'
scalar g6`n'=r(mean)
replace means6=g6`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V31`n' =((1-exp(-r*T1))/(1-exp(-r*T1)))*((pr1_saw`n' *psawlow+pr1_pulp`n'
*ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*T1)/(1-exp(-r*T2)))*(pr1_jump3`n'
*poplow*exp(-r*T2)-Cost2)-TC
gen U31`n'=100*ln(V31`n')
}

```

```

gen means7=0
forvalues n=1/29 {
sum U31`n'
scalar g7`n'=r(mean)
replace means7=g7`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V32`n' =((1-exp(-r*2*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*2*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U32`n'=100*ln(V32`n')
}

```

```

gen means8=0
forvalues n=1/29 {
sum U32`n'
scalar g8`n'=r(mean)
replace means8=g8`n' in `n'
}

```

```

forvalues n = 1/29 {
gen V33`n' =((1-exp(-r*3*T1))/(1-exp(-r*T1)))*((pr1_saw`n'
*psawlow+pr1_pulp`n' *ppulplow)*exp(-r*T1)-Cost1)+(exp(-r*3*T1)/(1-exp(-
r*T2)))*(pr1_jump3`n' *poplow*exp(-r*T2)-Cost2)-TC
gen U33`n'=100*ln(V33`n')
}

```



```

gen means9=0
forvalues n=1/29 {
sum U33`n'
scalar g9`n'=r(mean)
replace means9=g9`n' in `n'
}

forvalues n=1/9{
gen roundmeans`n'=round(means`n')
}

sum means1 means2 means3 means4 means5 means6 means7 means8 means9

```

APPENDIX D

Matlab codes for Chapter 4

%%Main.m

```

% solve the optimal land use problem-stochastic optimization %
Data=xlsread('Landusedata.xls');
RT_Lob=Data(:,1); % rotation of loblolly pine %
Pulp45=Data(:,2); % yields of pulpwood at site index 45 %
Stim45=Data(:,3); % yields of sawtimber at site index 45 %
Pulp60=Data(:,4); % yields of pulpwood at site index 60 %
Stim60=Data(:,5); % yields of sawtimber at site index 60 %
Pulp75=Data(:,6); % yields of pulpwood at site index 75 %
Stim75=Data(:,7); % yields of sawtimber at site index 75 %
Pr_Pulp=Data(:,8); % price of pulpwood %
Pr_Stim=Data(:,9); % price of sawtimber %
C_Lob=Data(:,10); % Costs of Loblolly pine %
r=Data(:,11); % interest rate %
RT_HP=Data(:,12); % rotation of hybrid poplar %
C_HP=Data(:,13); % Costs of hybrid poplar %
YHP_L=Data(:,14); % Yields of hybrid poplar/low quality %
YHP_M=Data(:,15); % Yields of hybrid poplar/AVRG quality %
YHP_H=Data(:,16); % Yields of hybrid poplar/High quality %
Pr_HP_IN=Data(:,17); % Initial price of hybrid poplar %

```

```

Pr_Corn=Data(:,18);           % Price of corn           %
YCORN_L=Data(:,19);          % Yield of corn at low quality %
YCORN_M=Data(:,20);          % Yield of corn at avrg quality %
YCORN_H=Data(:,21);          % Yield of corn at high quality %
LB_L=Data(:,22);             % labor input for low quality land %
LB_M=Data(:,23);             % labor input for avrg quality land %
LB_H=Data(:,24);             % labor input for high quality land %
Wgrate=Data(:,25);           % wage rate in total           %
Z1=Data(:,26);               % transaction costs:          10% of C_HP %
Z2=Data(:,27);               % transaction costs:          205 of C_HP %
N=length(RT_Lob);            % observations                   %

%intializations and backwad iteration
T=40; % the whole period of the horizon
%%%%% below: calculate the total revenue from agriculture on low, average and
% high quality land, respectively. %%%%%%%%%%%

[agRV_L,agRV_M,agRV_H]=aGprofit(YCORN_L,YCORN_M,YCORN_H,Pr_Corn,LB_L,LB_M,LB_
H,Wgrate,T,r);
[TProfit_L,TProfit_M,TProfit_H] = TimProfit(Pr_Pulp, Pr_Stim,RT_Lob,Pulp45,
Pulp60, Pulp75,Stim45, Stim60, Stim75,r,C_Lob);

N1=find(agRV_L>0); % find positive observations in agRV_L%
N2=find(agRV_M>0);
N3=find(agRV_H>0);
N4=find(TProfit_L>0);
N5=find(TProfit_M>0);
N6=find(TProfit_H>0);
a=[length(N1),length(N2),length(N3),length(N4),length(N5),length(N6)]; %
number of observations in agRV_L,agRV_M,,,,TProfit_H %
b=min(a); % find the minimal number of observations %
b1=find(a==b); % find which variable has the minimal observations %

%%%%%%%%% the following is about the land allocation and the net present
%%%%%%%%% value of land rents from agriculture and forestry on the land
%%%%%%%%% with low quality

```

```

%%%      for I=(N-b+1):N
    %% Be4value_L=@(OldLand_fL)  -(OldLand_fL.*TProfit_L(I,1)+(1-
OldLand_fL).*agRV_L);
    % options=optimset ('Display','iter','TolFun',1e-6,'TolX',1e-
6,'MaxIter',1e+6,'MaxFunEval',1e+6);
    % [OldLand_fL,fval,exitflg,output]=fminbnd(Be4value_L,0,1,options);
% end
% OldLand_fL;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%the following is about the land allocation and the net present
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% value of land rents from agriculture and forestry on the land
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% with average quality

%% for I=(N-b+1):N
    % Be4value_M=@(OldLand_fM)  -(OldLand_fM.*TProfit_M(I,1)+(1-
OldLand_fM).*agRV_M);
    % options=optimset ('Display','iter','TolFun',1e-6,'TolX',1e-
6,'MaxIter',1e+6,'MaxFunEval',1e+6);
    % [OldLand_fM,fval,exitflg,output]=fminbnd(Be4value_M,0,1,options);
    % end
% OldLand_fM;

%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%the following is about the land allocation and the net present
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% value of land rents from agriculture and forestry on the land
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% with high quality
% for I=(N-b+1):N
% Be4value_H=@(OldLand_fH)  -(OldLand_fH.*TProfit_H(I,1)+(1-
OldLand_fH).*agRV_H);
% options=optimset('Display','iter','TolFun',1e-6,'TolX',1e-
6,'MaxIter',1e+6,'MaxFunEval',1e+6);%
% [OldLand_fH,fval,exitflg,output]=fminbnd(Be4value_H,0,1,options);
% end
% OldLand_fH;

```

```

%%%%%%%%%% STOCHASTIC OPTIMIZATION %%%%%%%%%%%

%%%%%%%%%% calculate the land allocation%%%%%%%%%% not impacted by
%%%%%%%%%% timing difference as long as the decision is made
mu=0.5;    % adjustable
sigma=2;   % adjustable and use 2 possible numbers, 0.5 and 2

dt=1;
M=T/dt;
U=exp(sigma*sqrt(dt)); % up movement
D=1/U;                 % down movement
P=(exp(mu*dt)-D)/(U-D); % probability of the occurrence of one up movement
f7=1;

[RbL0,RbM0,RbH0] = BioProfit(Pr_HP_IN,YHP_L,YHP_M,YHP_H,r,RT_HP,C_HP);
RbL_d=zeros(M+1,1);
RbM_d=zeros(M+1,1);
RbH_d=zeros(M+1,1);
RbL_u=zeros(M+1,1);
RbM_u=zeros(M+1,1);
RbH_u=zeros(M+1,1);

%%%%%%%%%      RbL_d(f7+0,1)=RbL0(1,1)*D^M;      % situation with no up movement
%%%%%%%%%      RbM_d(f7+0,1)=RbM0(1,1)*D^M;      %%
%%%%%%%%%      RbH_d(f7+0,1)=RbH0(1,1)*D^M;      %%

for i=0:M
RbL_d(f7+i,1)=RbL0(1,1)*D^(M-i);    % situation with i (0 to M) up movement
RbM_d(f7+i,1)=RbM0(1,1)*D^(M-i);
RbH_d(f7+i,1)=RbH0(1,1)*D^(M-i);

```

end

for j=1:M

RbL_u(f7+j,1)=RbL_d(f7+j-1)*U/D;

RbM_u(f7+j,1)=RbM_d(f7+j-1)*U/D;

RbH_u(f7+j,1)=RbH_d(f7+j-1)*U/D;

end

RbL=P*RbL_u+(1-P)*RbL_d; %%%%Rb from low quality land

RbM=P*RbM_u+(1-P)*RbM_d; %%%%Rb from average quality land

RbH=P*RbH_u+(1-P)*RbH_d; %%%%Rb from high quality land

%%LAND ALLOCATION and Timing

%%

beta=T:-1:1;

agRV_L2(beta)=-(1/r(1,1))*(Pr_Corn(1,1)*LB_L(1,1)^(0.5).*YCORN_L(1,1)-
Wgrate(1,1)*LB_L(1,1))*(exp(-r(1,1)*beta)-1); % Ag. NPV on low quality
land from T to 1; one row

agRV_M2(beta)=-(1/r(1,1))*(Pr_Corn(1,1)*LB_M(1,1)^(0.5).*YCORN_M(1,1)-
Wgrate(1,1)*LB_M(1,1))*(exp(-r(1,1)*beta)-1);

agRV_H2(beta)=-(1/r(1,1))*(Pr_Corn(1,1)*LB_H(1,1)^(0.5).*YCORN_H(1,1)-
Wgrate(1,1)*LB_H(1,1))*(exp(-r(1,1)*beta)-1);

agRV_L3=agRV_L2'; % Transpose to one column

agRV_M3=agRV_M2';

agRV_H3=agRV_H2';

T=40;

%%%for land of low quality

```

if (agRV_L-agRV_L3(T,1))> RbL(T+1,1)/(1+r)
    VTL=agRV_L-agRV_L3(T,1);
    display ('ag is max');
else VTL=RbL(T+1,1)/(1+r);
    display ('Rb is max');
end

DL=agRV_L3(T,1)+VTL(1,1)-agRV_L(1,1);
if DL-Z1<0
    display ('no investment')
else display ('investment')
end
if DL-Z2<0
    display ('no investment')
else display ('investment')
end
Newtotal_L=agRV_L3(T,1)+VTL(1,1); % total land rents with land use change
%%% for land of average quality

if (agRV_M-agRV_M3(T,1))> RbM(T+1,1)/(1+r)
    VTM=agRV_M-agRV_M3(T,1);
    display ('ag is max');
else VTM=RbL(T+1,1)/(1+r);
    display ('Rb is max');
end

DM=agRV_M3(T,1)+VTM(1,1)-agRV_M(1,1);
if DM-Z1<0
    display ('no investment')
else display ('investment')
end

if DM-Z2<0
    display ('no investment')
else display ('investment')
end
Newtotal_M=agRV_M3(T,1)+VTM(1,1); % total land rents with land use change

```

```

%% for land of high quality

if (agRV_H-agRV_H3(T,1))> RbH(T+1,1)/(1+r)
    VTH=agRV_H-agRV_H3(T,1);
    display ('ag is max');
else VTH=RbH(T+1,1)/(1+r);
    display ('Rb is max');
end

DH=agRV_M3(T,1)+VTH(1,1)-agRV_M(1,1);
if DH-Z1<0
    display ('no investment')
else display ('investment')
end

if DH-Z2<0
    display ('no investment')
else display ('investment')
end
Newtotal_H=agRV_H3(T,1)+VTH(1,1); % total land rents with land use change

T=39;

if (agRV_L-agRV_L3(T,1))> RbL(T+1,1)/(1+r)
    VTL=agRV_L-agRV_L3(T,1);
    display ('ag is max');
else VTL=RbL(T+1,1)/(1+r);
    display ('Rb is max');
end

DL=agRV_L3(T,1)+VTL(1,1)-agRV_L(1,1);
if DL-Z1<0
    display ('no investment')
else display ('investment')
end
if DL-Z2<0

```

```

        display ('no investment')
    else display ('investment')
    end
    Newtotal_L=agRV_L3(T,1)+VTL(1,1); % total land rents with land use change
    %%%% for land of average quality

    if (agRV_M-agRV_M3(T,1))> RbM(T+1,1)/(1+r)
        VTM=agRV_M-agRV_M3(T,1);
        display ('ag is max');
    else VTM=RbL(T+1,1)/(1+r);
        display ('Rb is max');
    end

    DM=agRV_M3(T,1)+VTM(1,1)-agRV_M(1,1);
    if DM-Z1<0
        display ('no investment')
    else display ('investment')
    end

    if DM-Z2<0
        display ('no investment')
    else display ('investment')
    end
    Newtotal_M=agRV_M3(T,1)+VTM(1,1); % total land rents with land use change

    %%%% for land of high quality

    if (agRV_H-agRV_H3(T,1))> RbH(T+1,1)/(1+r)
        VTH=agRV_H-agRV_H3(T,1);
        display ('ag is max');
    else VTH=RbH(T+1,1)/(1+r);
        display ('Rb is max');
    end

    DH=agRV_M3(T,1)+VTH(1,1)-agRV_M(1,1);
    if DH-Z1<0
        display ('no investment')

```



```

else display ('investment')
end

if DH-Z2<0
    display ('no investment')
else display ('investment')
end
Newtotal_H=agRV_H3(T,1)+VTH(1,1);    % total land rents with land use change

%%% NPV of land rents from agriculture on the infinite time horizon
%[agRV]=aGprofit(Pr_Corn, LB, Qua, Wgrate, Time1, r)
%
% aGprofit calculates the profits from agricultural production;
%OUTPUT:
%agRV:profit;

%INPUTS:
%      LB:labor input;
%      Qua:land quality;
%      Wgrate:wage rate;
%      Pa: price of agricultural products;
%      h(LB,Qua): production function for agriculture
%      r:interest rate or discount rate here;
function [agRV_L,agRV_M, agRV_H] =
aGprofit(YCORN_L,YCORN_M,YCORN_H,Pr_Corn, LB_L, LB_M, LB_H, Wgrate, T, r)
agRV_L=(1/r)*(Pr_Corn.*LB_L.^(0.5).*YCORN_L-Wgrate.*LB_L);
agRV_M=(1/r)*(Pr_Corn.*LB_M.^(0.5).*YCORN_M-Wgrate.*LB_M);
agRV_H=(1/r)*(Pr_Corn.*LB_H.^(0.5).*YCORN_H-Wgrate.*LB_H);

end

%%% NPV of land rent from loblolly pine production on the infinite time horizon
function [TProfit_L,TProfit_M,TProfit_H] = TimProfit(Pr_Pulp,
Pr_Stim,RT_Lob,Pulp45, Pulp60, Pulp75,Stim45, Stim60, Stim75,r,C_Lob)
% Profits from conventional timber production
% [Timprofit]=TimProfit(RT_Lob,Qua,R)
% RT_Lob=rotation of convential tree species, loblolly pin here.

```

```

% r=interest rate or discount rate

TProfit_L=((Pr_Pulp.*Pulp45+Pr_Stim.*Stim45).*exp(-r.*RT_Lob)-C_Lob)./(1-
exp(-r.*RT_Lob));
TProfit_M=((Pr_Pulp.*Pulp60+Pr_Stim.*Stim60).*exp(-r.*RT_Lob)-C_Lob)./(1-
exp(-r.*RT_Lob));
TProfit_H=((Pr_Pulp.*Pulp75+Pr_Stim.*Stim75).*exp(-r.*RT_Lob)-C_Lob)./(1-
exp(-r.*RT_Lob));
end

%%% initial forest biomass land rents from hybrid poplar
function [RbL0,RbM0,RbH0] =
BioProfit(Pr_HP_IN,YHP_L,YHP_M,YHP_H,r,RT_HP,C_HP)
% BioProfit: land rents from woody biomass production for energy use on the
land with
% low, average and high quality
% OUPUTS
% BMPprofit_L : from the land with low quality
% BMPprofit_M : from the land with avrg quality
% BMPprofit_H : from the land with high quality
% INPUTS
% Pr_HP_IN : initial price
% YHP_L : yields from the land with low quality
% YHP_M : yields from the land with avrg quality
% YHP_H : yields from the land with high quality
% r : interest rate
% RT_HP :rotation
% C_HP :COSTS

RbL0=(Pr_HP_IN.*YHP_L.*exp(-r.*RT_HP)-C_HP)./(1-exp(-r.*RT_HP));
RbM0=(Pr_HP_IN.*YHP_M.*exp(-r.*RT_HP)-C_HP)./(1-exp(-r.*RT_HP));
RbH0=(Pr_HP_IN.*YHP_H.*exp(-r.*RT_HP)-C_HP)./(1-exp(-r.*RT_HP));
end

```