ECONOMICS OF FOREST BIOMASS BASED BIOENERGY IN THE SOUTHERN UNITED STATES

By

ANDRES IGNACIO SUSAETA LARRAIN

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To my family:
Toyi, Ignacio, Cristobal, Doquinha, Vivi and Juancri
…I know that someday we all will be together again...
To my own private Gainesville experience

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LIST OF ABBREVIATIONS

ACES	American Clean Energy Security Act
AR	Arkansas
BS	Black-Scholes
CPS	Consumer Population Survey
CV	Contingent Valuation
DW	Durbin Watson
EFI-GTM	European Forest Institute Global Trade Model
EIA	Energy Information Agency
EHF	Enzymatic Hydrolosis Fermentation
ENFA	European Non Food and Agriculture
E10	Ethanol 10
E85	Ethanol 85
FASOM	Forest and Agriculture Sector Optimization Model
FL	Florida
FR	Fusiform Rust
GAPPS	Georgia Pine Plantation Simulator
GF	Gasification Fermentation
GFPM	Global Forest Products Model
GHG	Greenhouse Gas
GJ	Gigajoule
GLPF	Generalized Leontief profit function
IRR	Internal Rate of Return
KN	Knowledge Networks
LEV	Land Expectation Value

RES	Renewable Electricity Standards
RFS	Renewable Fuel Standards
NIPF	Nonindustrial Private Forest Landowner
NPV	Net Present Value
OLS	Ordinary Least Squares
OPEC	Organization of the Petroleum Exporting Countries
SPB	Southern Pine Beetle
TE	Total Expenditures
TMS	Timber Mart South
3SLS	Three Stage Least Squares
2SLS	Three Stage Least Squares
TWh	Terawatt hour
U.S	United States
VA	Virginia
WTP	Willingness to Pay

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By

Andres Ignacio Susaeta Larrain

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Concerns about greenhouse gas (GHG) emission and dependency on foreign oil have prompted policy makers to develop environmentally friendly sources of energy. Forest biomass, a carbon dioxide (CO_2) neutral source of energy, is thought to provide higher energy ratios, better environmental benefits regarding GHG reduction and be potentially cost competitive compared to agricultural crops. Furthermore, the use of forest biomass for energy can decrease the risk of wildfires and increase the profitability of forestlands.

This dissertation explores the economics of using forest biomass for energy in the southern United States. First, the effects of bioenergy markets on nonindustrial private forest management are modeled using a Black-Scholes formula integrated with a modified Hartman model. This combined model assumes that stumpage prices are stochastic and forests are affected by catastrophic disturbances such as wildfires pest outbreaks. Second, public perceptions and views about using forest biomass biofuels are analyzed. A contingent valuation survey was conducted in Arkansas, Florida and Virginia to estimate the willingness to pay for biofuels to assess the effect of socioeconomic variables on the choice for renewable energy. Third, the effects of bioenergy markets on traditional forest product sectors are estimated. Assuming a Leontief profit

function, both supply and demand functions for different components of the forest sector are derived. In addition, the effects of an increase demand for biomass for bioenergy on the sawtimber and pulpwood markets were simulated.

Results of this research show that bioenergy markets would increase the profitability of forest stands. Forestland values are shown to be greater when thinning material is used for bioenergy production relative to pulpwood production. Furthermore, revenues are shown to increase as the rate of catastrophic disturbances is reduced. On average, bioenergy production increased the forestland value around 11.6% compared to pulpwood production. As bioenergy markets evolve, it is expected that profitability of forestlands will increase. Public perception study indicates that people tend to pay for biofuels to realize environmental and social benefits. Although people show heterogeneous preferences in terms of environmental attributes, their willingness to pay is greater when higher reduction of CO_2 and improvements of biodiversity are offered. For an ethanol blend of 10% (E10), people were willing to pay an extra \$0.56 gallon^{-1}, \$0.58 gallon^{-1}, and \$0.50 gallon^{-1} in Arkansas, Florida and Virginia, respectively. For an ethanol blend of 85% (E85), the extra willingness to pay was \$0.82 gallon^{-1}, \$1.17 gallon^{-1}, and \$1.06 gallon^{-1} for the same states.

Finally, an increase in the demand for biomass for bioenergy causes an increase in the price of biomass for bioenergy, pulpwood and sawtimber and the quantity of pulpwood and sawtimber are shown to be decreased. Price of biomass for bioenergy, pulpwood and sawtimber increased 52%, 104% and 6.5%, respectively. Quantity of pulpwood and sawtimber decreased 20% and 11%, respectively. On the other hand, forest landowners and bioenergy sectors would benefit from bioenergy production while pulp and sawmill sectors are shown to contract with an increase in the demand for biomass for bioenergy.

CHAPTER 1
INTRODUCTION

Overview

Currently, around 26% of the total energy used in the United States (U.S.) is imported, and 84% of the imports are represented by crude oil and petroleum products (EIA, 2009). Furthermore, 46% of the petroleum imports come from the Organization of the Petroleum Exporting Countries (OPEC) (EIA, 2009). The transportation sector was the largest consuming sector of petroleum in 2008, standing at 13.7 million barrels day^{-1} (70% of all petroleum used), and motor gasoline was the single largest petroleum product consumed (64% of all petroleum consumption) (EIA, 2009). On the other hand, the continued increase in anthropogenic emissions of greenhouse gases (GHG), predominantly carbon dioxide (CO_2), is expected to have dramatic impacts on climate, such as glacier shrinkage, worldwide sea level rise, and threats to biodiversity.

This strong dependency on foreign markets, particularly from volatile Middle Eastern countries, together with concerns about the effects of greenhouse gas (GHG) emissions, has prompted policy makers to find alternative renewable energy sources. Currently, biofuels represent 19% of the total consumption from renewable energy sources, which account for only 7% of the total energy consumption in the U.S. Further, 53% of renewable energy consumption comes from biomass (EIA, 2009). In spite of the low share of renewable energy in total energy consumption, the U.S has the potential to displace 30% of current petroleum consumption with biofuels by 2030, providing a sustainable supply of biomass of more than 1 billion dry tons (Patzek, 2005).

United States Policies for Biofuels

Liquid biofuels such as ethanol have been strongly encouraged since the late 1970s, although the first policies were energy security-oriented. The Energy Tax Act of 1978 provided a \$0.40 $gallon^{-1}$ exemption from the federal gasoline excise tax for a blend with at least 10% ethanol, which increased to \$0.60 $gallon^{-1}$ when the Tax Reform Act of 1984 was enacted. It was reduced to the current level of \$0.51 $gallon^{-1}$ by the 1998 Transportation Equity Act of the 21st Century. The American Jobs Creation Act of 2004 replaced the excise tax exemption with a volumetric ethanol excise tax credit of \$0.51 $gallon^{-1}$ until 2010. Further, a tariff of \$0.54 $gallon^{-1}$ was imposed on imported ethanol under the purview of the Omnibus Reconciliation Tax Act of 1980 to stimulate domestic industry.

Several other federal policies have been adopted to address environmental concerns about the use of fossil fuels. For example, the Clean Air Act amendment of 1990 established an oxygenated gasoline program to create a new, balanced strategy to address the problem of urban smog. The Energy Policy Act of 1992 extended the tax exemption to include blends of 7.7% and 5.7% ethanol. The Energy Policy Act of 2005 introduced the concept of a Renewable Fuel Standard (RFS) requiring that a minimum amount of renewable fuel production must be met, starting with 4 billion gallons in 2006 and achieving 7.5 billion gallons in 2012. After 2012, renewable fuel and gasoline production will grow at the same rate (Duffield and Collins 2006). The Energy Independence and Security Act of 2007 requires a RFS of 36 billion gallons by 2022, of which 21 billion gallons must come from cellulosic products. The 2002 and 2008 Farm Bills, in their Title IX's, also established new programs and grants for the procurement of biobased products to support development of biorefineries and assistance to farmers and ranchers in purchasing renewable energy systems. Finally, the draft legislation "American Clean Energy and Security Act” (ACES) of 2009 suggests setting an initial Renewable Electricity Standard (RES) of 6% in 2012, which can be gradually increased to 25% by 2025.

Ethanol Production: Corn versus Cellulosic Biomass

The U.S. became the main producer of ethanol worldwide in 2006 (Hettinga et al., 2009), and around 95% of it came from corn (Solomon et al., 2007). Corn based ethanol production has been criticized for its effect on food security, and consequently, the increasing prices of related products such as milk, meat, and eggs (Pimentel and Patzek, 2005). Additionally, several environmental impacts and low (even negative) net energy balance ratios have been claimed (Pimentel and Patzek, 2005; Hill et al., 2006; Solomon et al., 2007). However, it has also been argued that food prices will remain high along with higher energy prices (Renewable Fuels Association [RFA], 2008). Urbanchuk (2007) argues that the increase in food prices due to corn prices is expected to have half the impact of the same percentage increase in energy prices on the CPI for food. Further, as ethanol production expands and new technologies and ethanol feedstocks materialize, any increase in food prices will be offset by lower energy prices (Evans, 1998).

Cellulosic biomass[1] for ethanol production, on the other hand, has a higher net energy balance ratio, provides more environmental benefits in term of GHG reduction, and is potentially cost competitive compared to food-based biofuels (Hill et al., 2006). In addition, the use of forest biomass for cellulosic ethanol production could make non-commercial components such as harvest residues marketable and reduce flammable materials left in the field as waste. Such a development would also reduce the risk of wildfires (Neary and Zieroth, 2007; Polagye et al.,

[1] Cellulosic feedstock is comprised of cellulose, hemicellulose, lignin, and solvent extractives (Dwivedi et al., 2009). Percent range of constituents in wood differs from other cellulosic feedstocks such as agricultural waste, grass and municipal solid waste (Olsson and Hagerdal, 1996).

2007; Nicholls et al., 2009) and pest outbreaks (Roser et al., 2006; Evans, 2007) besides improving the profitability of forest landowners and stimulating employment (Faaij and Domac, 2006). On the other hand, the use of renewable energy coming from woody biomass, assuming no land use changes, ensures a neutral carbon dioxide source of energy (Richardson et al., 2002) representing a diversification strategy to reduce dependence on foreign oil.

However, careful considerations must be taken when managing forests intensively for bioenergy. Without appropriate planning and incorporating optimal harvest systems and maintaining the connectivity of habitat networks, the production of bioenergy could lead to loss of biodiversity (Cook et al., 1991). Extensively degraded lands can be considered for bioenergy plantations — trees or other energy crops— to reduce erosion, restore ecosystems, and provide shelter to communities (Riso, 2003), but these benefits would only be realized under clear land use regulations, especially in places where forests are at risk of conversion to other land uses (Worldwatch Institute, 2007).

Current Situation of Nonindustrial Private Forest Landowners

The southern United States (U.S.) contains 214 million acres of forestland. Out of this, 204 million acres (95.3%) are categorized as timberland. About 145 million acres of timberland (71.8%) are owned by nonindustrial private forest (NIPF) landowners, also called family forests. NIPF landowners contribute 68% (7.7 million cubic feet) of annual growth and 68% of annual removals (Smith et al., 2009). Thus, private forests, and particularly NIPF landowners, are significant contributors to the southern U.S. forest sector.

Currently, southeastern U.S. NIPF landowners managing slash pine (*Pinus elliotti*) plantations face several challenges, including catastrophic risk events, increased offshore competition (Paun and Jackson, 2000), and low pulpwood prices. The combined effect of fire suppression, lack of prescribed burning, and high planting densities has been that extensive areas are overstocked and are susceptible to wildfires and pest attacks (Graham et al., 1999; Le Van Green and Livingstone, 2003; Polagye et al., 2007). For example, the average annual number of wildfires in the state of Florida is as high as 5,550 incidents burning 220,000 acres each year (Florida Department of Community Affairs and Florida Department of Agriculture and Consumer Services Division of Forestry, 2004). In order to prevent and manage wildfires, $58 million was allocated for fiscal year 2007-08. Pest outbreaks such as fusiform rust (*Cronartium quercuum* [Berk.] Miyabe ex Shirai f. sp. fusiforme) (FR) and southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) have caused significant damage to NIPF landowners. For example, FR caused an annual economic loss of $35 million in five southern states and $8 million in Florida (Schmidt, 1998); SPB caused southwide damages of $1.5 billion between 1970 and 1996 (Price et al., 1998).

Foreign competition is also of concern. Costs for producing fiber in the southern hemisphere are lower compared to the U.S. due to lower labor and other input costs. Wear et al. (2007) found delivered cost differentials of 24% and 27% in Brazil and Chile as compared to the southern U.S., respectively. Further, low pulpwood prices have resulted from a contraction of domestic pulp and paper demand, as evidenced by declining pulp mill capacity and expanded use of recycled material. Softwood pulpwood prices in the southern U.S. decreased by 36% between 1998 and 2005 (Timber Mart South, 2007), while pulping capacity decreased by 11% between 1997 and 2006 (Johnson et al., 2008). Timber inventory reductions, however, have not kept pace with reduced demand, further exacerbating the problem.

Previous Research on Economics of Forest Biomass Based Energy

Several authors have investigated the potential availability of forest based biomass for energy. Smeets and Faaij (2006) explored the biomass potential from forestry for the year 2050. The authors estimated that forests can become a major source of bioenergy without threatening the supply of traditional forest products and without deforestation. However, regional shortages of industrial roundwood might occur in South Asia, the Middle East, and North Africa. Supporting this, in a previous study conducted by Yamamoto et al. (2001), the authors approached bioenergy potential with a multiregional global land use energy model. They concluded that the total area of global forests will remain stable, although mature forest area will decrease because of increased population growth and demand for biomass in developing countries especially in Central Asia, the Middle East, North Africa, and South Asia.

Perlack et al. (2005) predicted a 30% replacement of current U.S. petroleum consumption with biofuels by 2030 based on agricultural and forestland biomass potential—around 1.3 billion dry tons per year. 368 million dry tons would come from forestlands, including 52 million tons of fuelwood, 145 million tons from wood processing mills, 47 million tons from urban wood residues, 64 million tons from logging and site clearing operations, and 60 million tons from fuel treatment operations. Galik et al. (2009) showed that in spite of large amounts of forest residues within the states of North Carolina, South Carolina, and Virginia, they would not be sufficient to meet the long term biomass electricity production requirements imposed by a hypothetical national Renewable Portfolio Standard (RPS) and RFS.

Walsh (1998) determined a marginal price for bioenergy crops at the farm gate of \$24 dry ton^{-1} and \$26 dry ton^{-1} at national level for 2010 and 2020, considering total bioenergy crops quantities of 50 million dry tons and 110 million dry tons, respectively. It was also assumed that two thirds of total biomass quantity would be supplied by switchgrass and one third would be supplied by hybrid poplar and hybrid willow in 2010. By 2020 switchgrass would provide half of the biomass quantity, and the other half would be supplied by woody crops. Gan and Smith (2006) explored the availability of logging residues and their potential for electricity production in the U.S. They calculated that recoverable residues might generate 67.5 TWh electricity per year, displacing 17.6 million tons of carbon emitted from coal generated electricity at a cost ranging from US$60 ton^{-1} to $80 ton^{-1} of carbon.

The economics of cellulosic biomass have been widely explored in the literature. Piccolo and Bezzo (2009) investigated the economics of the enzymatic hydrolosis and fermentation (EHF) process and the gasification and fermentation (GF) process for bioethanol production. The Net Present Value (NPV) of both the EHF and GF processes were shown to be only positive for a 5 year investment payback period, but as a result, the ethanol selling price needed to be 38% and 106% higher, respectively, than the present market value of fuel grade ethanol. Additionally, a low internal rate of return (IRR) of less than 15% was found for both processes, implying a poorly profitable investment choice. Hamelic et al. (2005) concluded that with a higher EHF efficiency, lower capital investments, increased scales of operations, and lower biomass stocks might reduce ethanol production costs by 40% in a 10 to 15 year time scale and even by 90% over 20 or more years. Similarly, Hess et al. (2007) claimed that the competitiveness of cellulosic ethanol is highly dependent on biomass stock, accounting for 35-50% of the total ethanol production cost. On the other hand, Solomon et al. (2007) found an encouraging cost of producing cellulosic ethanol of $2.16 $gallon^{-1}$, $0.24 $gallon^{-1}$ lower than the price of grain ethanol and $0.08 $gallon^{-1}$ below the gasoline price. Other factors such as the use of cheap residues for biomass feedstocks, low cost mechanisms to finance debt, and the integration with biorefineries platform might reduce the cost of production of ethanol even further.

Economic analysis of silvicultural intervention based bioenergy has also been a subject of research. Polagye et al. (2007) explored the economic feasibility of utilizing thinning of overstocked forests to produce bioenergy and reduce wildfires in the western U.S. Findings suggested cofiring of thinnings with coal as the most viable option for transportation distances of less than 500 km. Other conversion pathways such as pelletization, fast pyrolosis, and methanol synthesis became cost competitive for different ranges of thinning yields (50-500 km^2 of annual thinned area) and duration (1-15 years) beyond 300 km of transportation distance. Ahtikoskia et al. (2008) investigated the economic viability of using thinning based energy from young stands in Finland. They concluded that thinning based energy would be economically viable if removal exceeded 42 m^3 ha^{-1} with an average ethanol volume per stem larger than 15 l. However, without government intervention, the use of thinning for bioenergy would be unprofitable.

Research Plan

So far, the main concerns that the U.S. is facing in terms of energy security and GHG emissions have been outlined. Further, corn based ethanol production has raised the challenge of low energy ratios, food security, and increasing food prices. On the other hand, NIPF landowners have had to confront a detriment in the profitability of forest stands due to risk events, offshore competition, and low pulpwood prices. Forest biomass, a renewable and more carbon neutral energy resource, could provide a potential solution to GHG emissions, high energy prices, and dependency on foreign oil. Additionally, cellulosic ethanol can be a viable alternative to food based biofuels, increasing profitability of forestlands and stimulating rural employment.

Previous research on forest biomass based bioenergy suggests that a research gap exists with regard to the integrated effect of bioenergy markets with the risk of current catastrophic events on profitability of nonindustrial private forests, assuming that stumpage prices follow a stochastic approach. Furthermore, information is required on public preferences for the use of bioenergy relative to traditional fossil fuels considering the impacts of bioenergy on reducing the risk of wildfires and pest outbreaks in southern forestlands. Similarly, existing research has not accounted for the tradeoffs between bioenergy markets and conventional forest product sectors.

The aim of this dissertation is to fulfill the identified research gap by exploring some aspects of the economics of forest biomass based energy in the southern U.S. Chapter 2 assesses the potential impacts of forest biomass markets for energy on slash pine plantations by applying a model that combines the stochastic condition of timber prices (Black-Scholes formula) and the risk of natural disturbances such as wildfire and pest outbreaks, assuming that catastrophic events follow a Poisson distribution (modified Hartman model). It analyzes the impact of bioenergy markets on the profitability of the forest stand, the effect on profitability of reducing the risk of natural disturbances through thinnings, and changes in price and price volatility. Chapter 3 explores public preferences for forest biomass based transportation biofuels, particularly for blends of 10% and 85% ethanol, by conducting a contingent valuation (CV) study in the southern U.S. A discrete choice model is run and the willingness to pay (WTP) and total expenditures (TE) for both blends are calculated in Arkansas, Florida, and Virginia. Further, socioeconomic conditions and their effects on the probability of choosing a particular blend are discussed. Chapter 4 assesses the dynamic effects of an increased demand for woody biofuels on the traditional forest products sector. We apply the model developed by Just, Hueth, and Schmitz (2004), along the lines proposed by Brannlund and Kristrom (1996) and Arkanhem et al. (1999). Specifically, we determine the partial equilibrium model for the supply and demand for sawtimber, pulpwood, and biomass for bioenergy and their respective cross price elasticities. Also, we simulate an increased demand for biomass for bioenergy and estimate the effect on equilibrium quantities and prices of traditional forest products. Finally, results and policy implications are summarized in Chapter 5, as well as future directions for research.

CHAPTER 2
MODELING IMPACTS OF BIOENERGY MARKETS ON NONINDUSTRIAL PRIVATE FOREST MANAGEMENT

Introduction

The main utilization of forest biomass for bioenergy purposes has been the generation of steam or electricity for the forest products industry (Guo et al., 2007). However, with further advancements in cellulosic, enzymatic, and thermochemical technologies forest biomass based bioenergy could open up new opportunities for nonindustrial private forest (NIPF) landowners. At present, the traditional pulpwood market is suppressed thus landowners are less inclined to undertake thinnings (Mason et al., 2006). On the other hand, forests can be affected by catastrophic events such as wildfires and pest outbreaks. In general, catastrophic disturbance rates in forests are around 1% annually, ranging from 0.5% to 2% (Runkle, 1985).

Several studies have demonstrated the effect of catastrophic risk on forest management. For example, Reed (1984) extended the Hartman model by incorporating the probability of a stand of being affected by catastrophic events. A similar approach was recently followed by Stainback and Alavalapati (2004) to model the effect of catastrophic risk on carbon sequestration in slash pine forests. Furthermore, Englin et al. (2000) explored the optimal rotation age in a multiple use forest in the presence of fire risk. All these studies showed that the presence of risk of catastrophic of stand destruction decreases the optimal rotation age and the land expected values.

In general, catastrophic events can yield several economic implications that can affect all timber market participants. Prestemon and Holmes (2000, 2004) and Prestemon et al. (2006) illustrated the short and long run timber price dynamics after a natural catastrophe. In the short run inventory is reduced and salvaged timber gluts the market. Prices fall and decrease producer welfare while at the same time causing an increase in consumer welfare. In the long run this situation might be reversed: prices increase due to losses of standing inventory and contracted supply (time of salvageable exhaustion) improving producer and reducing consumer benefits.

Silvicultural practices such as stand thinnings are commonly used to extract small diameter wood and reduce excessive amounts of forest biomass, which enhances residual stand growth as well as lowers wildfire and pest risk. Research suggests that thinning from below is more effective in reducing crown fire compared to crown and selection thinnings (Graham et al., 1999; Peterson et al., 2003). Further, it is well known that maintaining an appropriate stand density is an effective way to reduce southern pine beetle (SPB) damage. Overstocked stands reduce tree vigor making them more susceptible to SPB attack (Cameron and Billings, 1988; Belanger et al., 1993). Thus, the use of forest biomass for energy purposes can provide additional avenues for small diameter trees and help out NPIF landowners to meet management goals and increase the profitability of their forest stands.

Model Specification

The stochastic condition of forest stumpage prices has been extensively explored in the literature. It has been shown that the expected value of the stand increases when stochastic prices are incorporated (Haight, 1991; Haight and Smith, 1991; Plantinga, 1998; Lohmander, 2000; Lu and Long, 2003). The Black-Scholes (BS) formula (1973), which considers the stochastic nature of prices, was primarily developed to value options but has been widely used in forestry analyses as well. Shaffer (1984) proposed the option pricing methodology for valuing long term timber cutting contracts. Zinkhan (1991) applied the option pricing theory to the problem of valuing the land use conversion option. Thomson (1992) explored the binomial option pricing model to determine the optimal forest rotation age. Yin and Newman (1996) studied the effect of catastrophic risk on forest investment decisions following the option approach under investment uncertainty. Plantinga (1998) analyzed the rotation age problem highlighting the role of the option value in determining the optimal timing of harvest by assuming that stumpage prices follow a random walk or an autoregressive process. Hughes (2000) used the Black-Scholes option formula to value the forestry corporation's forest assets. Yap (2004) modeled the Philippine forest plantation lease as an option considering market uncertainty and irreversible sunk establishment costs.

The BS formula is extended to include the probability of risk of natural disturbances and integrate with the Hartman model. The BS formula assumes that prices follow a diffusion process (random walk with a drift or geometric Brownian motion) which can be represented as:

$$dP = \mu P\, dt + \sigma P\, dz \qquad (2\text{-}1)$$

Where P is the stock price, μ is the drift rate of the stock price, dt is the time increment, σ is the volatility of stock price, and dz is the increment of a Weiner process defined as $dz = \varepsilon_t \sqrt{dt}$ where ε_t is a normally distributed random variable with E(ε_t) = 0, E(ε_t^2) = 1 and E($\varepsilon_t \varepsilon_s$) = 0 for all t ≠ s (Dixit and Pyndick, 1994); dz is independent and normally distributed with mean zero and variance *dt*. Equation (1) states that a change in *P* depends on a deterministic component $\mu P\, dt$ and stochastic term $\sigma P\, dz$. The other underlying assumptions of the BS formula are that the stock pays no dividends, the option is exercised at the time of expiration, there are no transaction costs, and there are no penalties to short selling (Black-Scholes, 1973). The BS formula is represented as:

$$C = SN(d1) - Xe^{-rT}N(d2) \qquad (2\text{-}2)$$

Where *C* is the value of an option (premium), *S* is the market or stock price, *N(d)* represents the cumulative normal density function, *X* is the strike or exercise price, *r* stands for the risk free interest rate and *d1* and *d2* show a relationship among the stock price, risk free interest rate, strike price, volatility and current and maturity date; d1 and d2 are represented as follows:

$$d1 = \frac{\ln\left(\frac{S}{X}\right) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} \tag{2-3}$$

$$d2 = d1 - \sigma\sqrt{T-t} \tag{2-4}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left[ln\left(\frac{S_i}{S_{i-1}}\right) - ln(\bar{S})\right]^2}{n-1}} \tag{2-5}$$

$\bar{S}$ represents the average stock price, n is the horizon time in which volatility is calculated, *t* and *T* are the current and maturity date, respectively, *N(d1)* and *N(d2)* stand for the probabilities that a normal variable takes on values less than or equal to *d1* or *d2*, respectively. *N(d1)* is also known as the option delta; the degree to which an option value will change given a small change in the stock price. *N(d2)* is the probability that the option will be exercised or the change of the stock price at expiration time. *N(d1)* is always larger than *N(d2)*, because *d1* is greater than *d2* by $\sigma\sqrt{T-t}$. Thus, the difference between *N(d1)* and *N(d2)* will be greater for higher stock volatilities and/or long dated options. *SN(d1)* reflects the benefits of acquiring the option while *XN(d2)* represents the price of paying the option at expiration time.

Following Hughes (2000) *S* is the stumpage price at time t, σ is the stumpage price volatility (the standard deviation of the natural logarithm of stumpage prices), and *X* is the cumulated exercise forest costs per unit of merchantable volume at time *T*. The exercise cost has to be interpreted as the option of the forest landowner of holding the forest stock (stumpage) and incurring costs associated with certain activities such as site preparation, planting, fertilization, weed control, management, etc., or selling the stumpage. Revenues from thinnings are considered as a negative cost (Hughes, 2000). The decision to sell the stumpage will depend on whether the payoffs from doing so are greater than the value of waiting (Plantinga, 1998). If the value of the timber exceeds the cumulated cost incurred by the forest landowner, the stumpage will be sold otherwise the sale will be put off. The expected value and net expected value of the timber can be represented respectively as:

$$val(T) = V(T) * [S * N(d1)] \tag{2-6}$$

$$Nval(T) = V(T) * [S * N(d1) - X * e^{-rT} * N(d2)] \tag{2-7}$$

Where *V(T)* is the total merchantable volume at time T. Contrary to financial options where the time of expiration of the option is fixed, the harvest date T for forest options can be variable (Hughes, 2000). The expected net present value of the timber for the first rotation can be expressed as:

$$Npv(T)_{timber} = Nval(T) * e^{-\delta T} \tag{2-8}$$

Where δ is the discount rate. If the land is assumed to be used for timber production in perpetuity the land expectation value can be modeled as:

$$LEV(T) = \frac{Nval\,(T)*e^{-\delta T}}{(1-e^{-\delta T})} \qquad (2\text{-}9)$$

Where *LEV(T)* is the BS formula based Land Expectation Value. Starting from bare land (*t*=0) and simulating harvest dates T_1, T_2, T_3, etc., the time *T* that maximizes *LEV(T)* is the expected optimal rotation age.

The BS formula is integrated with a modified Hartman model (1976) accounting for catastrophic disturbance rates in forests. It is assumed that these catastrophic events follow a Poison process which means they are independent and occur at the same average probability λ per unit of time. Thus, the Poisson parameter represents the average rate of a catastrophic event. The second assumption is that the waiting time between successive catastrophic events is also a random variable. Following Reed (1984) the time between each successive destructions of the stand are denoted by x_1, x_2,..x_n. Further λ occurs every year and x follows the exponential distribution $(1 - e^{-\lambda x})$. The probability density function of x before reaching the optimal rotation age ($x < T$) age is given by $(\lambda e^{-\lambda x})$. At the optimal rotation age ($x = T$) the probability density function is $\left(e^{-\lambda T}\right)$. Therefore the probability of a stand being destroyed by a catastrophic event before the time of rotation age T and the probability of the stand reaching the rotation age T are, respectively:

$$prob(x < T) = 1 - e^{-\lambda T};\ prob(x = T) = 1 - prob(x < T) = e^{-\lambda T} \qquad (2\text{-}10)$$

The net return will depend on both the timing of the catastrophic events and the timing of the landowner's decisions during the rotation (Amacher et al., 2005). It is also considered that some portion of the stand is salvageable on a proportion k after a catastrophic event. If a catastrophic event occurs the landowner will harvest any salvageable timber and replants to start a new rotation. Thus, the value of one rotation can be represented for the following two states:

$$Yn = \begin{bmatrix} Nval(T) \text{ if } \mathrm{x} = T \\ \\ \mathrm{k}Nval(x) \text{ if } \mathrm{x} < T \end{bmatrix} \tag{2-11}$$

If a catastrophic event happens at time ($x < T$) the landowner salvages a proportion of the stand and incurs in the exercise costs associated with the development of a new forest stand. The net rent at time x is given by $\mathrm{k}Nval(x)$. However, if the stand reaches the optimal rotation age without being affected by a catastrophic event (x=T) the landowner harvests all the timber and incurs in the exercise costs associated with the development of a new forest stand. The net rent obtained at time T is $Nval(T)$. On the other hand, Reed (1984) showed that when risk is present the *LEV* can be modeled as follows:

$$LEV(x) = E\left[\sum_{n=1}^{\infty} e^{-\delta(x_1+x_2+\cdots+x_n)} Y_n\right] \tag{2-12}$$

Furthermore, because of the independence of the variables x_n, Equation 2-12 can be rewritten as:

$$LEV(x) = \sum_{n=1}^{\infty} E[e^{-\delta(x_1+x_2+\cdots+x_{n-1})}] E\left[e^{-\delta x_n} Y_n\right] \tag{2-13}$$

$$= \sum_{n=1}^{\infty} \prod_{i=1}^{n-1} E\left[e^{-\delta x_i}\right] E\left[e^{-\delta x_n} Y_n\right]$$

$$= \frac{\mathrm{E}\left[e^{-\delta x_n} Y_n\right]}{1-E\left[e^{-\delta x_n}\right]}$$

In addition,

$$E\left[e^{-\delta x_n}\right] = \int_0^{\infty} e^{-\delta x_n}\, dF_x(t) \tag{2-14}$$

$$= \int_0^{T} e^{-\delta x} \lambda e^{-\lambda x} dx + e^{-\delta T} e^{-\lambda T}$$

$$= \frac{\lambda + \delta\, e^{-(\lambda+\delta)T}}{(\lambda+\delta)}$$

Using Equations 2-10, 2-11 and 2-14 we obtain an expression that incorporates the outcomes represented in Equation 2-12. The left hand side of Equation 2-15 represents the expected value of a single rotation that can be expressed as the sum of: the stand being affected by a catastrophic event with a salvageable portion harvested before reaching the optimal rotation (first term of the right hand side) and the stand being harvested at the optimal rotation age (second term of the left hand side). Both expressions are multiplied by their probabilities of occurring and discounted to year zero. Thus:

$$E\left[e^{-\delta x_n} Y_n\right] = \int_0^{T} e^{-\delta x} \mathrm{k} Nval(x) \lambda e^{-\lambda x} d\mathrm{x} + e^{-\delta T} [Nval(T)] e^{-\lambda T} \tag{2-15}$$

Using equations (2-15) and (2-14) and substituting them into Equation 2-13, the *LEV* can be redefined:

$$LEV(T) = \frac{(\lambda+\delta)}{\delta\,(1-e^{-(\lambda+\delta)T})}\left[e^{-(\delta+\lambda)T}[Nval(T)] + \int_0^T e^{-(\delta+\lambda)x}\lambda \mathrm{k} Nval(x)dx\right] \qquad (2\text{-}16)$$

Again, the time T that maximizes the *LEV* is the optimal rotation age. Recall that if λ is set to zero, Equation 2-16 reverts to Equation 2-9. A numerical solution with slash pine will be presented next to facilitate the model comprehension.

The Model Application to Slash Pine Stands

Slash pine (*Pinus elliottii*) is one of main commercial timber species in the southern U.S., occupying around 10 million acres. It is a fast growing species that yields good quality fiber and lumber (Barnett and Sheffield, 2002). The software GaPPS 4.20 (Georgia Pine Plantation Simulator, Bailey and Zhou, 1997) was used to obtain the growth and yield data. Three scenario sets were considered: "*status quo*" or "*no thinning scenario*", "*thinning scenario for pulpwood*" and *"thinning scenario for bioenergy"*. The thinning age was set at year 16 and the percentage of trees left was 70%. Slash pine stands are typically thinned between years 12 to 18 or when the total tree height reaches 40 feet (Dickens and Will, 2002).

The site index and stand density at year 5 were assumed to be 70 and 585 trees acre^{-1}, respectively. Four product classes were defined: sawtimber (*st*), chip and saw (*cs*), pulpwood (*pw*) and forest biomass for bioenergy (*fbb*). It was assumed that the small end diameter for *st*, *cs*, *pw* and *fbb* was 10, 6, 3 and 0.1 inches respectively while the minimum length for *st*, *cs*, *pw* and *fbb* was 8, 8, 5 and 0.1 feet respectively. *St*, *cs* and *pw* were assumed to be obtained under the "*no thinning scenario*" and *"thinning scenario for pulpwood"* while *st*, *cs*, *pw* and *fbb* were assumed to be obtained under the "*thinning scenario for bioenergy*".

The nominal stumpage prices for *st*, *cs*, *pw* were obtained from Timber Mart South (TMS, 2006). TMS has been one of the main sources of prices and trends for forest products in southern states. Several studies have used TMS's reports for their economic analyses such as Munn et al. (2002), Stainback and Alavalapati (2004), Newman (1987), Prestemon and Holmes (2000) and Washburn and Binkley (1990), among others. The nominal prices were deflated by using the lumber Producer Price Index (PPI) (base year=2005) provided by the U.S. Department of Labor, Bureau of Labor Statistics (2007). Thus, the real stumpage prices for *st*, *cs*, *pw* were \$42.2 ton^{-1}, \$25.75 ton^{-1} and \$7.46 ton^{-1}, respectively. While there is no formal market for forest biomass to utilize for bioenergy, we assumed the real price for *fbb* to be \$3 ton^{-1}.

The historical real volatility for sawtimber (σ_{st}), chip and saw (σ_{cs}) and pulpwood (σ_{pw}) was obtained from Yin and Caulfield (2002) and the values for σ_{st}, σ_{cs} and σ_{pw} were 19%, 24% and 24%. The volatility for wood residue for bioenergy (σ_{fbb} = 15%) was calculated using the 1970-2004 deflated time series of biomass based electricity industrial prices for five southeastern U.S. states: Florida, Georgia, Alabama, Arkansas and Virginia (EIA, 2007). The risk free interest rate and the real discount rate were set to 3% and 5%, respectively.

The common costs associated with the silvicultural activities for the three scenarios were based on Smidt (2005). Costs of \$205 acre^{-1} and \$58 acre^{-1} were assumed for mechanical site preparation (shear, pile, rake and bed) and mechanical planting, respectively. Weed control and fertilization costs were assumed to be \$78 acre^{-1} and \$55 acre^{-1}, respectively. Fertilization was considered at years 1 and 7. An extra fertilization for both "*thinning scenario for pulpwood*" and "*thinning scenario for bioenergy*" was considered in year 16 after thinning. In addition, a timber marking cost of \$14.6 acre^{-1} before thinning (year 16) was considered. Annual forest management costs such as taxes, general fire protection and management plans were set to \$6 acre^{-1}. In both scenarios where thinning was undertaken, the thinning cost is reflected by the stumpage price that is paid to the landowner. For this case *fbb* was multiplied by a factor of 0.9.

Slash pine plantations under "*no thinning scenario"* and both "*thinning scenarios*" are expected to have different rates of catastrophic risk. The former was modeled with a risk of 3% while both *"thinning scenarios"* were modeled with risk levels from 0 to 3%. Outcalt and Wade (2000) found that the highest tree mortality rate of southern pines after a catastrophic even such as fire occurred when prescribed burning had not been used since plantation establishment, averaging a mortality of 89%. Thus, two situations concerning the salvageable portion after a catastrophic event for the three scenarios were considered: the stand being completely destroyed (k=0) and 80% the stand is salvageable (k=0.8).

Results and Discussion

The maximum *LEVs* for the three scenarios are shown in Table 2-1. With a positive salvageable portion (k=0.8), the *LEV* for the *thinning scenario for pulpwood* and *the thinning scenario for bioenergy* was greater than the *no thinning scenario* at all risk levels—4.6% and 5.8% higher *LEVs*, respectively. When salvage is zero (k=0), the land value for the *no thinning scenario* exceeded both of the thinning scenarios at the same risk level (λ=0.03) by 3.5% and 2.6%, respectively (for *thinning for pulpwood* and *thinning for bioenergy*).

The *LEV* for the *thinning scenario for bioenergy* was greater than the *thinning scenario for pulpwood* at all comparable risk/salvage levels, exceeding the latter by 11.2%, 11.4%, 11.6% and 11.7% when λ was 0.03, 0.02, 0.01 and 0 respectively for a salvage level of k=0.8. When k=0 the difference between *LEVs* was steady at 11.7% for all levels of risk. A one percent reduction in risk increased *LEVs* by between 9% (k=0.8) and 19% (k=0). Thus, land values are impacted less by increased risk levels when salvage is possible. The optimal rotation for the *thinning scenarios* was longer than the *no thinning scenario*, 27 versus 21 years, respectively.

The incorporation of thinnings for bioenergy increased the profitability of slash pine forestry over the no thinning scenario when salvage was possible, but not when salvage was not possible at a risk level of 3%. In fact, if the stumpage price for *fbb* was set equal to \$0 ton^{-1} (λ =0.03 and k=0.8) the land value for *the thinning scenario for bioenergy* was still greater (\$659.17 acre^{-1}) than the *no thinning scenario*, the reason being the high revenues obtained by producing more proportion of sawtimber and less proportion of pulpwood. The breakeven point for stumpage price for *fbb* was \$2.1 ton^{-1} (λ =0.03 and k=0.8) when the *thinning scenario for bioenergy* was compared to the *thinning scenario for pulpwood*. At this price level the land value was the same for both thinning scenarios, \$679.2 acre^{-1}. For k= 0, the breakeven stumpage price for *fbb* was slightly greater, \$2.2 ton^{-1}.

Regardless of the risk level, and consistent with findings of Stainback and Alavalapati (2004), the *LEV* was greater when the salvageable portion increased for the three scenarios (Figures 2-1, 2-2, 2-3 and 2-4). Further, as risk decreased for both thinning scenarios, the relative difference in *LEVs* when k=0 as compared to when k=0.8 also decreased. The increase in *LEV* for a stand partially salvaged as compared to a stand completely destroyed under both thinning scenarios was consistent across thinning scenarios at 26.4%, 16.6%, 7.8% and 0% for risk levels of 0.03, 0.02, 0.01 and 0, respectively. When the risk continuously drops, the probability of selling the stumpage and replanting due to a catastrophic event declines as such the difference decreases.

The decrease in merchantable volume due to thinnings caused the land values to drop in year 16 (Figures 2-1, 2-2, 2-3 and 2-4). Although the total volume before the thinning was the same for the three scenarios the land value for the *no thinning scenario* was lower than *the thinning scenario for bioenergy* due to the inclusion of biomass for bioenergy that could be harvested at age 16. In the *no thinning scenario* only *sw, cs* and *pw* were included as merchantable volume. However in the *thinning scenario for bioenergy*, *fbb* was included along with these other three products. This difference became greater when risk (λ) was reduced regardless of the salvageable portion (Figures 2-1 and 2-2). The results (except for the impacts of risk) did not extend to the *thinning scenarios for pulpwood* (Figures 2-3 and 2-4) since *fbb* was not a factor. With regard to the *thinning scenario for pulpwood*, there was no difference in *LEV* compared to the *no thinning scenario* before the year 16 for the same level of salvageable portion and catastrophic risk. For both scenarios the merchantable volume was the same without including *fbb*. However as λ was reduced the *LEV* for the *thinning scenario for pulpwood* became greater than the status quo (Figure 2-3 and 2-4). In general the difference between *LEVs* for the *no thinning scenario* and thinning scenarios became greater when λ was reduced because the rate at which the *LEV* was discounted became higher.

At year 16 the *LEVs* for the thinning scenarios fell strongly due to the 30% of the tree removal and the cost of thinning and marking. This drastic decline of the land value can be explained by the fact that the percentage of tree removal represented around 22% of total merchantable volume. Before thinning nearly 50% and 57% of the total merchantable volume was pulpwood for the *thinning scenario for bioenergy* and *thinning scenario for pulpwood* respectively. Further, the inclusion of the cost of thinning and marking increased the cumulated silvicultural exercise cost. On average, the *LEVs* for the *thinning scenario for bioenergy* decreased by 31.4% and 33.1% for a k=0.8 and k=0 respectively. The *LEVs* for the *thinning scenario for pulpwood* decreased by 28.3% and 30% for a k=0.8 and k=0 respectively. After thinning the *LEV* started increasing because a larger proportion of *sw* and lesser proportion of *pw* were produced. In addition, λ was reduced thus the growing *LEV* trend was accelerated by increasing the discount rate. The timing when the *LEVs* for the thinning scenarios started exceeding the *no thinning scenario* varied depending on k or λ. When k=0 and regardless of λ the break even age occurred earlier than when k=0.8. For example for a k=0.8 and λ=0.03, when comparing with the *thinning scenario for bioenergy* the break even age was 24 years compared to 22 years when k=0 and λ=0.03 (Figure 2-1 and 2-2). On the other hand regardless of k the break even age occurred earlier as λ was decreased. For example for a k=0.8 it was 24 and 21 years when λ=0.03 and λ=0.02 respectively for the *thinning scenario for bioenergy* (Figure 2-2). Thus, when positive environmental effects are considered once thinnings are carried out landowners would financially benefit as the land value peaks faster exceeding the value when thinnings are not undertaken.

Although the inclusion of thinnings increased *LEVs*, the difference between the thinning scenarios versus the no thinning scenarios was relatively small for the same risk level. As forest biomass based bioenergy markets continue to expand it is plausible that prices paid for woody biomass may increase, as well as their volatility. We simulated independently two impacts: increased price ($5 ton^{-1}, $10 ton^{-1} and $15 ton^{-1},) and increased price volatility (0.2, 0.25, and 0.3) for *fbb*. Table 2-2 shows the *LEVs* for different level of prices and volatility.

From Table 2-2 and consistent with expectations the *LEV* increased as *fbb* price increased. This increase was slightly higher when salvageable was possible. For example, on average the increase when *fbb* price changed from $5 ton^{-1} to 10 ton^{-1} and $10 ton^{-1} to $15 ton^{-1} was 6.4% and 6.1% for a k=0.8 and k=0 respectively. Furthermore when comparing to the original scenario for bioenergy, the *LEV* increased by 9.6% and 9% for k=0.8 and k=0 respectively. In addition, the profitability of the forest stand was greater when comparing to the *no thinning scenario* and *thinning scenario for pulpwood*. Compared to the former the *LEV* increased on average by 34% and 41% for k=0.8 and k=0 respectively when *fbb* price was increased. With regard to the latter, the *LEV* increased by 10.8% and 10.2% for k=0.8 and k=0 respectively.

Regarding volatility, the increase of the LEV was lower compared to the increase of the *LEV* when price was increased. The average increase in the *LEV* when volatility changed from 0.2 to 0.25 and 0.25 to 0.3 was 0.6% steady for all levels of salvageable portions. With regard to the *no thinning scenario*, the land value was on average 24.4% and 31% higher for k=0.8 and k=0 respectively. The difference with regard to the previous bioenergy scenario and the thinning scenario for pulpwood accounted for 1.4% and 1.2% and 2.5% and 2.4% for k=0.8 and k=0 respectively. Thus, as bioenergy prices are expected to rise and consequently their volatility, this combined effect will result in greater returns to forest landowners.

Conclusions

The incorporation of thinnings increased forestland values regardless of the risk level when the salvageable value of the stand was positive. Results suggested that once pulpwood or forest biomass for bioenergy is incorporated and the whole stand became commercially marketable, the revenues obtained due to stochastic price variation could offset the cost of performing silvicultural activities such as thinning. However, when the landowner was not allowed to salvage any portion of the stand and the risk level was assumed to be 0.03 the land value for the *no thinning scenario* was higher than for the thinning scenarios. Under these conditions, the revenues associated with the increase of the volumetric growth after thinning for greater value added product and the low price for forest biomass based bioenergy were not enough to cover the loss of volume and consequently the profits at the time of thinning. Bioenergy price of \$5 ton^{-1} broke even the land value for the bioenergy scenario with regard to the status quo when stand was completely destroyed and risk was 0.03.

Including thinnings for bioenergy increased the land value around 11.6% compared to the thinning for pulpwood scenario. As expected, increased risk decreased land values for all salvage levels, dropping greater when salvage was zero. On average, the increase of the land value when risk was decreased by 1% was 10% and 19% for both thinning scenarios when the salvageable portion was 0.8 and 0, respectively—the higher risk damage being proportionally more compensated by revenues from salvage. On average, salvage increased land values 17%. Thus, policies that help landowners mitigate risk through silvicultural interventions to reduce the size of the damage would have a positive impact on the profitability of forest stands.

Although the inclusion of thinnings increased the land value of a forest stand the difference with the status quo scenario might be consider small. Furthermore landowners would have to wait longer to harvest. However it is expected as the supply and demand of bioenergy increases bioenergy prices will also increases. Thus, by increasing stumpage price and volatility for bioenergy and consistent with features of the Black-Scholes formula the land value increased. The impact on the land value was higher when price was increased: the increase in the land value with regard to the original scenario for bioenergy was 9.6% and 9% and when the salvageable portion was 0.8 and 0 respectively while it was 1.4% and 1.2% for the same salvageable portions when volatility was increased.

Increase in land values due to thinning and bioenergy markets will benefit landowners. Current NIPF landowners will become more competitive and future landowners can be influenced to undertake thinning and even switch from other land uses to forestry. Thinnings will concentrate growth on fewer large trees which will bring higher stumpage prices. Furthermore as bioenergy markets continue evolving small diameter wood for bioenergy purposes will become a competitor for other uses for this type product, for example pulpwood, raising their prices.

However, current fluctuating pulpwood markets and the lack of a formal market for forest biomass based bioenergy could be a threat for NPIF landowners to undertake thinnings. In this study, the thinning age was set at year 16. Further research is needed to set an optimal thinning age maximizing the amount of forest biomass to be thinned and the benefit cost of this silvicultural practice.

In addition, the incorporation of thinnings will also benefit society. Other commercial activities such as the possibility of silvopastoral use will be allowed. Due to a decrease of risk and the intensity of the catastrophic event, positive externalities will arise. Forest health and wildlife habitat will be improved because of a reduction of pest outbreaks and wildfires respectively. Dependency on external markets for oil and concerns about greenhouse emissions on can be alleviated. In addition other environmental services such as landscape and recreation values will be enhanced. Thus, more factors can be requested an incorporated in order to assess the profitability of southern pines.

Table 2-1. *LEV* (\$ acre^{-1}) for the three scenarios at different levels of risk and salvage

Scenarios	No thinning scenario		Thinning scenario for pulpwood		Thinning scenario for bioenergy		Relative increase in *LEV* for a 1% reduction in risk		Relative increase in *LEV* for a 1% reduction in risk	
Risk\salvage	k=0.8	k=0	k=0.8	k=0	k=0.8	k=0	k=0.8	k=0	k=0.8	k=0
λ = 0			901.1	901.1	911.7	911.7	-	-		-
λ = 0.01			822.3	762.3	831.8	771.3	1.09	1.18	1.09	1.18
λ = 0.02			748.3	641.5	756.8	649.0	1.09	1.19	1.09	1.19
λ = 0.03	649.3	556.2	679.2	537.1	686.8	543.4	1.10	1.19	1.10	1.19

Table 2-2. *LEV* ($ acre^{-1}) for *the thinning scenario for bioenergy* for different bioenergy prices and levels of volatility

Fbb price $ ton^{-1}	Scenarios	Thinning scenario for bioenergy		*Fbb* volatility	Scenarios	Thinning scenario for bioenergy	
	Risk\salvage	k=0.8	k=0		Risk\salvage	k=0.8	k=0
	λ = 0	934.9	934.9		λ = 0	917.4	917.4
5	λ = 0.01	853.5	790.9	0.2	λ = 0.01	837.4	776.1
	λ = 0.02	777.1	665.5		λ = 0.02	762.2	657.0
	λ = 0.03	705.8	557.2		λ = 0.03	692.1	546.9
	Risk\salvage	k=0.8	k=0		Risk\salvage	k=0.8	k=0
10	λ = 0	993.3	993.3		λ = 0	922.9	922.9
	λ = 0.01	908.3	840.3	0.25	λ = 0.01	842.7	780.7
	λ = 0.02	828.3	707.1		λ = 0.02	767.4	707.1
	λ = 0.03	753.6	592.0		λ = 0.03	697.1	550.0
	Risk\salvage	k=0.8	k=0		Risk\salvage	k=0.8	k=0
15	λ = 0	1052.2	1052.2		λ = 0	928.5	928.5
	λ = 0.01	963.7	890.2	0.3	λ = 0.01	848.2	785.5
	λ = 0.02	880.3	749.1		λ = 0.02	772.7	661.0
	λ = 0.03	802.2	627.1		λ = 0.03	702.2	553.4

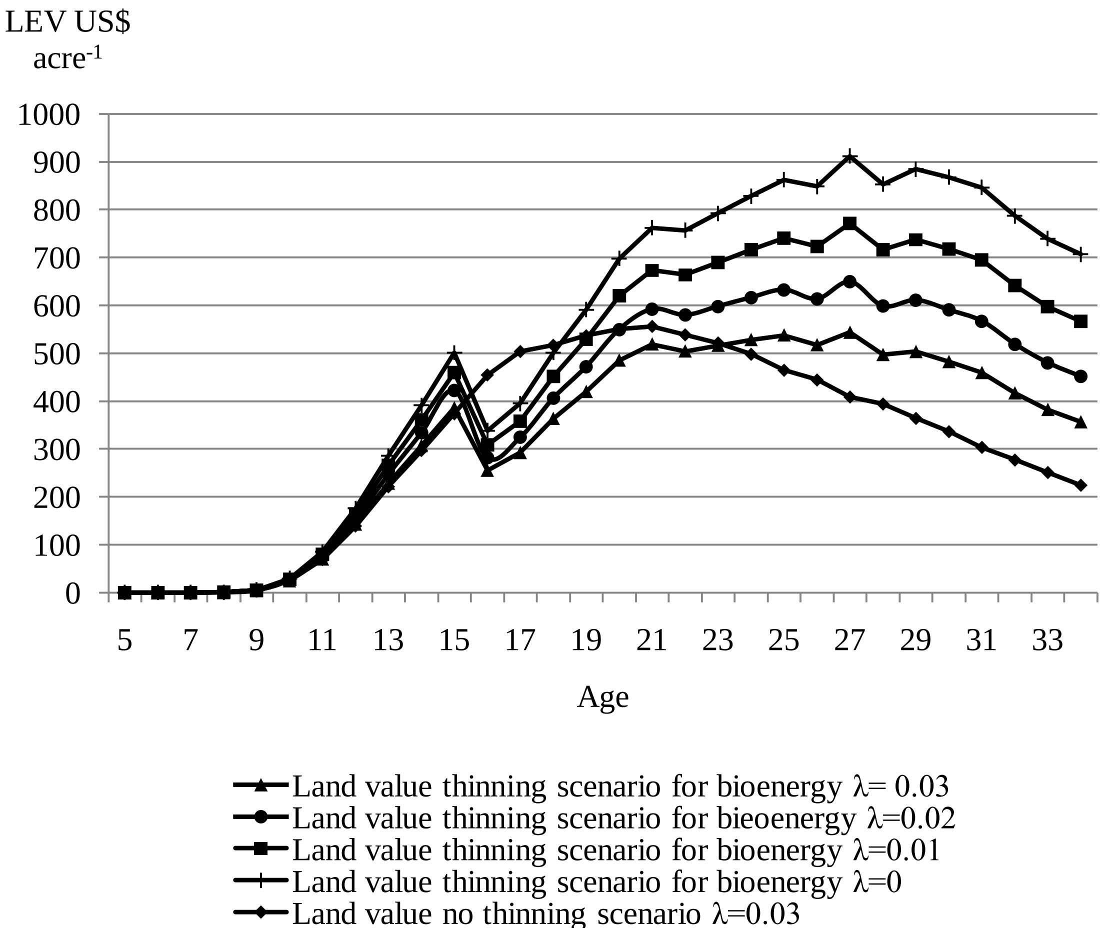

Figure 2-1. *LEVs* for both the *no thinning scenario* and *thinning scenario for bioenergy* when the salvageable portion is zero

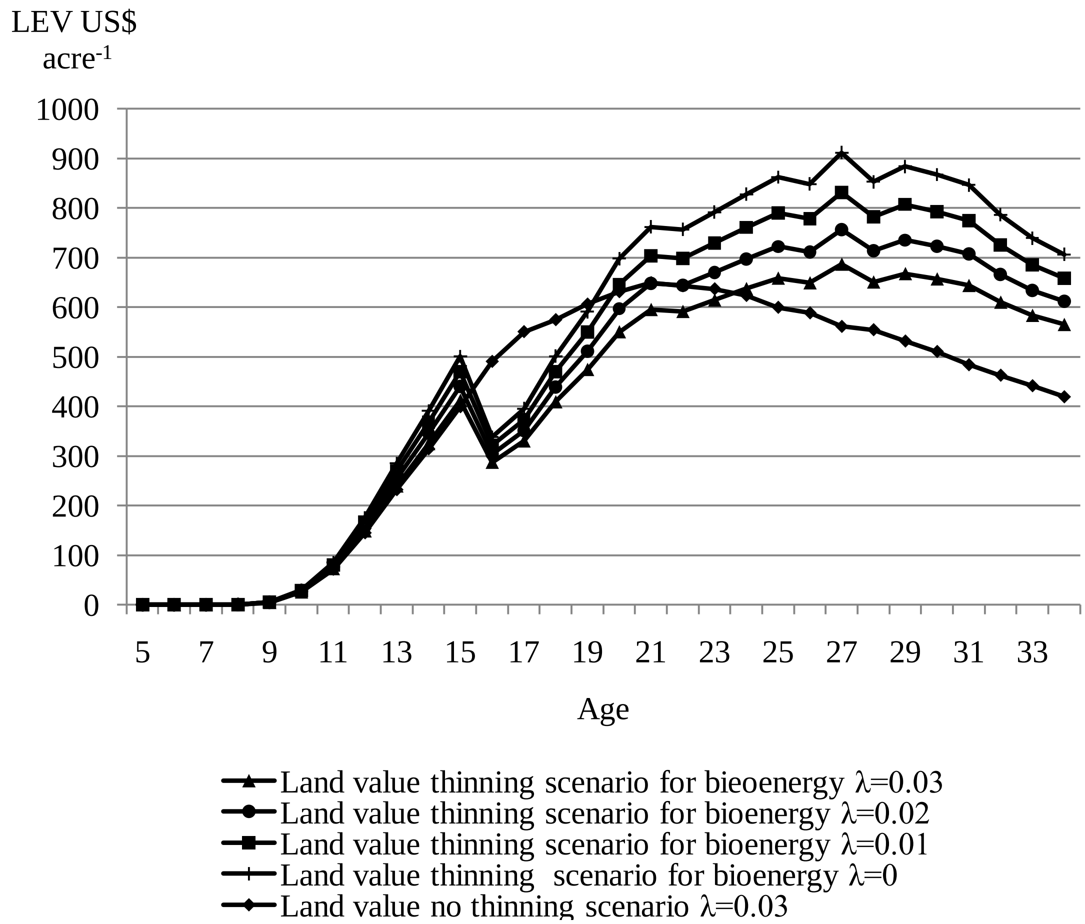

Figure 2-2. *LEVs* for both the *no thinning scenario* and *thinning scenario for bioenergy* when the salvageable portion is 0.8.

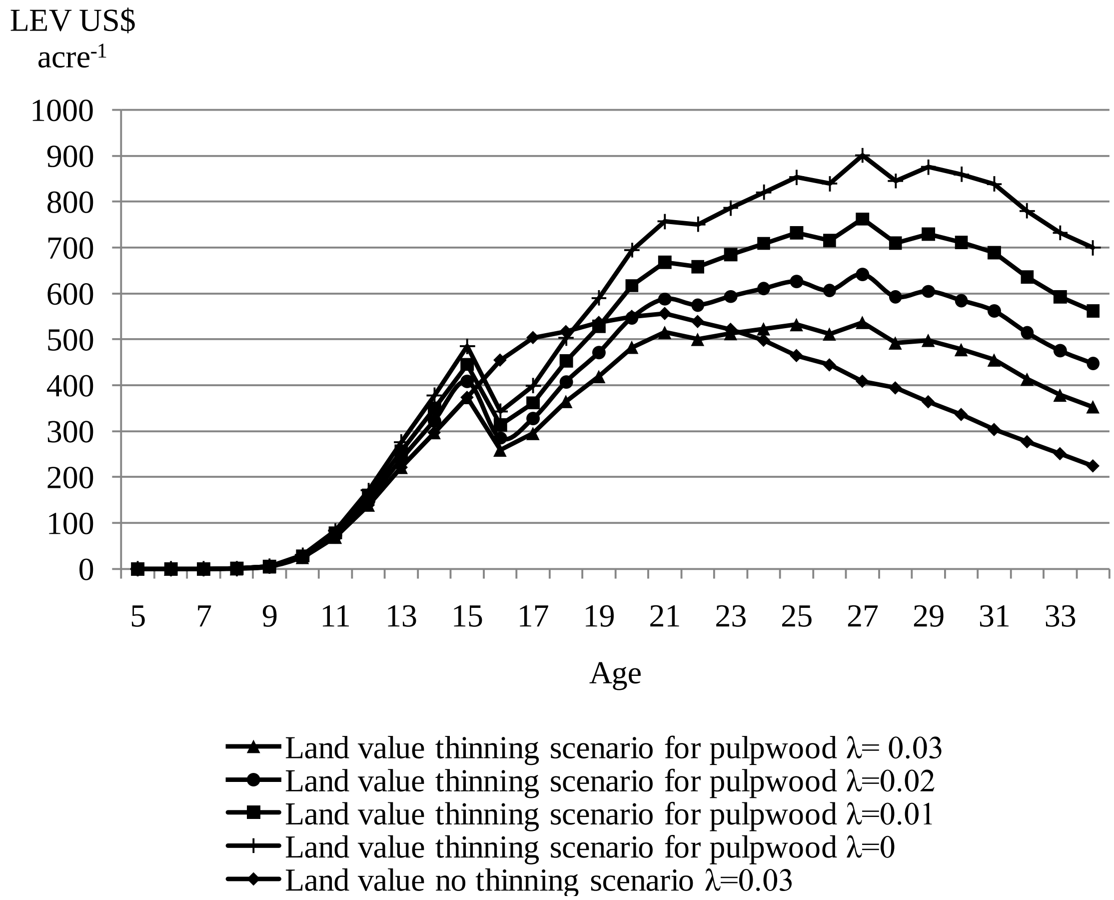

Figure 2-3. *LEVs* for both the *no thinning scenario* and *thinning scenario for pulpwood* when the salvageable portion is zero.

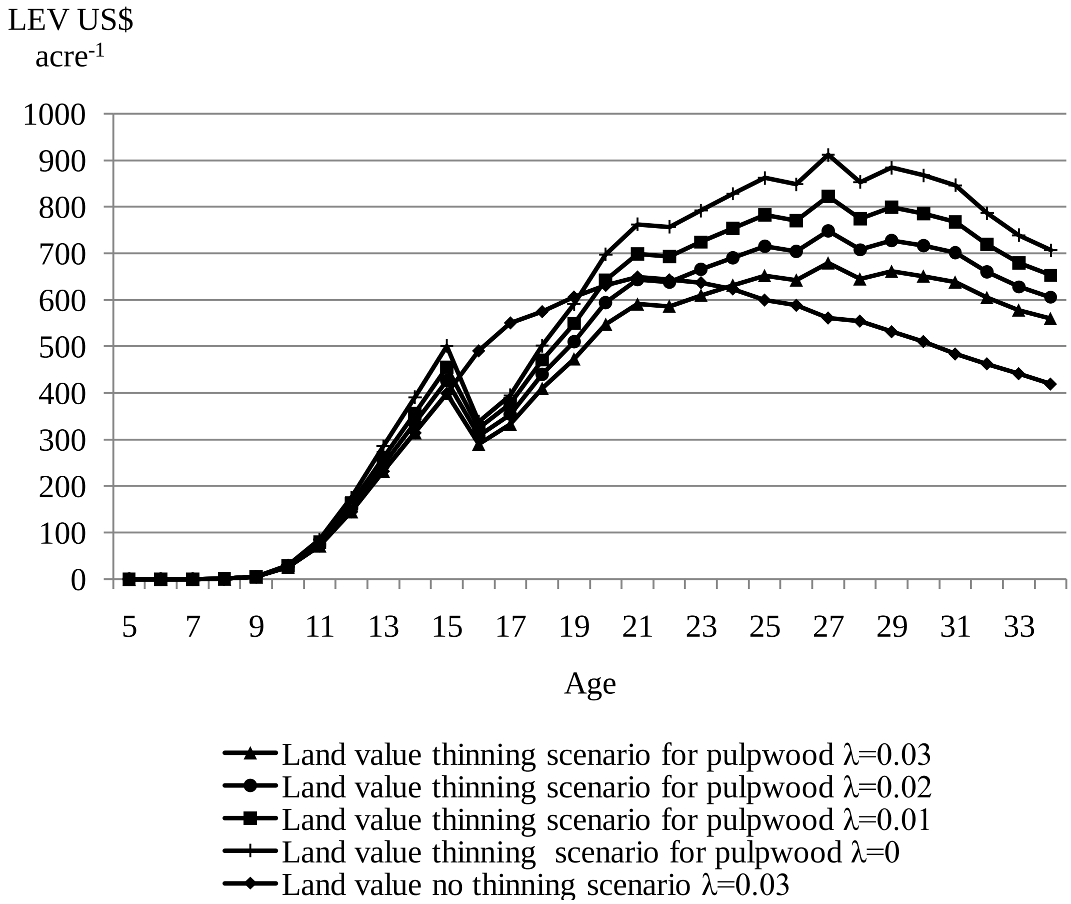

Figure 2-4. *LEVs* for both the *no thinning scenario* and *thinning scenario for pulpwood* when the salvageable portion is 0.8.

CHAPTER 3
ASSESING PUBLIC PREFERENCES FOR FOREST BIOMASS BASED BIOENERGY

Introduction

Ethanol blends are the most widely used liquid biofuels in the U.S. transportation sector, accounting for 95% of the total biofuel consumption (EIA, 2009). Blends of 10% (*E10*) and 85% (*E85*) are currently found on the market; the former can be run in any vehicle, while the latter can be accommodated only by Flexible Fuel Vehicles. The main disadvantages of these blends are their low energy content: *E10* and *E85* have 3.3% and 24.7% less energy content per gallon, respectively, compared to gasoline. This implies that around 1.03 gallons of *E10* and 1.33 gallons of *E85* are required for a vehicle to cover the same distance that it would cover with 1 gallon of gasoline (EIA, 2007). However, the use of ethanol blends has the inherent benefits of contributing to environment and energy security by decreasing the use of petroleum and reducing GHG emissions (Wang et al., 1999). Greenhouse gas emissions per mile traveled are reduced by around 2% and 25% by using corn based *E10* and *E85*, respectively. These reduction levels increase to 10% and 90% for cellulosic based *E10* and *E85* (Wang et al., 1999).

Besides the environmental benefits already described we expect that developing new bioenergy markets will improve forest sustainability by increasing rural employment and financial returns to landowners. In addition to the traditional environmental benefits related to reduction of GHG emission we also considered the benefits associated to biodiversity such as reduction of wildfires and pest outbreaks. Despite several environmental and social benefits and favorable incentives for potential producers of cellulosic biofuels, the arising question is does the public care for the environmental benefits associated with this bioenergy use? If they do, how much of a premium is the public willing to pay for this bioenergy?

Traditionally stated preference techniques have been applied to value renewable energy. A vast number of studies that explored this issue (e.g., see Menegaki, 2007) mainly focused on the generation of green electricity. For example, Batley et al. (2001) found that respondents would pay 16.6% extra for electricity generated from renewable resources in the United Kingdom (UK). Roe et al. (2001) projected a median willingness to pay ranging between $0.38 and $5.66 year^{-1}, depending upon the consumer's level of education and affiliation with an environmental organization, for decreasing 1% of GHG emissions using green electricity in the U.S. Nomura and Akai (2004) estimated a willingness to pay of 2000 yens month^{-1} household^{-1} for green electricity in Japan. Bergmann et al. (2006) claimed that respondents would be willing to pay an additional £14.03 year^{-1} household^{-1} in Scotland for having renewable energy projects that do not increase air pollution, compared to a program which results in a slight increase in pollution. Solomon and Johnson (2009) conducted a study more directly related to our research. They used a multipart survey to assess the public's valuation of mitigating global climate change through estimating willingness to pay for cellulosic ethanol in the upper Midwestern U.S. They applied a contingent valuation method and a fair share method finding a mean total willingness to pay of $556 per capita year^{-1} and a fair share of $472 per capita year^{-1}.

Study Design and Data Collection

Contingent Valuation Questionnaire

We applied Contingent Valuation (CV), a survey based method, to elicit public preferences for public goods. We conducted a survey at the household level in three southern U.S. states: Arkansas (AR), Florida (FL), and Virginia (VA), to understand public attitudes towards transportation biofuels. The online questionnaire was administered and hosted by Knowledge Networks (KN). KN was founded in 1998 seeking to develop online research methodologies, and established the first online research panel — KnowledgePanel — based on probability sampling covering online and offline populations in the U.S. KN selects households using random digit dialing (RDD), and households are provided with access to the internet and hardware if needed. Once a person decides to join the panel, she/he is sent a survey by email. Thus, KN surveys are not limited only to web users or computer owners. KN sample design is an equal probability sample that is self weighting. However, there are some inherent deviations from an equal probability sample design, such as oversampling of minorities or households with access to the internet and subsampling of telephone numbers without an address, among others. Adjustments addressing geographic frame and language are incorporated into the base weights. Thus, all base weights are adjusted with a post stratification weight obtained from the Current Population Survey (CPS) demographic and geographic distribution benchmarks for all adults older than 18 years of age.

Web based surveys have strongly emerged during the last decade (Champ, 2003) due to their low cost, speed, and accuracy in stated preferences studies (Berrens et al., 2004; Banzhaf et al., 2006; Marta-Pedroso et al., 2007). Although web based surveys provide similar welfare estimates compared to traditional mail surveys (Fleming and Bowden, 2007), the main criticisms are related to the sample frame selection and non response bias (Lozar Manfreda, 2001). KN takes several complementary measures in order to minimize non response bias. KN encourages participation through incentives, newsletters, and other techniques (e.g., a toll free helpline for providing assistance with survey questions). Further, KN follows up and contacts non respondents. Wiebe and et al. (2001) conducted a key study of non response bias using the KN methodology, finding that the inclusion of data from non response follow-up of panel recruitment non responders did not affect the statistical estimates, concluding that non response bias was operating at a low level. Lastly, final data are subject to a post stratification using current demographic distribution as a benchmark to adjust for non response bias and non coverage (Huggins et al., 2002). All of this is reflected in higher response rates, around 65% in our study, which reduced chances of non response bias significantly. A random sample of 630 households was drawn from the KN online research panel that met the criteria of being in the general population and over 18 years old. The questionnaire was administered to these households.

The questionnaire contained two parts. The first part comprised the CV section. The second part incorporated questions concerning respondents' socioeconomic conditions. In the CV section, respondents were asked to choose between two alternative plans: Plan A and Plan B. Plan A was described in terms of the attributes associated with using fuel ethanol. The attributes were developed based on a literature review regarding fuel ethanol and discussions with stakeholders and experts specializing in biomass forestry research. Additionally, two steps were carried out to determine the attributes and levels: two focus groups of 12 people each — randomly selected and contacted by phone — were conducted at the University of Florida. Furthermore, a pilot survey was conducted in the three study states. Plan B reflected the status quo of not using fuel ethanol. Another similar stated preference method is conjoint analysis[1] (CJ), popularized in the marketing literature. Individuals make choices about different states of the world they prefer based on the attributes and their respective levels. Typical CJ formats are contingent rating, contingent ranking, and the binary response format (closely related to contingent ranking). The binary response option is mathematically similar to the dichotomous choice CV method (Adamowicz et al., 1994; Roe et al., 2001). Although Plan A is described in

[1] Choice modeling (CM) is another popular technique that has arisen from conjoint analysis. Generally, individuals are asked to choose a particular option according to levels of each attribute (Adamowicz et al., 1998). However, CM has been also applied to rank and rank attribute based alternatives (Hanley et al., 2001).

terms of attributes and their levels in our study, we have used the CV terminology because we do not focus on valuing attributes but on a particular improvement of environmental quality. However, we are aware that our study is somewhat a “hybrid” between CV and attribute based methods.

When the CV questionnaire was introduced to respondents, they were informed about the purpose of using forest biomass as feedstock for ethanol. The expected benefits of using these biofuels were described regarding the reduction of GHG emissions and improvement of biodiversity through reduction of wildfires and pest outbreaks. In order to avoid the typical problem of stated preference experiments (i.e., the difference between stated and actual behavior), the design of a cheap talk script, suggested initially by Cummings and Taylor (1999) and used in several studies (Cummings and Taylor 1999; List 2001; Menges et al., 2005; Carlsson et al., 2005), was included. The attributes and their respective levels were explained to respondents, and an example was provided to facilitate comprehension. Respondents were then asked to provide their views about bioenergy and outline their stated preferences.

Respondents were provided only one questionnaire, regarding the use of either *E85* or *E10*. The attributes chosen were (1) reduction of CO_2 emission per mile traveled, (2) improvement of biodiversity by decreasing wildfires and pest outbreaks, and (3) increase in the price of fuel at the pump. A brief description of the attributes and their levels is given in Table 3-1. The levels of percentage reduction depend on the energy and chemical usage intensity of biomass farming, ethanol yield per dry ton of biomass, and electricity credits in cellulosic ethanol plants (Wang et al., 1999). In order to facilitate understanding of the study, we linked each level to a non numerical category: low, medium or high reduction. Catastrophic disturbance rates in forests are generally around 1% annually, ranging from 0.5% to 2% (Runkle, 1985). The levels of reduction of pest outbreaks and wildfires were assumed following Susaeta et al. (2009). Again, each level of reduction was linked to a non numerical category: low, medium, or high reduction. We assumed a higher premium level for *E85* based on its better benefits and its lesser energy content per gallon. Because the decision to pay a premium for biofuels depends on current market fuel prices, a reference price of gasoline was provided to facilitate the respondent's decision. For AR, FL, and VA the average gasoline prices were \$3.13 gallon^{-1}, \$3.07 gallon^{-1} and \$3.69 gallon^{-1}, respectively (http://e85prices.com/archive.php).

The three attributes and their respective levels provided 36 possible combinations (3^2 x 4^1) for Plan A, achieving a 100% A efficiency. Because it is practically unfeasible for an individual to answer 36 different CV questions, the orthogonal full factorial experiment design followed in this experiment was blocked into six different questionnaire versions, each having six pair wise alternative plans. The SAS 9.1 %MKTRuns and %MktEx macros were used to determine the number of alternative plan sets and the linear design (Kuhfeld, 2005). This was in accordance with previous CV studies, which have considered the number of alternative plan sets to range between 4 and 12 (Carlsson et al., 2003; Shresta and Alavalapati, 2004; Mogas et al., 2006) without violating the assumption of stability of preferences (Hanemann, 1984).

Each respondent answered six sets of questions, each consisting of two plans, Plan A and Plan B, representing six different observations. Table 3-2 presents an example of the alternative plan situation. The valuation question in this particular example is: "Are you willing to pay an extra \$0.60 per gallon at the pump for reducing the CO_2 emissions between 61-70% (medium reduction) and improving the biodiversity between 1-25% (low improvement) (Plan A) or not to pay a premium at all without having any changes in CO_2 emissions and biodiversity improvement (Plan B)?". The other questions dealt with socioeconomic variables, described in Table 3-3. An example of the survey is included in Appendix B.

Econometric Model

We applied a probit model to the CV. The theoretical framework to analyze the CV method is the random utility model developed by McFadden (1974). Under this framework, the indirect utility of an individual results from the sum of a deterministic part and a stochastic element. Formally:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{3-1}$$

Where U_{ij} is the utility for each respondent *i* to choose among different *j* alternatives, V_{ij} is the deterministic part of the utility, and ε_{ij} reflects the uncertainty or unobservable influences on respondent choice. In the case of CV studies, alternatives are reduced to two; therefore, the individual has the option to choose alternative *j*, which reflects an improved state, over alternative *k* (status quo) if the utility associated with alternative *j* exceeds the utility of alternative *k*. Because a random component is involved, only probability statements about either option can be made. Thus, the probability that individual *i* will choose alternative *j* over *k* can be formally expressed as:

$$P_{ij} = P\left(V_{ij} + \varepsilon_{ij}\right) > P\left(V_{jk} + \varepsilon_{ik}\right), j \neq k \tag{3-2}$$

By using this framework, Hanemann (1984) conceptualized dichotomous CV responses and designed a framework to obtain welfare estimates. Following Haab and McConnell hereafter

(2002), and assuming a linear utility function in income and covariates, the deterministic part of the indirect utility function for an individual *i* can be written as:

$$V_{ij}(y_i) = \alpha_j z_i + \beta_j y_i \tag{3-3}$$

Where y_i is the income of individual *i* and z_i is the matrix of attributes and socioeconomic characteristics of individual i, and α_j and β_j are the multidimensional vector and the marginal utility of income of alternative *j*, respectively. The dichotomous question requires each individual to choose between alternative *j* paying an amount t_j and the status quo. Thus, the deterministic parts of a utility function for alternatives *j* and *k* are:

$$V_{ij}(y_i - t_j) = \alpha_j z_i + \beta_j (y_i - t_j) \tag{3-4}$$

$$V_{ik}(y_i) = \alpha_k z_i + \beta_k (y_i) \tag{3-5}$$

Replacing Equations 3-4 and 3-5 into Equation 3-2 and rearranging, we obtain the following expressions:

$$P(yes_i) = P\big(\alpha_j z_i + \beta_j (y_i - t_j) + \varepsilon_{ij}\big) > P(\alpha_k z_i + \beta_k (y_i) + \varepsilon_{ik}) \tag{3-6}$$

$$P(yes_i) = P\big(\alpha_k - \alpha_j) z_i + \beta_j (y_i - t_j) - \beta_k (y_i) + \varepsilon_{ij} - \varepsilon_{jk}\big) > 0 \tag{3-7}$$

Assuming that the marginal utility of income is constant and denoting $\propto = \alpha_k - \alpha_j$ and $\varepsilon_i = \varepsilon_{ij} - \varepsilon_{ik}$ the probability of a yes response is:

$$P(yes_i) = P\left(\alpha z_i + \beta t_j + \varepsilon_i\right) > 0 \tag{3-8}$$

We assumed that $\varepsilon_i \sim N(0, \sigma^2)$ and by converting the errors to a standard normal, we obtained the probit model:

$$P(yes_i) = \varphi\left({}^{\alpha z_i}/_{\sigma} - {}^{\beta t_j}/_{\sigma}\right) \tag{3-9}$$

Estimates for the parameters ${}^{\propto}/_{\sigma}$, ${}^{\beta}/_{\sigma}$ are obtained by maximizing the likelihood function. In the case of a probit model, the log likelihood function takes the following form:

$$\operatorname{Ln} L\left(\frac{\propto}{\sigma}, \frac{\beta}{\sigma} | y, z_i, t_j\right) = \sum_{i=1}^{T} I_i \, ln\left[\left(\varphi\left({}^{\alpha z_i}/_{\sigma} - {}^{\beta t_j}/_{\sigma}\right)\right)\right] + (1 - I_i) ln\left[1 - \varphi\left({}^{\alpha z_i}/_{\sigma} - {}^{\beta t_j}/_{\sigma}\right)\right] \tag{3-10}$$

Where T is the sample size and I_i= 1 if individual *i* answers yes.

Welfare Estimates

Two measures of central tendency were developed by Hanemann (1984), the expected willingness to pay (E[WTP]) and the median willingness to pay (Md[WTP]), which are equal under the assumption of a linear utility function. Thus,

$$E(WTP) = Md(WTP) = {}^{\propto\,\bar{z}}/_{\beta} \tag{3-11}$$

Where $\bar{z}$ is the mean of attributes and socioeconomic characteristics.

Results and Discussion

The online questionnaire was administered during March and April 2008. A total of 408 questionnaires were completely answered (65% response rate), 201 questionnaires regarding *E10* (56 in AR, 76 in FL, and 69 in VA) and 207 questionnaires about *E85* (53 in AR, 79 in FL, and 74 in VA). We used STATA 9.0 to estimate the probit models for *E10* and *E85*. Tables 3-4 and 3-5 present the descriptive statistics for the socioeconomic variables of the *E10* and *E85* samples, respectively. Generally, respondents were not part of any environmental organization. In addition, most of them had achieved one of the two highest levels of education and owned an automobile. Further, respondents belonged mainly to the middle income category, with the exception of *E10* respondents in VA. Non automobile owners, even though they were few in number, were included in the survey because they might also be interested in purchasing biofuels. However, the findings showed that preferences of automobile owners and non automobile owners were dissimilar. The percentages of non automobile owners who chose to use *E10* were 100% in AR, 50% in FL, and 64% in VA. These percentages were lower for *E85* in the cases of AR and FL (17% and 25%, respectively), while in VA 100% of non automobile owners chose to use biofuels.

Consistent with expectations, the sample showed that respondents were less likely to accept the premium when the bid was increased (Figures 3-1 and 3-2). Regardless of the premium level, the average relative decrease for a yes response was around 10% in each state for *E10*. In the case of E85, the average relative decrease amounted to 15.1%, 9%, and 8.6% for AR, FL, and VA, respectively. The majority of the respondents were willing to pay a premium for both blends in FL and for only *E85* in AR. In VA, the majority of the respondents tended not to be willing to pay a premium for either *E10* or *E85*.

Attributes

Tables 3-7 and 3-8 show the coefficients, *p* values, and standard deviations of the probit model in AR, FL, and VA for *E10* and *E85*, respectively. The log likelihood ratios ($p < 0.001$) suggested that the overall models for both blends were statistically significant in all three states. STATA routines dropped variables that perfectly predicted success or failure in the dependent variable. For *E10*, all respondents owned a car in AR; thus, this dummy variable only took the value of 1, showing no variation across the sample. In the case of educational variables, *Less high* was not included in the model to avoid the dummy variable trap. However, this variable only took the value of 0 in AR, as all respondents had some high school level. Thus, *College* was dropped to avoid collinearity. For *E85 Member* in AR and *Ownership* in VA were dropped. Almost none of the respondents were members of an environmental organization, and almost all owned an automobile.

Regarding *E10*, the coefficient of the attribute “Percentage reduction of CO_2 emissions” (*Reco2*) — statistically significant only in FL and VA — was positive in all three states. Likewise, “Percentage improvement of Biodiversity” (*Biomp*) — not statistically significant in any of the states — was positive in AR and FL. This indicates that the probability of paying a premium increased as the reduction of CO_2 increased and biodiversity conditions improved. Along with improvements in environmental conditions at higher rates, respondents from AR and VA were less likely to use *E85*. The variable *Reco2,* which was significant only in AR, had negative coefficients in AR and VA, while the variable *Biomp* had negative coefficients in all three states. Interestingly, *Biomp* was not significant in any of the states.

Except for the variable *Reco2* in VA, the results for *E85* fuel were consistent with the probabilities of the model for the environmental attributes (Table 3-6). The probability of paying a premium for *E10* increased in all three states as either the reduction of CO_2 increased or biodiversity improved. These results were consistent with previous studies (Roe and et al., 2001; Bergmann et al., 2004) which found that when environmental quality improved, the utility of respondents increased, and therefore they were willing to pay more for green electricity. However, the same trend was not observed in the *E85* scenario, as respondents did not intend to pay a premium for reducing CO_2 in AR or improving biodiversity in all states at higher rates.

Consistent with economic theory under the assumption of a negative price elasticity of demand, the utility of individuals decreased as the premium increased for either blend. Further, this attribute was statistically significant in all three states.

Socioeconomic Variables

Neither the condition of being a "Member of an environmental organization" (*Member*) nor having "Knowledge of other natural resources based energy" (*Knowledge*) was statistically significant in any of the states for *E10*. For *E85,* while Member was not significant in FL or VA, *Knowledge* was significant only in VA. Further, the likelihood of switching to biofuels would increase if respondents were members of an environmental organization in AR and VA for *E10* and in VA for *E85*. Similar behavior was observed for *E85* respondents in AR if they were aware of other options for green energy. In the case of the variable “Ownership of an automobile” (*Ownership*), this probability increased only for *E85* and was significant in AR and FL.

The variable “Distance driven weekly*”* (*Miles week*) was found to be significant when deciding whether to switch to biofuels. For *E10,* the probability of switching to biofuels increased in FL and decreased in VA. However, the results showed that *Miles week* was not significant in any of the states for *E85*.

Educational background showed different trends in the three states. The variable “Respondent with exclusively high school level” (*High*) was statistically significant and positive, and “Respondent with exclusively bachelor degree or higher” (*Bachelor*) was not statistically significant for *E10* in AR. In the same state, the likelihood of choosing *E85* increased for individuals who had higher education levels compared to individuals with less than a high school education. The same situation was observed in FL for *E10*. In VA, no education variables were statistically significant for this blend. Individuals with some high school or with bachelor’s degrees were not likely to pay a premium, but individuals with some college education would tend to use the *E10* blend. Individuals with high school in FL and some college education in VA showed no intention of using *E85*.

Income was another variable that showed heterogeneity in individuals’ perceptions about biofuels. In AR, only “Households with high income” (*Hincome*) was statistically significant for both biofuels. Contrary to expectations, the probability of paying a premium decreased as an individual had greater earnings. Although this is inconsistent with economic theory, respondents from Arkansas might have considered exogenous factors such as the unfavorable economic situation prevailing in the country during the time the survey was conducted.

In FL, the variables “Households with middle income” (*Mincome*) and *Hincome* were statistically significant as compared to the lowest income level for *E10*. Although this situation was not observed for *E85*, the utility of choosing any of the biofuel blends increased when individuals came from middle income and high income households. In VA, neither income category provided statistically significant results for *E10*. However, for *E85*, the middle income category showed significant differences compared to low income individuals.

Age was significant only in AR for *E10* and *E85*. Further, as AR respondents aged they would only be likely to choose *E10*. On the other hand, *Gender* was statistically significant in all three states for *E10*, and in FL and in VA for *E85*. The probability that females would choose either blend was lower compared to males in FL. The variable “Respondent was working” (*Work*) was not significant in any of the states for *E10* and significant only in AR for *E85*. It was also found that individuals would continue using cheaper fuel if they were unemployed in AR for *E10* and FL and VA for *E85*.

The “Size of the household” (*Size*) was statistically significant in AR and VA for *E10*. Consistent with expectations, as the number of people in the household increased, individuals were less likely to use biofuel blends. For *E85*, *Size* was statistically significant only in AR, where the results showed that an increase in number of people in the household would decrease the utility of individuals. The respondent status of being the “Head of the household” (*Head*) was significant in FL for *E10* and AR and FL for *E85*. Respondents were not likely to choose *E85* in AR and FL or *E10* in VA. Finally, the effect of unobservable influences was statistically significant in all three states for *E10* and in VA and AR for *E85*. Further, respondents had a natural tendency not to pay a premium for *E85* in AR and in FL for *E10*.

Willingness to Pay

The extra WTP estimates are shown in Table 3-9. The greatest WTP for E10 was in FL (\$0.58 gallon^{-1}), followed closely by AR. VA was the state with the lowest WTP (\$0.50 gallon^{-1}). Similar findings were obtained by Bhattacharjee et al. (2008), who calculated a mean WTP of \$0.49 gallon^{-1} for *E10* in a U.S. nationwide study. The WTP for *E85* was greater than the WTP for *E10*. The increase in the WTP for *E85* accounted for 1.46, 2.00 and 2.1 times the WTP for *E10* in AR, FL and VA, respectively. Three multiple comparison tests (Bonferroni, Scheffe and Sidak tests) were performed to detect differences in WTP among the three states for both blends. For *E10* there were no significant differences in WTP among the three states. For *E85* there were significant differences in the WTP between AR and FL and between AR and VA. However, there were no significant differences in the WTP between FL and VA.

The average prices of *E85* when the questionnaire was administered were \$2.52 gallon^{-1}, \$3.00 gallon^{-1}, and \$3.07 gallon^{-1} in AR, FL, and VA, respectively (www.e85prices.com). As noted earlier, average gasoline prices were \$3.13 gallon^{-1}, \$3.21 gallon^{-1}, and \$3.69 gallon^{-1} for the same states. Thus, the ratios of WTP to actual *E85* price were 1.57, 1.46, and 1.54 in AR, FL, and VA, respectively, averaging 1.52. On the other hand, assuming the current price of gasoline as a proxy for *E10*, the ratios were much lower: 1.18, 1.18, and 1.13 in AR, FL, and VA, respectively, averaging 1.16. The ratios for both blends might be higher in the future, as market prices for gasoline and *E85* are expected to increase. Gasoline is predicted to have an annual increase of 1.4% reaching \$4 gallon^{-1} (2007 dollars) in 2030, while the annual price increase of *E85* will be 0.5% over the same period, reaching less than \$3 gallon^{-1} (EIA, 2008a).

It was interesting to note that respondents were willing to pay more for biofuels once the proposed change offered better conditions for the environment. In VA, the respondents might have considered that the change in environmental conditions would not compensate for the premium to be paid for *E10*; thus, the state had the lowest WTP. The opposite happened for *E85*, for which VA's respondents stated the second greatest WTP (\$1.06 gallon^{-1}). Although the percentages of rejection of the premiums were almost the same for both blends in VA (Figs. 1 and 2), the percentages of rejection of the higher premiums were greater. For example, the rejection percentages for premiums of \$0.75 gallon^{-1} and \$1 gallon^{-1} were 65% and 67%, respectively, for *E10*, whereas in the case of *E85*, the rejection percentages for premiums of \$1 gallon^{-1} and \$1.5 gallon^{-1} were 55% and 62%, respectively. Further, the ratios of no versus yes responses for the premiums described were 1.86 and 2.03 for *E10* and 1.22 and 1.63 for *E85*.

The extra WTP for ethanol was converted into total future expenditures per year (TE_e). Following Solomon and Johnson (2009), the total expenditures were calculated by multiplying the total WTP by the quantity of gallons of ethanol (Q_e) consumed as a proportion of total fuel consumption in the next period compared to the previous one. This proportion is given by the price elasticity of the demand for biofuels (Ed_e) obtained in the model. The average per capita motor gasoline expenditures in 2006 (EIA 2008b) were used to calculate the quantity of gallons of ethanol. The real motor gasoline expenditures (2007= 100) accounted for \$1295, \$1200, and \$1373 per capita in AR, FL, and VA, respectively. The total WTP is separated into an average price of gasoline (P_g) previously described in this section and the mean WTP for ethanol in each state (WTP_e). Formally:

$$TE_e = (P_g + WTP_e)Q_e * Ed_e \tag{3-12}$$

Equation 3-12 was applied for *E10* and *E85* in each state. The mean total expenditures for *E10* were \$585.20, \$485.90, and \$596.20 per capita year^{-1} in AR, FL, and VA, respectively. For *E85* the total expenditures were \$919.60, \$330.80, and \$532.60 per capita year^{-1} in the same states. With the exception of *E85* in AR, the results were somewhat similar to those found by Solomon and Johnson (2009). They reported a mean total future expenditure of WTP of $556 per capita $year^{-1}$ in Michigan, Minnesota, and Wisconsin. The ratios of total expenditures of *E85* to *E10* were 1.57, 0.68, and 0.93 in AR, FL, and VA, respectively. The price elasticity of the demand was relatively inelastic ($-1 < Ed_e < 0$) for both blends in the three states. The values for Ed_e for *E10* were -0.38, -0.34, and -0.38 in AR, FL, and VA, respectively, while those for *E85* were -0.56, -0.2, and -0.31. In general, the Ed_e for *E85* was less elastic compared to the Ed_e for *E10*, with the exception of AR, where the total expenditures for Arkansans were higher.

Conclusions

This chapter reported the findings of a contingent valuation experiment designed to elicit WTP for *E10* and *E85* and assess public preferences for these biofuels in AR, FL, and VA. The results indicated that individuals had a positive WTP for both blends and a greater WTP for biofuels that led to environmental improvements. No significant differences were found in the WTP among the three states for *E10*. For *E85*, significant differences were found in WTP between AR and FL and between AR and VA. The WTP ratios of *E85* to *E10* were 1.46, 2.00, and 2.12 for AR, FL, and VA, respectively. Thus, southern U.S. consumers value the environmental benefits obtained from a modified transportation fuel. When the WTP was converted into future total expenditures, the ratios of total expenditures of *E85* to *E10* were 1.57, 0.68, and 0.93 in AR, FL, and VA, respectively. With the exception of AR, the total future expenditures were slated to be higher for *E10* because of a more elastic price elasticity of the demand.

The results also showed heterogeneous preferences for environmental attributes. Respondents' views suggested that they were willing to pay a premium for *E10* in order to achieve CO_2 reduction in all three states and biodiversity improvement in AR and FL. However, in all three states, respondents stated the opposite for biodiversity conditions for *E85*. This heterogeneity was also observed in some socioeconomic variables. For example, individuals with higher levels of education would only change to *E10* in FL and *E85* in AR. The high oil prices at the time of the survey and the higher premium proposed for *E85* might explain why individuals from middle and high income households in AR and VA were reluctant to pay more for that biofuel.

We assumed that the attributes and the socioeconomic variables of this discrete choice model were exogenous. It might be argued that the distance driven per week is correlated with the error term (endogenously determined). If endogeneity arises for this particular case, the estimated coefficient of weekly mileage will be upwardly or downwardly biased depending on the direction of the correlation with the error terms. Potential solutions to correct for endogeneity are the use of instrumental variables or the determination of the endogenous variable by equilibrium model (Besanko et al., 1998). Correction for endogeneity bias was beyond the purview of this research.

Understanding present and future individual preferences for bioenergy is an important tool for policymakers. This positive elicited WTP might support the initiation of a consistency policy instrument such as the Renewable Fuel Standards (RFS), aiming to produce 7.5 billion gallons of renewable fuels by 2012. However, it also underscores the need for continuous reinforcement of benefits from federal or state governments for consumers of green energy. Although the findings suggested that individuals were willing to pay a premium for biofuels, periodic revisions of these studies are certainly important to formulate policies based on changing public perceptions and preferences. Further, different approaches might be used to allow welfare measures to be to be adjusted for different policy contexts. For instance, the use of meta analysis is particularly interesting to validate and explore the systematic and identifiable variation of WTP in order to determine its appropriateness for benefit transfer. Another situation considered for this study was that we assumed that people were homogeneous within each state. However, people's choices might be influenced by different geographical locations and other people's preferences. Thus, a more specific level of aggregation or an incorporation of spatial variation could be a plausible extension of this study.

Table 3-1. Description of the attributes and levels

Attribute	Description	Level	
		E10	*E85*
Reco2	Percentage reduction of CO_2 emissions (per mile traveled)	1-3 % (low) 4-7% (medium) 8-10% (high)	1-60% (low) 61-70% (medium) 71-90% (high)
Biomp	Percentage improvement of biodiversity by reducing wildfire risk & improving forest health	1-20% (low) 21-40% (medium) 41-60% (high)	1-25% (low) 26-50% (medium) 51-75% (high)
Prem	Increase of the price of fuel at the pump per gallon	\$0.2, \$0.5, \$0.75, \$1	\$0.3, \$0.6, \$1, \$1.5

Table 3-2. Description of the choice situation

Please choose	Plan A	Plan B
Reco2	Reduction of CO_2 between 61-70% per mile traveled	No reduction (0%)
Biomp	Improvement of biodiversity between 1-25%	No improvement (0%)
Prem	Additional payment of $0.60 per gallon at the pump	No extra payment ($0)

Table 3-3. Socioeconomic variables

Variable	Description
Member	Membership in an environmental organization: 1 if respondent is a member and 0 otherwise
Knowledge	Knowledge of other natural resources based energy: 1 if respondent knows and 0 otherwise
Ownership	Ownership of an automobile: 1 if respondent owns and 0 otherwise
Age	Years
Miles week	Distance driven weekly (miles)
Education	*Less high*: 1 if respondent has exclusively less than high school level and 0 otherwise
	High: 1 if respondent has exclusively high school level and 0 otherwise
	Some college: 1 if respondent has exclusively some college level and 0 otherwise
	Bachelor: 1 if respondent has exclusively bachelor degree or higher level and 0 otherwise
Income	*Lincome*: 1 if household Annual Income is less than $24,9999 and 0 otherwise
	Mincome: 1 if household Annual Income is between $25,000 - $74,999 and 0 otherwise
	Hincome: 1 if Household Annual Income is greater than $75,000 and 0 otherwise
Size	Number of people in the household
Work	1 if respondent is working and 0 otherwise
Gender	1 if respondent is male and 0 otherwise
Head	1 if respondent is the household head and 0 otherwise

Table 3-4. Descriptive statistics for socioeconomic variables, *E10*

Variable	AR				FL				VA			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Member	0.05	0.23	0	1	0.11	0.31	0	1	0.12	0.32	0	1
Knowledge	0.46	0.50	0	1	0.54	0.50	0	1	0.49	0.50	0	1
Ownership	0.98	0.13	0	1	0.89	0.31	0	1	0.90	0.30	0	1
Miles Week	169.3	142.7	0	750	121	102.4	0	420	168.4	179.7	0	1100
Age	51.9	12.8	22	76	52.3	17	18	81	46.7	15.4	20	89
Less high	0	0	0	1	0.08	0.27	0	1	0.06	0.23	0	1
High	0.21	0.41	0	1	0.26	0.44	0	1	0.30	0.46	0	1
College	0.34	0.47	0	1	0.34	0.47	0	1	0.32	0.47	0	1
Bachelor	0.45	0.50	0	1	0.32	0.47	0	1	0.32	0.47	0	1
Gender	0.41	0.49	0	1	0.45	0.50	0	1	0.46	0.50	0	1
Head	0.93	0.26	0	1	0.92	0.27	0	1	0.87	0.34	0	1
Lincome	0.14	0.35	0	1	0.21	0.41	0	1	0.17	0.38	0	1
Mincome	0.63	0.48	0	1	0.51	0.50	0	1	0.35	0.48	0	1
Hincome	0.23	0.42	0	1	0.28	0.45	0	1	0.48	0.50	0	1
Size	2.39	1.31	1	6	2.30	1.40	1	9	2.65	1.26	1	6
Work	0.64	0.48	0	1	0.43	0.50	0	1	0.67	0.47	0	1
Number of observations	330				456				414			

Table 3-5. Descriptive statistics for socioeconomic variables, *E85* sample

Variable	AR				FL				VA			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Member	0.04	0.19	0	1	0.06	0.24	0	1	0.07	0.25	0	1
Knowledge	0.43	0.50	0	1	0.43	0.50	0	1	0.39	0.49	0	1
Ownership	0.96	0.19	0	1	0.92	0.27	0	1	0.99	0.12	0	1
Miles week	128.8	127.3	0	580	132.3	126.4	0	500	158.5	146.4	0	750
Age	53.1	14.6	21	87	51.1	18.9	19	89	45.4	15.1	18	81
Less high	0.02	0.14	0	1	0.10	0.30	0	1	0.07	0.25	0	1
High	0.13	0.34	0	1	0.24	0.43	0	1	0.31	0.46	0	1
College	0.42	0.49	0	1	0.37	0.48	0	1	0.26	0.44	0	1
Bachelor	0.43	0.50	0	1	0.29	0.45	0	1	0.36	0.48	0	1
Gender	0.36	0.48	0	1	0.82	0.38	0	1	0.45	0.50	0	1
Head	0.94	0.23	0	1	0.47	0.50	0	1	0.92	0.27	0	1
Lincome	0.21	0.41	0	1	0.27	0.44	0	1	0.12	0.33	0	1
Mincome	0.53	0.50	0	1	0.43	0.50	0	1	0.53	0.50	0	1
Hincome	0.26	0.44	0	1	0.30	0.46	0	1	0.35	0.48	0	1
Size	2.30	1.19	1	5	2.30	1.37	1	6	2.43	1.30	1	7
Work	0.53	0.50	0	1	0.55	0.50	0	1	0.68	0.47	0	1
Number of observations	306				474				444			

Table 3-6. Probabilities of using biofuels for level of environmental attributes

Attribute		*E10*				*E85*		
	Level	AR	FL	VA	Level	AR	FL	VA
Reco2	1-3%	0.476	0.382	0.367	1-60%	0.667	0.534	0.573
	4-7%	0.491	0.484	0.468	61-70%	0.520	0.563	0.577
	8-10%	0.506	0.588	0.573	71-90%	0.370	0.592	0.580
Biomp	1-20%	0.429	0.481	0.453	1-25%	0.530	0.585	0.583
	21-40%	0.490	0.489	0.449	26-50%	0.520	0.564	0.577
	41-60%	0.551	0.497	0.445	51-75%	0.510	0.543	0.570

Table 3-7. Probit model results for *E10* sample

Variable	AR		FL		VA	
	Coefficients	Std	Coefficients	Std	Coefficients	Std
Reco2	0.020	0.102	$0.261^{*,**,***}$	0.092	$0.262^{*,**,***}$	0.095
Biomp	0.159	0.107	0.020	0.093	-0.009	0.01
Prem	$-0.973^{*,**,***}$	0.322	$-0.883^{*,**,***}$	0.267	$-0.962^{*,**,***}$	0.310
Member	0.465	0.430	-0.180	0.266	0.409	0.277
Knowledge	-0.238	0.211	-0.191	0.142	-0.223	0.179
Ownership	n.a	n.a	$-1.146^{*,**,***}$	0.315	-0.320	0.305
Miles week	-0.0002	0.001	$0.002^{*,**,***}$	0.001	$-0.002^{*,**,***}$	0.000
Age	$-0.017^{**,***}$	0.009	0.000	0.006	0.010	0.007
High	$0.718^{*,**,***}$	0.239	$1.267^{*,**,***}$	0.445	-0.341	0.315
College	n.a	n.a	$1.705^{*,**,***}$	0.391	0.570	0.377
Bachelor	-0.050	0.269	$2.095^{*,**,***}$	0.427	-0.134	0.396
Gender	$0.528^{*,**}$	0.207	$-0.572^{*,**,***}$	0.151	-0.355^{*}	0.210
Head	0.302	0.351	$1.767^{*,**,***}$	0.344	-0.423	0.267
Mincome	-0.093	0.278	0.409^{*}	0.230	-0.214	0.241
Hincome	$-0.763^{*,**}$	0.368	$0.660^{*,**,***}$	0.239	0.188	0.282
Size	$-0.205^{*,**}$	0.083	0.118	0.074	$-0.236^{*,**,***}$	0.074
Work	-0.140	0.209	0.001	0.189	0.029	0.252
Intercept	1.393^{*}	0.829	$-2.848^{*,**,***}$	0.774	1.352^{*}	0.775
Number of observations	330		456		414	
Log likelihood	-186.7		-227.3		-237.84	
Log likelihood ratio	67.34		129.9		86.47	
p value	0.00		0.00		0.00	
Pseudo R^2	0.178		0.278		0.172	

Notes**:** ***** Significant at $p < 0.1$; ****** Significant at $p < 0.05$; ******* Significant at $p < 0.01$.

Table 3-8. Probit model results for *E85* sample

Variable	AR		FL		VA	
	Coefficients	Std	Coefficients	Std	Coefficients	Std
Reco2	-0.441*,**,***	0.156	0.073	0.087	-0.005	0.082
Biomp	-0.017	0.161	-0.053	0.090	-0.012	0.082
Prem	-1.431*,**,***	0.227	-0.508*,**,***	0.163	-0.803*,**,***	0.153
Member	n.a	n.a	-0.521	0.335	0.293	0.295
Knowledge	0.310	0.194	-0.004	0.170	-0.316*	0.167
Ownership	2.936*,**,***	0.738	1.532*,**,***	0.309	n.a	n.a
Miles week	-4.14E-06	0.0008	0.0003	0.0006	-3.2E-05	0.0005
Age	0.055*,**,***	0.010	0.007	0.005	-0.006	0.006
High	3.281*,**,***	0.636	-0.037	0.287173	-0.181	0.289
College	1.614*,**,***	0.493	0.179	0.289	-0.056	0.290
Bachelor	1.870*,**,***	0.516	0.404	0.285	0.0148	0.304
Gender	0.320	0.213	-0.465*,**,***	0.155	0.287*,**	0.143
Head	-1.501*,**,***	0.414	-0.733*,**,***	0.206	0.400	0.315
Mincome	-0.187	0.309	0.258	0.193	-0.463*	0.245
Hincome	-0.702*	0.386	0.266	0.211	-0.285	0.252
Size	0.349*,**,***	0.099	-0.081	0.059	0.073	0.058
Work	0.569*,**	0.257	-0.139	0.167	-0.07	0.190
Intercept	-5.234*,**,***	1.141	-0.559	0.540	1.055*,**	0.512
Number of observations	306		474		438	
Log likelihood	-144.1		-275.8		-272.8	
Log likelihood ratio	114.4		88.8		43.36	
p value	0.00		0.00		0.00	
Pseudo R^2	0.316		0.16		0.09	

Notes: ***** Significant at $p < 0.1$; ****** Significant at $p < 0.05$; ******* Significant at $p < 0.01$.

Table 3-9. WTP ($ gallon^{-1}) for biofuels at state level

Blend	AR	FL	VA
E10	0.56	0.58	0.50
E85	0.82	1.17	1.06

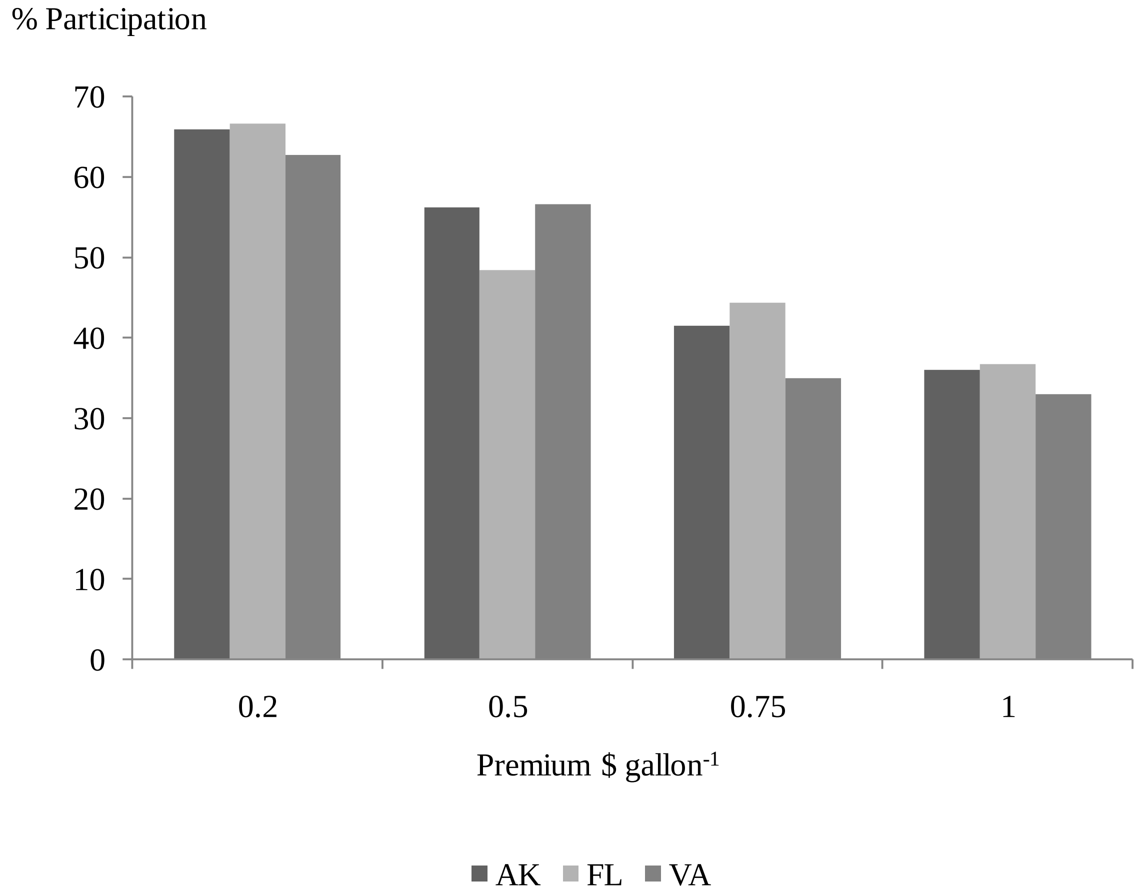

Figure 3-1. Percentage of yes responses for *E10*

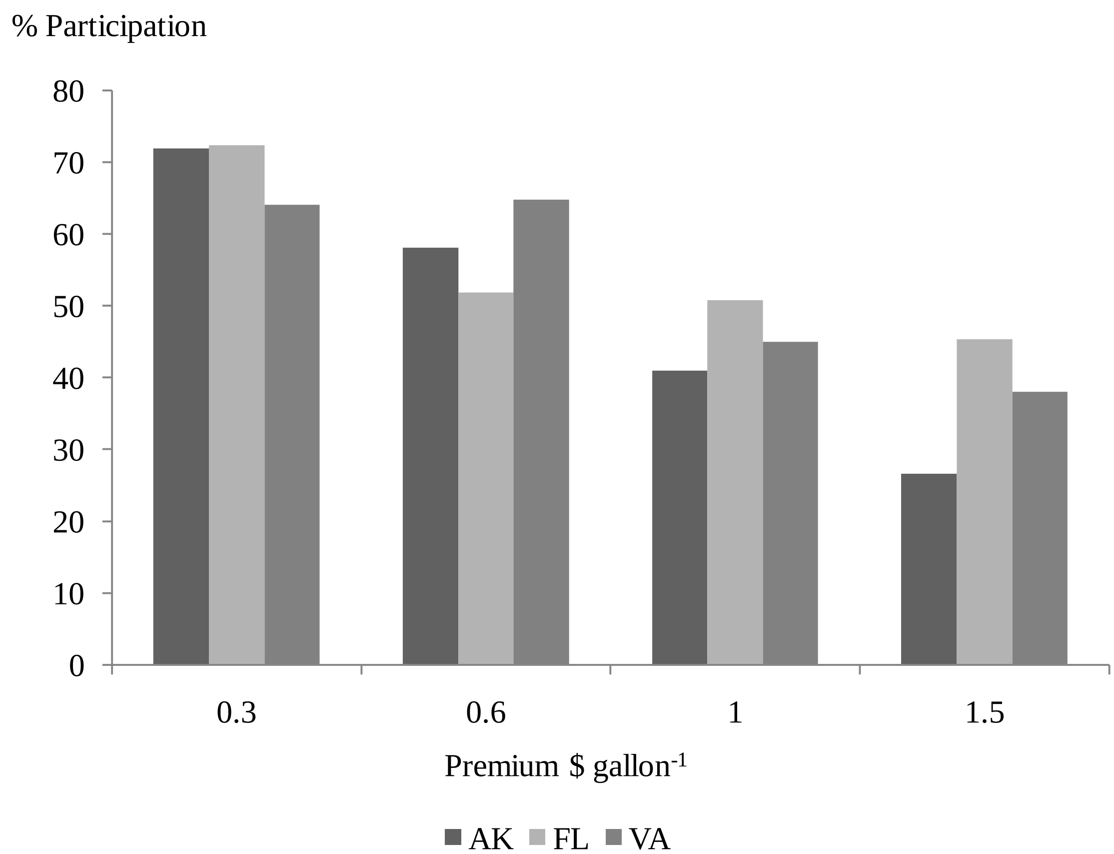

Figure 3-2. Percentage of yes responses for *E85*

CHAPTER 4
MODELING EFFECTS OF BIOENERGY MARKETS ON TRADITIONAL FOREST PRODUCT SECTORS

Introduction

Southern U.S. forests, comprising 27% of the total forestland nationwide and being about 86% privately owned (Smith et al., 2009), can potentially account for a large portion of the annual national estimate of 348 million dry tons of woody materials that can be diverted from the U.S. forests for bioenergy purposes (Perlack et al., 2005). However, agricultural or even forest bioenergy markets might adversely impact traditional forest industry. Bioenergy production might lead to land use competition between food based biofuels and forestry (Aulisi et al., 2007).

Conversion of forestlands to agricultural lands would be likely if energy policies favor food based biofuels (Malmsheimer et al., 2008). Converting forestlands and using them to produce food crop based biofuels releases more carbon dioxide into the atmosphere as compared to the greenhouse gas reduction provided by using these biofuels for energy production (Fargione et al., 2008; Searchinger et al., 2008). Degraded lands can be considered for bioenergy plantations— trees or other energy crops— to reduce erosion, restore ecosystems, and provide shelter to communities (Riso, 2003), but these benefits would only be realized under clear land use regulations, especially in places where forests are at risk of conversion to other land uses (Worldwatch Institute, 2007).

On the other hand, diverting wood for bioenergy production would increase competition among wood users (FAO, 2008). Increased demand of wood for energy implies that bioenergy plants would likely face competition with the energy industry for low quality fiber (Hillring, 2006). Aulisi et al. (2007) suggest that the pulp and paper industry and panel industry are more likely to be hurt by the emerging wood based energy industry. This study reports that the panel industry would face more competition because of absence of secondary products (sawdust, slabs, and chips) to be provided to the energy sector. Although chemical pulp mills would also face competition and increased prices for fiber, they might opt for manufacturing high value products and position themselves as integrated forest biorefineries (Aulisi et al., 2007). High value solid wood product markets, on the other hand, are not likely to be affected by new bioenergy markets because they have no competition with woody biomass for energy (Scott and Tiarks, 2007). In fact, sawmills might benefit from bioenergy development due to the higher prices for secondary products such as sawdust and chips demanded by bioenergy markets (Bolskesjo et al., 2006; Aulisi et al., 2007).

Different studies have explored the economic impact of emerging bioenergy markets on the agricultural sectors in the U.S. Generally, these studies point towards an increase in crop and livestock prices, farm income, and employment. Westcott (2007) claimed that corn prices will increase by more than 50 cents a bushel by 2016. Walsh et al. (2003) determined that crop prices and annual farm income will increase by 9% to 14% above a baseline farm gate price of \$2.44 GJ^{-1} and \$6 billion above baseline. Birur et al. (2008) explored the impact of biofuels in world agricultural markets. Their finding revealed increases of 9%, 10%, and 11% in the prices of coarse grains, oilseeds and sugarcane in the U.S., European Union (E.U.), and Brazil, respectively. Although an extensive number of international economic models of forest and agricultural sectors have been developed that can include bioenergy trade assessment, such as the European Forest Institute Global Trade Model (EFI-GTM), Global Forest Products Model (GFPM), Forest and Agriculture Sector Optimization Model (FASOM), and European Non Food and Agriculture (ENFA) (Solberg at al., 2007), to the best of our knowledge, the implications of emerging woody bioenergy markets on the U.S. equilibrium supply and demand for other forest product markets have not been deeply researched. Thus, we define an econometric model that accounts for the participation of forest bioenergy markets along with traditional forest product sectors. Further, we quantify the effects on the traditional forest product sectors by simulating an increase in the demand for forest biomass for bioenergy.

Model and Econometric Specification

The model consists of four sectors, namely forest landowners, sawmills, pulpmills, and the bioenergy sector. The supply side of the model is represented by the forest landowners who require labor and capital to produce sawtimber, pulpwood, and biomass for bioenergy production. The demand side of the model is represented by sawmills, pulpmills, and bioenergy producing firms. Sawmills demand sawtimber, energy, labor, and capital to produce lumber. Pulpmills use pulpwood, energy, labor, and capital to produce pulp. Finally, bioenergy producing firms require biomass, energy, labor, and capital to generate electricity for household use. For simplicity's sake, other intersectoral flows, e.g., trade of waste residues from sawmills to pulpmills or energy from bioenergy firms to either sawmills or pulpmills, are not considered. Furthermore, flows within sectors such as the self supply of energy are ruled out. Other assumptions are: firms maximize their profits and only output and input variables adjust when prices change, i.e., capital remains fixed in the short run.

Given perfect competition in the four sectors, the dual restricted profit function is defined as $\pi(p, w, v)$ where π is the short run profit function, p and w are vectors of output and input prices respectively with $q = (p, w)$ and v is the fixed vector of fixed inputs and outputs. The profit function satisfies the following properties: (i) non negativity; (ii) non increasing in w; (iii) non decreasing in p; (iv) convex and continuous function in (p, w); (v) homogenous of degree 1 in (p, w); and (vi) differentiable in p and w (Chambers, 1988). The last condition (Hotelling's lemma) allows for obtaining functional forms for supply and demand. Thus:

$$\frac{\partial \pi(\mathrm{p,w,v})}{\partial p_i} = Y_i(p, w, v) \quad (4\text{-}1)$$

$$-\frac{\partial \pi(\mathrm{p,w,v})}{\partial w_i} = X_i(p, w, v) \quad (4\text{-}2)$$

Where Y_i and X_i are the supply function and demand function for output and input i, respectively. The conditions for the supply and demand functions are the following: (i) supply is increasing in p; (ii) demand is non increasing in w; (iii) supply and demand are homogenous of degree zero in (p, w); (iv) cross price effects are reciprocal in nature (Chambers, 1988).

Flexible functional forms have been widely adopted for econometric analysis of supply and demand (Christensen et al., 1971; Diewert, 1973). Flexibility refers to a process by which consumer preferences can be represented without imposing prior restrictions at a base point (Caves and Christenhen, 2009). Contrary to traditional forms such as Cobb Douglas and Leontief, in which the elasticities of substitution are 1 and 0, respectively, the elasticity of substitution depends on data and varies across the sample (Chambers, 1988). However, this flexibility has its limitations. Flexible functional forms are well behaved over a limited range of points (Despotakis, 1986). Certain issues such as multicollinearity and lack of requisite degrees of freedom forestall the process of approximating the underlying structural relation due to the limited number of observations in practical applications (Mountain and Hsiao, 1989). Further, these functional forms are not flexible while representing separable technologies (Chambers, 1988). For our study we chose the restricted generalized Leontief profit function (GLPF) widely used in the forest sector (Newman and Wear, 1993; Hardie and Parks, 1996; Brannlund and Kristrom, 1996; Williamson et al., 2004). GLPF has some advantages over other flexible functional forms such as the Translog and the Normalized quadratic. Morrison (1988) claims that due to the nonlinear logarithm form of the Translog it is difficult to obtain numerical convergence for long run elasticities. Further, the use of the Normalized Quadratic functional form implies an arbitrary normalization using a numeraire input price, leading to an asymmetry of demand equations and lack of invariance of empirical results (Morrison, 1988). On the other hand, the primary limitation of GLPF is that it provides a poor regional approximation if the true technology allows easy input substitution or output transformation (Behrman et al., 1992), i.e., GLPF tends to underestimate price and substitution elasticities (Williamson et al., 2004).

Following Diewert (1973), the restricted GLPF must: (i) be linear in parameters; (ii) contain precisely the number of parameters needed to provide a second order approximation to an arbitrary twice differentiable profit function; (iii) have a functional form that satisfies the appropriate regularity conditions over a range of values for the independent variables, given a simple set of inequalities restrictions on the unknown parameters; (iv) be homogenous of degree 1 in v (constant return to scale in all factors). The GLPFs for the forest landowners, sawmills, pulpmills and bioenergy sector are defined as follows:

$$\pi^f\left(w_{sv}, w_{pv}, w_{bv}, w_{fl}, K_f\right) = \sum_i \sum_j \alpha_{ij} w_i^{\frac{1}{2}} w_j^{\frac{1}{2}} + \sum_j \alpha_{kj} w_j K_f \qquad (4\text{-}3)$$

$$i, j = sv, pv, bv, fl$$

$$\pi^s(P_s, w_{sv}, w_{se}, w_{sl}, K_s) = \sum_i \sum_j \beta_{ij} w_i^{\frac{1}{2}} w_j^{\frac{1}{2}} + \sum_j \beta_{kj} w_j K_s \qquad (4\text{-}4)$$

$$i, j = s, sv, se, sl$$

$$\pi^p(P_p, w_{pv}, w_{pe}, w_{pl}, K_p) = \sum_i \sum_j \delta_{ij} w_i^{\frac{1}{2}} w_j^{\frac{1}{2}} + \sum_j \delta_{kj} w_j K_p \qquad (4\text{-}5)$$

$$i, j = p, pv, pe, pl$$

$$\pi^b(P_b, w_{bv}, w_{be}, w_{bl}, K_b) = \sum_i \sum_j \gamma_{ij} w_i^{\frac{1}{2}} w_j^{\frac{1}{2}} + \sum_j \gamma_{kj} w_j K_f \qquad (4\text{-}6)$$

$$i, j = b, bv, be, bl$$

Where π^f, π^s, π^p, π^b are the short run profit functions for the forest landowner sector, sawmill industry, pulpmill industry, and bioenergy sector, respectively; w_{sv}, w_{pv}, w_{bv} are the output prices of sawtimber, pulpwood, and biomass for bioenergy production, respectively, for the forest landowner sector; w_{fl} is the wage rate in forestry and K_f is the forest capital. For the sawmills, P_s is the price of lumber, w_{sv}, w_{se}, w_{sl} denote the input prices of sawtimber, energy and wage rate and K_s is the capital stock. For the pulpmills, P_p is the price of pulp, w_{pv}, w_{pe} and w_{pl} refer to the input prices of pulpwood, energy, and wage rate, respectively, and K_p is the capital stock. For the bioenergy sector, P_b is the price of electricity in the residential sector. The input prices of biomass, energy, and wage rate are denoted by w_{bv}, w_{be}, w_{bl} respectively, and K_b represents the capital stock. Recall that $P_s = w_s$, $P_p = w_p$ and $P_b = w_b$. Symmetry is imposed on the system, i.e., $\alpha_{ij} = \alpha_{ji}$, $\beta_{ij} = \beta_{ji}$, $\delta_{ij} = \delta_{ji}$ and $\gamma_{ij} = \gamma_{ji}$ for all i and j.

Applying Hotelling's lemma to Equation 4-3, we obtain the supply of sawtimber, pulpwood, and biomass for bioenergy, and the demand for labor in forestry. Likewise, applying Hotelling's lemma to Equations 4-3, 4-4, 4-5 and 4-6, we obtain the supply function of lumber, pulp, and electricity, and the demand function for inputs in the sawmill, pulpmill, and bioenergy sector, respectively. In our study we are particularly interested in deriving the forest landowner supply functions and sawmill, pulpmill, and bioenergy sector demand functions for sawtimber, pulpwood, and biomass for bioenergy. Equations 4-7 to 4-12 represent our system of equations to be estimated.

$$Y_{sv} = \sum_i \alpha_{svi} \left(\frac{w_i}{w_{sv}}\right)^{\frac{1}{2}} + \alpha_{svk} K_f \quad i = sv, pv, bv, fl \tag{4-7}$$

$$Y_{pv} = \sum_i \alpha_{pvi} \left(\frac{w_i}{w_{pv}}\right)^{\frac{1}{2}} + \alpha_{pvk} K_f \quad i = sv, pv, bv, fl \tag{4-8}$$

$$Y_{bv} = \sum_i \alpha_{bvi} \left(\frac{w_i}{w_{bv}}\right)^{\frac{1}{2}} + \alpha_{bvk} K_f \quad i = sv, pv, bv, fl \tag{4-9}$$

$$-Y_{sv} = \sum_i \beta_{svi} \left(\frac{w_i}{w_{sv}}\right)^{\frac{1}{2}} + \beta_{svk} K_s \quad i = s, sv, se, sl \tag{4-10}$$

$$-Y_{pv} = \sum_i \delta_{pvi} \left(\frac{w_i}{w_{pv}}\right)^{\frac{1}{2}} + \delta_{pvk} K_p \quad i = p, pv, pe, pl \tag{4-11}$$

$$-Y_{bv} = \sum_i \gamma_{bvi} \left(\frac{w_i}{w_{bv}}\right)^{\frac{1}{2}} + \gamma_{bvk} K_b \quad i = b, bv, be, bl \tag{4-12}$$

Where Y_{sv}, Y_{pv} and Y_{bv} derived from Equations 4-7, 4-8, and 4-9 are the supply of sawtimber, pulpwood, and biomass for bioenergy, respectively. On the other hand, $-Y_{sv}$, $-Y_{pv}$ and $-Y_{bv}$ from Equations 4-10, 4-11, and 4-12 represent the demand for sawtimber, pulpwood, and biomass for bioenergy, respectively. The market equilibrium conditions for sawtimber, pulpwood, and biomass for bioenergy are obtained by equating supply with demand, i.e., $Y_{sv} = -Y_{sv}$, $Y_{pv} = -Y_{pv}$ and $Y_{bv} = -Y_{bv}$. The system of equations so arrived at becomes an econometric model by adding a disturbance term to each supply and demand equation.

A salient feature of this simultaneous equation system is that quantities of sawtimber, pulpwood, and biomass for bioenergy and their respective prices are jointly determined with the input and output factors. The right hand side endogenous variables from Equations 4-7 to 4-12 are correlated with the disturbance terms. The use of traditional ordinary least squares (OLS) in such situations will produce biased and inconsistent estimators (Wooldridge, 2002). Thus, an instrumental variable method is required, where the instruments are the exogenous variables correlated with endogenous variables but not correlated with the disturbance term. The estimation technique proposed is the two stage least squares (2SLS), which provides a consistent estimator and produces the most efficient instrumental variable estimator under the absence of heterokedasticity and autocorrelation (Greene, 2003).

Following Baum (2007), the 2SLS approach can be represented as $Y = X\beta + \varepsilon$ where Y and ε represent $n \; x \; 1$ matrices of the dependent variable and the disturbance term, respectively, and where n is the number of observations. X is the $n \; x \; K$ matrix of independent variables. X can be divided in $[X_1 X_2]$ with K_1 regressors X_1 assumed to be endogenous i.e., $\mathrm{E}[X_i \varepsilon_i] \neq 0$ and $K - K_1$ exogenous regressors. Z exogenous instrumental variables are considered i.e., $\mathrm{E}[Z_i \varepsilon_i] = 0$, forming a matrix $n \; x \; L$. The instruments can also be partitioned into $[Z_1 Z_2]$ where L_1 instruments Z_1 are excluded instruments and $L - L_1$ instruments Z_2 are included instruments. Recall that Z_2 is identical to X_2. Summarizing, we have regressor $X = [X_1 X_2] = [X_1 Z_2]$ =[Endogenous Exogenous] and instruments $Z = [Z_1 Z_2]$ =[Excluded and Included]. The first stage of the 2SLS approach requires regressing X_1 on Z performing OLS. The second stage implies replacing X_1 with their fitted values $\dot{X}_1$ and performing OLS of Y on $\dot{X}_1$. A sufficient condition to solve the structural equations is to meet the rank condition, i.e., the $L\ x\ K_1$ matrix θ_{11} from first stage, X_1 = $[Z_1 Z_2]$ $[\theta'_{11}\ \theta'_{12}]'$ + μ has to have full column rank K_1. If the rank is < K_1 the equation is underidentified. Another condition that is necessary but not sufficient is the order condition for identification. There must be at least as many excluded instruments L_1 as there are endogenous regressors K_1. If $L_1 = K_1$ or $L_1 \geq K_1$, the equation is identified or overidentified, respectively.

We also derive the short run supply and demand elasticities. The own price and cross price elasticities of the system can be determined as:

$$\varepsilon_{ii}{}^{s} = \frac{-\left({}^{1}\!/_{2}\right) \sum_i \alpha_{ij} \left(\frac{w_j}{w_i}\right)^{1/2}}{Y_i} \quad i, j = sv, pv, bv, fl; i \neq j \tag{4-13}$$

$$\varepsilon_{ii}{}^{d} = \frac{-\left({}^{1}\!/_{2}\right) \sum_i [\cdot] \left(\frac{w_j}{w_i}\right)^{\frac{1}{2}}}{X_i} \quad i = sv; j = sl, se, s \tag{4-14}$$

$$i = pv; j = pl, pe, p$$

$$i = bv; j = bl, be, b$$

$$\varepsilon_{ij}{}^{s} = \frac{\left({}^{1}\!/_{2}\right) \alpha_{ij} \left(\frac{w_j}{w_i}\right)^{1/2}}{Y_i} \quad i, j = sv, pv, bv, fl; i \neq j \tag{4-15}$$

$$\varepsilon_{ij}{}^{d} = \frac{(1/2)[\cdot]\left(\frac{w_j}{w_i}\right)^{1/2}}{X_i} \quad i = sv; j = sl, se, s \tag{4-16}$$

$$i = pv; j = pl, pe, p$$

$$i = bv; j = bl, be, b$$

Where $\varepsilon_{ii}{}^{s}$ and $\varepsilon_{ii}{}^{d}$ are the own price elasticities of the supply and demand functions respectively; $\varepsilon_{ij}{}^{s}$ and $\varepsilon_{ij}{}^{d}$ denote the cross price elasticity of the supply and demand; $[\cdot]$ represents the parameters β_{ij}, δ_{ij}, γ_{ij} for $i = sv, pv, bv$, respectively.

Data Construction

This study uses annual input and output prices and capital data for the southern U.S between 1970 and 2006. The data used for this study were primarily derived from official statistical reports of the forest and energy industries. A total of 37 annual sets of observations were obtained. In cases where part of the information was not available for some years, data were generated through a method of linear interpolation between time periods. To facilitate comparison among different year datasets, all prices were deflated to 1997 dollars.

Traditional Forest Product Sector

Annual saw log production information was used for historical quantity of sawtimber. The saw log production information was obtained from *United States Timber Industry – An Assessment of Timber Product and Use, 1996* (Johnson, 2001). This report provided discontinued saw log production data for the following years: 1970, 1976, 1986, 1991 and 1996. Linear interpolation using the rate of growth of historical softwood lumber production as per Howard (2007) was used to arrive at values between those given years to complete the dataset through 2006. Pulpwood production was procured from *Trends in the Southern Pulpwood*

Production, 1953-2006 (Johnson et al., 2008). The roundwood pulpwood production information was used to reflect quantity of annual pulpwood production for our study.

Prices for sawtimber and pulpwood stumpage were procured from *U.S. Timber Production, Trade, Consumption, and Price Statistics 1965-2005* (Howard, 2007). Softwood lumber and Southern Bleached Softwood Kraft (SBSK) pulp were used for the output price data of sawmills and the pulp industry, respectively. Annual data on earnings for logging camps and contractors, lumber and wood products except furniture, and paper and allied products, were used as labor prices for the forest landowner sector, sawmills, and pulp and paper industry, respectively. Output and labor prices for the sawmills and pulp industry were procured from *U.S. Timber Production, Trade, Consumption, and Price Statistics 1965-2005* (Howard, 2007) and Kinnucan and Zhang (2005). Data regarding electricity prices were obtained from the EIA- State Energy Data System database. For the sawmills and pulp industry, the average electricity price in the industrial sector was used as the input price for energy.

Standing inventory information was utilized as a proxy for capital in the forest landowner sector. Inventory data was sourced from the *Forest Resources of the United States 2007* report (Smith et al., 2009) and the *2005 RPA Timber Assessment Update* (Haynes et al., 2007). For the periods in which inventory data were not available, a linear interpolation technique was applied to generate information. Southern sawmill and pulpmill capacities were used as proxies for capital in the sawmill sector and pulp sector, respectively. Two sources were used to construct the time series information for the sawmill capacity. Data from 1995 onwards have been surveyed by Spelter (2007) and published in *Profile 2007: Softwood Sawmills in the United States and Canada Profiles.* Previous years' data (1970-1980) were recreated by accessing available yearly issues of the *Directory of the Forest Products Industry* published by Miller-

Freeman. Data gaps for certain years were filled by linear interpolation. Southern pulpmill capacity information was procured from *Trends in the Southern Pulpwood Production, 1953-2006* (Johnson et al., 2008).

Biomass for Bioenergy

Biomass for bioenergy production information was obtained from *Trends in the Southern Pulpwood Production, 1953-2006* (Johnson et al., 2008). Total Southern pulpwood production was divided into the sum of the production of roundwood pulpwood and wood residues. The former was used for quantifying pulpwood production. The wood residue production information was utilized as a proxy for biomass for bioenergy production, as this production is a relatively recent phenomenon and information regarding it is not available in historical time series dating back to 1970. Pine pulp chip prices at the consuming mills were used as a proxy for biomass for bioenergy prices. These data were obtained from Timber Mart South (TMS). However, TMS only maintained price series from 1976 onwards. For previous time periods, the average growth of the price pulp chip series information was used to extrapolate data back to 1970.

For the bioenergy sector, the output price was represented by the total electricity average price, and the input price was reflected by coal expenditures at the industry level (EIA- State Energy Data System database). The reasoning behind this allocation was that coal production is mainly used up by the electricity sector. 61% of coal production was consumed by the electric power sector in 1970, whereas this increased to 93% in 2008, averaging 83% for this period as a whole (EIA, 2009). Labor price information was procured from the U.S Department of Labor, Bureau of Labor Statistics Current Employment Statistics (CES) program.

Southern installed generating capacity was chosen as a proxy for capital in the bioenergy sector and was taken from the *U.S. Census Bureau Statistical Abstracts of the United States* from

1970 to 2006. Table 4-1 shows the descriptive statistics of the data set. The complete data set can be found in Appendix C.

Results and Discussion

STATA 9.2 software was used to estimate the econometric model. Initially, all the exogenous variables ($w_{.l}$, $w_{.e}$, w_{ss}, w_{pp}, w_{bb}, $K_{.}$) in the SES were employed as instruments for estimation. The Kleibegen-Paap *rk* LM statistic test was performed for each equation to test the rank condition under the null that the equation is underidentified (H_0= K_1-1) and distributed Chi-square with *L*-*K*+1 degrees of freedom. The Chi-square (6) for Y_{sv} and Y_{pv} accounted for 10.62 and 9.86, respectively, failing to reject the null of underidentification at $p = 0.05$ level of significance. However, the Chi-square (6) for Y_{bv} was 13.53, rejecting the null of underidentification at $p = 0.05$ but failing to reject it at $p = 0.01$ level of significance level (Table 4-2).

The redundancy of certain instrumental variables not likely to be correlated with the endogenous variable was also tested. For example, we postulated that wages, input energy price, and capital in the energy sector were not highly correlated with sawtimber and pulpwood prices. Likewise, we assumed that wages, input price of energy, and capital of the sawmill industry had little explanatory power on the biomass for bioenergy price. The redundancy test was performed under the null that *n* times the sum of the square canonical correlations between the potential redundant instrumental variables and the endogenous regressors was zero. It is distributed Chi-square with degrees of freedom equal to the number of endogenous variables times the number of instruments being tested. Thus, the Chi-square (18) for the instruments already mentioned was 14.51, 21.48, and 28.43 for Y_{sv}, $Y_{pv,}$ and Y_{bv}, respectively, failing to reject the null of the instruments being redundant at $p = 0.05$ level of significance (Table 4-2). Thus, a new set of instrumental variables was chosen, eliminating the exogenous variables that proved to be redundant.

Table 4-3 shows the coefficients, robust standard errors, and p values of this new model. Serial correlation was analyzed by the Durbin Watson (DW) statistic. The DW statistic for Y_{sv} and Y_{pv} was inconclusive, whereas it showed no evidence of positive autocorrelation for Y_{bv}. The rank condition was again tested. The Chi-square (3) for Y_{sv}, Y_{pv} and Chi-square (4) for Y_{bv} were 9.91, 8.90 and 8.17, respectively, rejecting the null hypotheses of underidentification at $p = 0.05$ for the first two and rejecting it at $p = 0.1$ level of significance for the third (Table 4-3). Thus, there is strong evidence that the instruments are adequate to identify the equations. As the number of excluded instruments is larger than the endogenous regressors, the Hansen test of overidentifying restrictions was also conducted in order to ascertain the validity of the instruments. Under the null hypotheses, the instruments are deemed to be valid, i.e., independent from the disturbances. The Hansen statistic is distributed Chi-square with *L-K* overidentifying restrictions. The Chi-square (2) for Y_{sv}, Y_{pv} was 13.80, 5.36, respectively. The Chi-square (3) for Y_{bv} was 11.61. We failed to reject the null hypotheses of valid instruments for the endogenous variables related to price of pulpwood at $p = 0.05$. This cast a slight doubt on the orthogonality of the instruments for the endogenous variables of equations Y_{pv} and Y_{bv}.

Symmetry was tested using a Chi-square statistic under the null that cross coefficients are equal. Results showed that the null was rejected at $p = 0.05$ (Table 4-4). An *F*-test was conducted to compare the model with constrained parameters (restricted model) versus the model without imposed symmetry (unrestricted model). The *F* (2, 28) values were extremely low, and we failed to reject the null that both models were identical. Thus, the symmetry imposed model was preferred over the unrestricted model. We also tested the contemporaneous correlation of the residuals, performing a Breusch-Pagan test under the null of independent residuals (Table 4-4). The Chi-square (3) statistic showed that the null was rejected at $p = 0.03$, indicating some evidence of correlation between the disturbances. This might suggest using 3SLS for solving the simultaneous equation system. Under the evidence of contemporaneous correlation of the residuals and overidentification in the system, the three stage least squares (3SLS) approach would result in a more efficient estimator than 2SLS (Wooldridge, 2002). However, 3SLS requires the equations to be correctly specified, and if that cannot be assured, a single equation procedure such as 2SLS is more robust (Wooldridge, 2002). Further, 2SLS performs better than 3SLS in small sample sizes (Heij et al., 2004). Thus, because of the small number of observations (37) and the lack of certainty regarding specification of the model, we preferred a conservative approach of following 2SLS, trading off efficiency for robustness.

Coefficients and Elasticities of the Residues Only Biomass (ROB) Model

Our data construction stated that wood residues are only used as a proxy for reflecting the production of biomass for bioenergy. As the coefficient values of the restricted model (hereafter called *ROB model*) do not provide intuitive interpretations, we have focused on the significance of the parameters. 33% of the parameters were significant at $p = 0.1$ or lower level of significance. Regarding the forest landowner sector, only the parameters representing wages for the supply of sawtimber as well as wages, sawtimber, and pulpwood price were significant at $p = 0.05$. Turning to the sawmill sector, parameters representing energy, wages, and capital were significant at $p =$0.05. Only capital in the pulp industry and output electricity price in the bioenergy sector were significant at $p = 0.1$.

The short run supply and demand elasticities valuated at the mean values and their standard errors are presented in Table 4-5. Practically all the elasticities were significant at $p =$

0.05. As expected, the own price elasticities of the supply of sawtimber and pulpwood are positive. However, the own price elasticity of the supply of biomass for bioenergy is negative, which is not consistent with the economic theory. The price elasticity of the supply of sawtimber proved to be elastic, while the supply of pulpwood and biomass for bioenergy were inelastic, showing less influence of changes in price on supply of the latter two products.

Cross price elasticities of the supply showed dissimilar results. The elasticity of the supply of sawtimber and pulpwood with respect to labor had the expected sign and a great influence on the supply of both products. The cross price elasticity of sawtimber with respect to the price of pulpwood was positive, indicating that sawtimber and pulpwood are complements. Likewise, biomass for bioenergy and pulpwood seemed to be complements. Sawtimber and biomass for bioenergy, on the other hand, proved to be substitute products. Dissimilar results have been found regarding short run elasticities in timber market models. Newman and Wear (1993) and Wear and Newman (1991) claimed negative cross price between pulpwood and sawtimber in the short run. Ankarhem et al. (1999) claimed that pulpwood and biomass for bioenergy are complements in a study about modeling the effects of a rise in the use of forest resources for energy generation in Sweden. In a similar study, Ankarhem (2005) found that sawtimber, pulpwood, and biomass for bioenergy are substitutes for each other.

Turning to the demand elasticities, the own price elasticity of the demand for sawtimber and pulpwood were negative, as expected. The own price elasticity of the demand for biomass for bioenergy was positive, which seems quite implausible. The response of demand to changes in price was elastic in the case of sawtimber and inelastic for pulpwood and biomass for bioenergy. As expected, labor and sawtimber, as well as input energy and biomass for bioenergy, came out as complements. The price of lumber had a positive effect on demand for sawtimber.

Smaller cross price effects occurred in the pulp and bioenergy industry. With the exception of energy in the pulp industry and output electricity price in the bioenergy industry, the demand elasticities were all less than one. This implies that a small percentage in any of the inputs for both industries results in a change less than proportional to the demand for pulpwood and biomass for bioenergy.

The signs of some elasticities are not consistent with economic theory. For example, the positive cross price elasticity of the demand for sawtimber with respect to the price of energy suggested that energy and sawtimber are substitutes in production. Other implausible implications from the cross price elasticities are that energy and pulpwood, labor and pulpwood, and labor and biomass for bioenergy seemed to be substitutes in production. Output prices of pulp and electricity have a negative impact on the demand for pulpwood and biomass for bioenergy, respectively. Thus, the results and implications outlined here should be considered with a degree of caution.

Calibration of the Residues Pulpwood Biomass (RPB) Model

We found that pulpwood and biomass for bioenergy were complements, implying that an increase in price of either pulpwood or biomass for bioenergy would lead to an increase in the supply of both forest products. This degree of complementarity is consistent as per our data construction. Wood residue production— used as a proxy for biomass for bioenergy— is a part of total southern pulpwood production, which has increased along with softwood pulpwood production (Johnson et al., 2008). However, competition for wood with biorefineries and pulpmills could lead to higher prices for forest products. Thus, under the scenario what *would have been if* part of the production of pulpwood was considered for production of biomass for bioenergy, we calibrated a new model called *RPB model*. Additionally, substitutability regarding the effect of labor on the supply of biomass for bioenergy and the price of electricity on the demand for biomass for bioenergy were also imposed.

We artificially modeled an increase in the share of wood residues over pulpwood production over time to reflect competition between these two forest products. We assumed that 1% of the pulpwood production would go for biomass for bioenergy production each year. Consistent with changes in production, it is also expected that pulpwood and biomass for bioenergy prices change over time. Available elasticities provided by the forestry literature were used to account for changes in prices. A short run own price supply elasticity of 0.48 was reported by Newman and Wear (1993) and was used for pulpwood. We also assumed a lower degree of market power for forest biomass for bioenergy. Thus, a supply elasticity of 0.3 found by Galik et al. (2009) for pulpwood was used as a proxy for biomass for bioenergy**.** The cross price elasticity between sawtimber and pulpwood proved to be complements in the *ROB model*. We maintained this assumption, thus, a cross price elasticity of pulpwood with respect to sawtimber of 0.15 (Wear and Newman, 1991) was chosen to calculate the sawtimber price. An own price elasticity of 0.55 (Newman, 1991) was considered for sawtimber. Because bioenergy production is a recent activity, historical data from 1990 until 2006 was used to simulate the elasticities of the *RPB model*.

Table 4-6 shows the coefficients, robust standard errors, and p values of the *RPB model*. The DW statistic for Y_{sv}, Y_{pv} and Y_{bv} were shown to be inconclusive. Table 4-7 shows the elasticities of the *RPB model*. All elasticities were significant at $p = 0.05$. The cross price elasticity of pulpwood with respect to the biomass for bioenergy was negative, confirming the substitutability between the products. This implies that an increase in the price of biomass for bioenergy will decrease the production of pulpwood, redirecting the production toward biomass for bioenergy. Further, consistent with economic theory, the own price elasticity of the supply and price elasticity of the demand for the three forest products were positive and negative, respectively. Contrary to the *ROB model*, the demand equations showed that biomass for bioenergy and energy are substitutes, and biomass for bioenergy and labor are complements.

Policy Simulation

The Energy Independence Policy Act of 2007 and American Clean Energy Security draft Bill of 2009 set renewable fuel and electricity standards. An induced government policy scenario would favor the production of bioenergy. Thus, the demand for biomass from the bioenergy sector is increased to produce renewable energy. For simulation purposes, we have considered a scenario in which the demand for biomass for bioenergy is increased by 15% for the *ROB* and *RPB model*.

The simulation procedure was carried out first, developing a baseline for quantities and prices of sawtimber, pulpwood, and biomass for bioenergy using the average data of labor, energy, capital, and output prices of each sector between 1990 and 2006. The estimated equations, then, were used to predict the output baseline for sawtimber, pulpwood, and biomass bioenergy. For our policy simulation, we increased the demand for biomass for bioenergy by 15% for both models. The estimated supply and demand equations were adjusted for the new equilibrium quantities and prices for sawtimber, pulpwood and biomass for bioenergy. Finally, the new equilibrium was compared and contrasted with baseline information to discern the percent change.

Table 4-8 shows the baseline and the policy scenario results for the *ROB* and *RPB model*. For the *ROB model*, the increase in the demand for biomass for bioenergy by 15% implied an increase of 4.5% in the quantity of sawtimber, while the sawtimber price decreased by 2.9%. The pulpwood price increased by 91.3%, while the quantity decreased by 27.3%. Price of biomass for bioenergy decreased by 4.9%. The demand for sawtimber and biomass for bioenergy moved in opposite directions supporting the evidence of substitutability found in the cross price elasticities.

Given the negative own supply elasticity of biomass for bioenergy, the increased demand for biomass for bioenergy resulted in a lower price for biomass for bioenergy for the forest landowner sector. The negative cross price elasticity of the sawtimber with respect to biomass for bioenergy implied expanding supply of sawtimber. The demand for sawtimber, facing an increased level of production, adjusted by reducing the equilibrium sawtimber price. The reduced price of sawtimber and biomass for bioenergy, in turn, led to an inward shift of the supply of pulpwood. Thus, the demand for pulpwood adjusted to meet the contracted production, increasing the equilibrium price of pulpwood.

With regard to the *RPB model*, the increased demand for biomass for bioenergy caused an increase in the price of biomass for bioenergy, stimulating the forest landowner to expand the supply. Price of biomass for bioenergy increased by 51.9%. The substitutability between biomass for bioenergy and pulpwood resulted in an inward shift of the supply of pulpwood. The demand for pulpwood adjusted to a lower level of production— a fall of 20%— increasing the equilibrium price by 103.5%. Cross price elasticity between sawtimber and biomass for bioenergy showed that both products were substitutes and had a magnitude higher than that between sawtimber and pulpwood. Thus, the supply of sawtimber would be expected to contract. The overall effect was a 11.1% decrease. The demand for sawtimber adjusted in terms of a rightward shift, reflecting a 6.5% increase in equilibrium price.

In summary, for the *ROB model,* the increased demand for biomass for bioenergy increased the price of pulpwood and decreased the prices of biomass for bioenergy and sawtimber. Quantity of pulpwood was reduced while quantity of sawtimber expanded**.** In case of the *RPB model,* prices of biomass for bioenergy, pulpwood, and sawtimber increased. Quantities of pulpwood and sawtimber supplied decreased.

The total value of the demand for forest resources increased in the case of both models. For the *ROB model* the values of the equilibrium quantities— price times quantity— increased by 1.5%, 38.9%, and 9.2% for sawtimber, pulpwood, and biomass for bioenergy, respectively, in case of a 15% increase in demand for biomass for bioenergy (Table 4-9). The gain of the quantity values for the forest landowners accounted for 10.9% (US$ 862.5 million). The forest landowners, in turn, sell less pulpwood at a higher price and more biomass for bioenergy and sawtimber. Therefore, the timber sales offset the losses incurred by selling more sawtimber and biomass for bioenergy at a lower price and less pulpwood. With regard to the *RPB model,* the values of the equilibrium quantities increased for pulpwood and biomass for bioenergy, accounting for a rise of 8.9% (US$ 565.3 million) of the total value.

On the other hand, the pulpmill sector was adversely affected in both models. Pulpmills would have to pay more for pulpwood and acquire less pulpwood from landowners. The bioenergy sector benefited, as it could afford buying more biomass for bioenergy in both models. Sawmills in the *ROB model* also benefited, buying more sawtimber at a lower price. However, this sector was negatively affected in the *RPB model*, buying less sawtimber at a higher price. The results of this study are in line with the findings of Ankarhem (2005), which claimed a positive effect of an increased demand for biofuels on the forest landowner and energy sector.

Conclusions

An econometric model was constructed to represent the interactions and impacts of wood bioenergy markets in the southern U.S. Four sectors were identified: the forest landowners, who supply sawtimber, pulpwood and biomass for bioenergy; the sawmill sector, which demands sawtimber to produce lumber; the pulpwood sector, which uses pulpwood to produce pulp and paper; and the bioenergy sector, which requires biomass to produce electricity. First, we estimated the partial equilibrium model; then, elasticities were calculated and we termed it the *ROB model*. In addition, we calibrated a new model under the assumption that production of biomass for bioenergy reduced the production of pulpwood. A policy scenario was simulated in which the demand for biomass for bioenergy was increased by 15%. The effect of increased demand for biomass for bioenergy on the other sectors was assessed for both models.

The short run supply and demand elasticities calculated at the mean values showed dissimilar results in the two models. In the *ROB model*, own supply price elasticities were positive for sawtimber and pulpwood, but the own elasticity supply of biomass for bioenergy was negative. The own supply price elasticities were all positive in the *RPB model*. In general, sawtimber supply proved to be more sensitive to changes in its own price compared to pulpwood and biomass for bioenergy supply functions. Evidence showed that sawtimber and pulpwood and sawtimber and biomass for bioenergy are complements and substitutes in the *ROB* and *RPP model*, respectively. However, pulpwood and biomass for bioenergy came out as complements in the *ROB model* but substitutes in the *RPB model*.

Consistent with expectations, the own price elasticities of the demand for sawtimber and pulpwood, in both models came out as negative. We only found inconsistency in the positive sign of the own price elasticity of the demand for biomass for bioenergy in the *ROB model*. The own price demand elasticity was elastic for sawtimber and inelastic in the cases of pulpwood and biomass for bioenergy.

In the *ROB model*, when biomass for bioenergy and pulpwood were complementary products, the increase in the demand for biomass for bioenergy resulted in an increase of the equilibrium price of pulpwood and a decrease in the equilibrium price of biomass for bioenergy. Further, the quantity of pulpwood was reduced. We are aware that the inconsistency regarding the sign of the own price elasticity of biomass for bioenergy implied a decrease in the price of this forest product. The price of sawtimber was reduced, while the quantity of sawtimber increased. The results of the *RPB model* concluded that an increase in the demand for bioenergy indicated an increase in the price of pulpwood and biomass for bioenergy and a decrease in the quantity of pulpwood. On the other hand, the quantity of sawtimber decreased while the price increased.

The inclusion of this policy scenario resulted in a greater value of the demand for forest resources, in turn benefiting the forest landowners. The bioenergy sector could afford to buy more biomass to generate bioenergy. The sawmill sector benefited by the increase in the demand for biomass for bioenergy in the *ROB model*. However, this sector was financially damaged regarding the *RPB model*. The pulpmill sector was adversely impacted in both models, having lower amounts of pulpwood available at a higher price.

Our study itself could be improved in different ways. Time series data could be used to forecast future production of biomass for bioenergy and its tradeoffs with other forest products**.** Incorporation of cross sectional data in light of data availability would provide a more complete assessment of the impacts of future bioenergy markets. Another plausible option would be to assume that capital stocks adjust over time to see the long run responses regarding change in input and output prices. Under this assumption, it is expected that elasticities become larger in magnitude due to the Chatelier principle. Finally, the paper industry has been historically concentrated over time, showing a high degree of market power (Mei and Sum, 2008). Thus, a reasonable assumption would be to model the pulp markets as an oligopsony.

Table 4-1. Descriptive statistics of the data set

Sector	Variable	Unit	Mean	Std	Min	Max
Forest landowners	Y_s	Million m^3	61.28	19.57	29.84	91.01
	Y_p	Million m^3	61.33	5.74	49.52	71.69
	Y_b	Million m^3	26.84	4.54	12.97	32.12
	w_{sv}	\$ m^{-3}	58.54	17.92	31.57	92.1
	w_{pv}	\$ m^{-3}	29.28	2.46	24.77	36.16
	w_{bv}	\$ m^{-3}	6.39	1.22	4.46	9.48
	w_{fl}	\$ $hour^{-1}$	9.91	3.39	3.43	15.56
	K_f	Million m^3	2917.59	161.21	2524.63	3295.57
Sawmill sector	w_{se}	\$ KWh^{-1}	0.048	0.0067	0.039	0.06
	w_{sl}	\$ $hour^{-1}$	8.19	3.06	2.97	13.32
	w_s	\$ m^{-3}	65.47	23.07	21.53	100.01
	K_s	Million ton $year^{-1}$	34.65	8.19	13.9	48.6
Pulpmill sector						
	w_{pe}	\$ KWh^{-1}	0.048	0.006707	0.039	0.06
	w_{pl}	\$ $hour^{-1}$	10.97	4.59	3.51	18.36
	w_p	\$ ton^{-1}	73.91	31.78	22.33	125.15
	K_p	Million ton $year^{-1}$	43.71	5.97	30.79	51.32
Bioenergy sector						
	w_{be}	\$ KWh^{-1}	0.0048	0.000695	0.00321	0.00588
	w_{bl}	\$ $hour^{-1}$	19.65	2.83	15.27	24.85
	w_b	\$ KWh^{-1}	0.066	0.00445	0.06	0.075
	K_b	Million KWh $year^{-1}$	283.98	77.40	127.4	429.01

Table 4-2. Rank and redundancy tests for all instruments

Equation	Kleibergen-Paap rk LM statistic	Chi-square (6) p value	LM test of redundancy instruments	test	Chi-square (18) p value
Y_s	10.62	0.1	w_{bl}, w_{be}, K_b	14.51	0.69
Y_p	9.86	0.13	w_{bl}, w_{be}, K_b	21.48	0.25
Y_b	13.53	0.03	w_{se}, w_{sl}, K_s	28.43	0.06

Table 4-3 Coefficients, standard errors, p values and serial correlation of the system of equations

Sawtimber supply	Coefficients	robust SE	p value	Sawtimber demand	Coefficients	robust SE	p value
α_{svsv}	-288.41	526.13	0.292	β_{svsv}	30.77	137.27	0.411
α_{svpv}	13.99	63.21	0.824	β_{svsl}	1358.62	633.47	0.032
α_{svbv}	-13.77	236.06	0.953	β_{svse}	-8568.66	2030.68	0.000
α_{svfl}	-862.21	430.08	0.045	β_{svs}	41.73	41.79	0.318
α_{svk}	0.24	0.11	0.267	β_{svk}	-8.058	1.57	0.010
Pulpwood supply	Coefficients	robust SE	p value	Pulpwood demand	Coefficients	robust SE	p value
α_{pvpv}	114.84	328.05	0.363	δ_{pvpv}	-130.72	87.27	0.067
α_{pvsv}	13.99	10.79	0.195	δ_{pvpl}	210.02	185.92	0.258
α_{pvbv}	27.09	51.28	0.597	δ_{pvpe}	616.56	1063.61	0.562
α_{pvfl}	-224.33	169.55	0.185	δ_{pvp}	-9.176	19.21	0.633
α_{pvk}	0.015	0.031	0.814	δ_{pvk}	1.7171	0.47	0.067
Biomass for bioenergy supply	Coefficients	robust SE	p Value	Biomass for bioenergy demand	Coefficients	robust SE	p value
α_{bvbv}	-157.39	150.63	0.148	γ_{bvbv}	112.27	31.51	0.000
α_{bvsv}	-13.77	3.88	0.000	γ_{bvbl}	-1.485	13.67	0.913
α_{bvpv}	27.09	9.27	0.003	γ_{bvbe}	1907.46	1383.73	0.168
α_{bvfl}	62.88	18.62	0.000	γ_{bvb}	-789.62	418.30	0.059
α_{bvk}	0.030	0.025	0.541	γ_{bvk}	-0.19	0.075	0.209
Equation	Y_s	Y_p	Y_b				
F value	42.72	11.51	18.63				
p value	0.00	0.00	0.00				
R square	0.92	0.75	0.84				
Durbin Watson	1.48	1.37	2.12				

Table 4-4 Rank, overidentifying restriction, model comparison, symmetry and contemporaneous correlation tests

Equation	Y_s	Y_p	Y_b
Rank test			
Kleibergen-Paap rk LM statistic	9.91	8.90	8.17
Chi-square (3) p value for Y_s, Y_p Chi-square (4) p value for Y_b	0.019	0.03	0.08
Overidentifying restriction test			
Hansen test Chi-square(2) p value Y_s, Y_p Chi-square (2) p value for Y_b	13.80	5.36	11.61
Model comparison			
Restricted vs. unrestricted model F (2, 28)	0.0008	0.0014	0.0007
Symmetry test			
	$\alpha_{svpv} = \alpha_{svpv}$	$\alpha_{svbv} = \alpha_{bvsv}$	$\alpha_{pvbv} = \alpha_{bvpv}$
Chi-square (1) p value	0.11	0.88	0.13
Contemporaneous correlation			
Breusch-Pagan test Chi-square (3) p value	8.99 0.03		

Table 4-5 Estimates and standard errors (SE) of the short run supply and demand elasticities of the *ROB model*

Sawtimber supply			Pulpwood supply			Biomass for bioenergy supply		
	Estimates	SE		Estimates	SE		Estimates	SE
w_{sv}	2.851	1.316*,**	w_{sv}	0.161	0.022*,**,***	w_{sv}	-0.776	0.181*,**,***
w_{pv}	0.081	0.044*	w_{pv}	0.800	0.177*,**,***	w_{pv}	1.080	0.227*,**,***
w_{bv}	-0.037	0.024	w_{bv}	0.103	0.016*,**,***	w_{bv}	-1.762	0.217*,**,***
w_{fl}	-2.894	1.333*,**	w_{fl}	-1.064	0.181*,**,***	w_{fl}	1.458	0.258*,**,***
Sawtimber demand			**Pulpwood demand**			**Biomass for bioenergy demand**		
	Estimates	SE		Estimates	SE		Estimates	SE
w_{sv}	-2.617	0.982*,**	w_{pv}	-0.969	0.142*,**,***	w_{bv}	0.577	0.216*,**
w_{se}	4.147	1.771*,**	w_{pe}	1.048	0.205*,**,***	w_{be}	-0.048	0.013*,**,***
w_{sl}	-2.013	1.271	w_{pl}	0.205	0.033*,**,***	w_{bl}	0.976	0.130*,**,***
w_{s}	0.483	0.196*,**	w_{p}	-0.284	0.057*,**,***	w_{b}	-1.504	0.324*,**,***

Elasticities valued at the mean values

Notes: *Significant at p <0.1; **Significant at p <0.05; ***Significant at p <0.01

Table 4-6 Coefficients, standard errors, p values and serial correlation of the *RPB* model

Sawtimber supply	Coefficients	robust SE	p value	Sawtimber demand	Coefficients	robust SE	p value
α_{svsv}	5.84	548.93	0.496	β_{svsv}	-156.35	280.30	0.288
α_{svpv}	4.24	55.85	0.469	β_{svsl}	1575.86	904.07	0.040
α_{svbv}	-7.37	208.00	0.486	β_{svse}	-7903.36	1970.73	0.000
α_{svfl}	-1139.65	609.96	0.031	β_{svs}	67.21	40.49	0.048
α_{svk}	0.18	0.09	0.021	β_{svk}	-7.12	1.86	0.000
Pulpwood supply	Coefficients	robust SE	p Value	Pulpwood demand	Coefficients	robust SE	p value
α_{pvpv}	172.14	706.51	0.403	δ_{pvpv}	-83.16	208.53	0.345
α_{pvsv}	4.24	6.94	0.271	δ_{pvpl}	33.10	113.90	0.385
α_{pvbv}	-20.54	49.79	0.339	δ_{pvpe}	1195.24	608.69	0.025
α_{pvfl}	-110.14	107.30	0.152	δ_{pvp}	-2.67	13.05	0.418
α_{pvk}	-0.02	0.03	0.229	δ_{pvk}	1.32	0.41	0.000
Biomass for bioenergy supply	Coefficients	robust SE	p Value	Biomass for bioenergy demand	Coefficients	robust SE	p value
α_{bvbv}	-284.28	1548.47	0.427	γ_{bvbv}	213.00	314.78	0.249
α_{bvsv}	-7.37	2.16	0.000	γ_{bvbl}	16.88	11.42	0.069
α_{bvpv}	-20.54	6.43	0.000	γ_{bvbe}	-694.04	1033.83	0.251
α_{bvfl}	179.82	16.68	0.000	γ_{bvb}	1627.23	305.14	0.000
α_{bvk}	0.05	0.02	0.000	γ_{bvk}	-0.23	0.06	0.000
Equation	Y_s	Y_p	Y_b				
F value	35.48	10.06	102.08				
p value	0.00	0.00	0.00				
R square	0.91	0.73	0.96				
Durbin Watson	1.37	1.43	2.34				

Table 4-7 Estimates and standard errors (SE) of the short run supply and demand elasticities of the *RPB model*

Sawtimber supply			Pulpwood supply			Biomass for bioenergy supply		
	Estimates	SE		Estimates	SE		Estimates	SE
w_{sv}	3.989	0.739*,**,***	w_{sv}	0.083	0.021*,**,***	w_{sv}	-0.125	0.010*,**,***
w_{pv}	0.019	0.004*,**,***	w_{pv}	1.171	0.332*,**,***	w_{pv}	-0.191	0.026*,**,***
w_{bv}	-0.048	0.008*,**,***	w_{bv}	-0.323	0.077*,**,***	w_{bv}	1.628	0.143*,**,***
w_{fl}	-3.960	0.734*,**,***	w_{fl}	-0.931	0.275*,**,***	w_{fl}	-1.312	0.139*,**,***
Sawtimber demand			**Pulpwood demand**			**Biomass for bioenergy demand**		
	Estimates	SE		Estimates	SE		Estimates	SE
w_{sv}	-4.307	0.687*,**,***	w_{pv}	-0.735	0.176*,**,***	w_{bv}	-0.895	0.084*,**,***
w_{se}	5.077	0.896*,**,***	w_{pe}	0.306	0.089*,**,***	w_{be}	0.158	0.014*,**,***
w_{sl}	-1.586	0.341*,**,***	w_{pl}	0.584	0.132*,**,***	w_{bl}	-0.099	0.010*,**,***
w_s	0.817	0.094*,**,***	w_p	-0.154	0.044*,**,***	w_b	0.836	0.081*,**,***

Elasticities valued at the mean values

Notes: *Significant at p <0.1; **Significant at p <0.05; ***Significant at p <0.01

Table 4-8 Baseline and policy scenario results for *ROB* and *RPB models*

Variable	Baseline *ROB model*	15% increase demand for biomass	% change	Baseline *RPB model*	15% increase demand for biomass	% change
w_{sv}	72.64	70.55	-2.87	68.29	72.72	6.48
w_{pv}	29.63	56.68	91.27	14.52	29.56	103.56
w_{bv}	5.82	5.53	-4.98	15.13	22.94	51.93
Y_s	79.67	83.24	4.47	74.36	66.06	-11.16
Y_p	66.03	47.96	-27.35	46.95	37.54	-20.03
Y_b	28.38	32.64	15.00	36.56	42.05	15.00

Table 4-9. Total timber sales values for *ROB* and *RPB models* (million US$)

Forest product	Baseline *ROB model*	Total value 15% biomass demand increase	% change	Baseline *RPB model*	Total value 15% biomass demand increase	% change
Sawtimber	5788.15	5873.26	1.47	5078.91	4804.57	-5.40
Pulpwood	1956.78	2718.94	38.94	681.956	1110.06	62.77
Biomass for Bioenergy	165.23	180.44	9.23	553.41	964.91	74.35
Total	7910.18	8772.65	10.9	6314.28	6879.55	8.95

CHAPTER 5
SUMMARY AND CONCLUSIONS

Introduction

Ongoing environmental issues such as global warming have prompted policy makers to promote new environmentally friendly technologies and energy systems to meet human requirements. Southern forests can play a dual role in fulfilling energy requirements, decreasing the dependency on foreign oil, and serving as a neutral source of $CO_{2.}$ Forests sequester carbon from the atmosphere, storing it in biomass, and produce biofuels, replacing fossil fuels. In addition, production of forest biomass bioenergy might increase the currently depressed profitability of southern forestlands.

Potential policies that enhance the production of energy from the forest to reduce GHG emissions, reduce energy dependence, and stimulate forestry sector are of national interest. Thus, it is necessary to evaluate the role that forest biomass bioenergy markets will have for family forests in terms of management and economic returns. Also, information about human behavior and its perspectives regarding the use of green energy is needed. Further, it is necessary to identify the implications of growing forest bioenergy markets on the traditional forest products due to policies favoring the development of new sources of bioenergy. Insights from these analyses are important to evaluating the efficiency and effectiveness of current and alternative potential policies that stimulate the use of bioenergy. Following this rationale, the aim of this dissertation was to explore some economic aspects of utilizing forest biomass based bioenergy in the southern U.S.

Results from Modeling Impacts of Bioenergy Markets on Nonindustrial Private Forest Management

In general terms, the inclusion of thinnings increased the profitability of slash pine forest stands regardless of the catastrophic disturbance risk levels. Assuming a positive salvageable portion, the profitability of forest stands measured as land expectation value (*LEV*) was higher when thinnings were performed for either pulpwood or bioenergy purposes—4.6% and 5.8%, respectively— than the *LEV* when no thinnings were carried out. Thus, when the whole forest stand becomes commercially marketable, the revenues obtained offset the costs of thinning. However, when salvage accounted for zero, the *LEV* for *no thinning scenario* exceeded both of the thinning scenarios by 3.5% and 2.6%, respectively. In the case of the *thinning scenario for bioenergy*, the revenues associated with the increase of the volumetric growth after thinning for greater value added product and the low price for forest biomass based bioenergy were not enough to cover the loss of volume and consequently the profits at the time of thinning. A bioenergy price of \$5 ton^{-1} made the land value break even for the bioenergy scenario compared to the status quo when the stand was completely destroyed.

Devoting part of the forest stand to bioenergy purposes was more profitable than the scenario of producing pulpwood. In fact, the *LEV* for the *thinning scenario for bioenergy* was higher than the *LEV* for the *thinning scenario for pulpwood* at all comparable salvage/risk levels, due to the utilization of non commercial forest biomass for bioenergy production. On average, the *LEV* was greater by 11.5% and 11.7% for salvage levels of k= 0.8 and k= 0, respectively. Further, when risk was decreased by 1%, the *LEV* increased by 9% and 19% for salvage levels of k= 0.8 and k= 0, respectively. Thus, policies that help landowners mitigate risk through silvicultural interventions to reduce the size of the damage would have a positive impact on the profitability of forest stands.

We also simulated an independent increase in bioenergy prices and volatility prices assuming that forest biomass based bioenergy markets continue to expand. As expected, the *LEV* increased as price and volatility increased. When price increased, the *LEV* increased by 6.4% and 6.1% for levels of k= 0.8 and k= 0, respectively. The *LEV* was greater than the original *thinning scenario for bioenergy*, *thinning scenario for pulpwood* and *no thinning scenario* by 9.4%, 10.6% and 16% respectively, for a salvage portion of k= 0.8. When the forest stand was completely destroyed, the differences were 9%, 10.2% and 6.4%, respectively. On the other hand, the increase in the *LEV* was much lower as volatility prices increased. On average, the increase was 0.6% for all levels of salvageable portions. Compared to the original *thinning scenario for bioenergy*, *thinning scenario for pulpwood* and *no thinning scenario*, the *LEV* increased by 1.4%, 2.5% and 1.07%, respectively, for a level of k = 0.8. For k = 0, the increase was 1.2%, 2.4%, and 1%, respectively. Thus, the combined effect of increasing prices and volatilities will be greater returns to forest landowners.

Results from Assessing Public Preferences for Forest Biomass based Bioenergy

The results indicated that individuals had a positive extra willingness to pay (WTP) for *E10* and *E85* and a greater WTP for biofuels that led to environmental improvements. For *E10*, the WTP was \$0.56 gallon^{-1}, \$0.58 gallon^{-1}, and \$0.50 gallon^{-1} in AR, FL, and VA, respectively. For *E85*, the WTP was \$0.82 gallon^{-1}, \$1.17 gallon^{-1} and \$1.06 gallon^{-1} in AR, FL, and VA, respectively. Thus, southern consumers valued the environmental benefits obtained from a modified transportation fuel and were willing to pay more for biofuels once the proposed change offered better conditions for the environment. The extra WTP for ethanol was converted into total future expenditures per year. The mean total expenditures for *E10* were \$585.20, \$485.90, and \$596.20 per capita year^{-1} in AR, FL, and VA, respectively. For *E85* the total expenditures were \$919.60, \$330.80, and \$532.60 per capita year^{-1} in the same states. The price elasticity of the demand was relatively inelastic, and for *E85* it was less inelastic compared to the price elasticity of the demand for *E10*, with the exception of AR.

Heterogeneous preferences for environmental attributes were also a characteristic of the respondents. Respondents were willing to pay a premium for *E10* in order to achieve CO_2 reduction in all three states, and for biodiversity improvement in AR and FL. However, respondents were not willing to pay a premium for *E85* for an increased reduction of CO_2 in AR or for biodiversity improvement in any of the three states. This heterogeneity was also observed in some socioeconomic variables. For example, educational background showed different trends in the three states. Individuals with higher levels of education would only change to *E10* in FL and *E85* in AR. On the other hand, in VA, respondents with some high school or with bachelor's degree were not likely to switch to *E10*, but individuals with some college education would tend to pay a premium for *E10*. Income was another variable that showed heterogeneity in individuals' perceptions about biofuels**.** In AR, the probability of paying a premium decreased as an individual had greater earnings. In FL, individuals that came from high or middle income households were likely to pay a premium and change to both blends.

Results from Modeling Effects of Bioenergy Markets on Traditional Forest Product Sectors

Two models were calibrated, namely *ROB* and *RPB model*. Estimation of the supply functions indicated that sawtimber and pulpwood showed positive own price elasticities and a negative own price elasticity of the supply of biomass for bioenergy for the *ROB model*. For the *RPB model* all own price elasticities had the expected sign. The supply of sawtimber proved to be more sensitive than either the supply of pulpwood or biofuels with respect to changes in their own prices. The cross price elasticity of sawtimber with respect to the price of pulpwood was positive, indicating that sawtimber and pulpwood are complements. Likewise, evidence showed that biomass for bioenergy and pulpwood are complements for the *ROB model*. In the case of the

RPB model, biomass for bioenergy and pulpwood were substitutes. Sawtimber and biomass for bioenergy, on the other hand, proved to be substitute products for both models.

Turning to the demand functions, for the *ROB model*, the own price elasticities of the demand for sawtimber and pulpwood were negative, and it was positive for the demand for biomass for bioenergy. For the *RPB model*, all own price elasticities had the expected sign. The response of demand to changes in price was more sensitive in the case of sawtimber compared to pulpwood and biomass for bioenergy. On the other hand, the demand for biomass for bioenergy was increased by 15%. For the *ROB model* and *RPB model*, the price of pulpwood increased by 91.3% and 103.5%, respectively. The price of biomass for bioenergy decreased by 4.9% for the *ROB model*, but increased by 51.9% for the *RPB model*. The quantity of pulpwood decreased by 27.3% and 20%, respectively. The price of sawtimber decreased by 2.9% and increased by 6.5% in the *ROB model* and *RPB model*, respectively. The quantity of sawtimber increased by 4.5% in the *ROB model*, but it decreased by 11.1% in the *RPB model*.

As a result of the policy, the total value of the demand for forest resources was also increased. In total, the gain of the quantity values for the forest landowners accounted for 10.9% and 8.9% for the *ROB model* and *RPB model*, respectively. The forest landowner and bioenergy sectors were net winners in both models. In the *ROB model*, sawmills were also benefited. However, sawmills were financially damaged in the *RPB model*. Pulpmills were negatively affected by the increase in the demand for biomass for bioenergy in both models.

Policy Implications and Further Research

Production of bioenergy showed to increase the profitability of forest stands and larger socioeconomic benefits are expected as bioenergy markets evolve. However, lower prices for forest biomass for bioenergy and high cost of thinnings and transportation might become a barrier for bioenergy production. Policy incentives for biomass production would stimulate forest landowners to encourage the production of bioenergy. However, careful considerations must be taken when managing forests intensively for bioenergy thus policy incentives must also aim sustainable silvicultural activities. Although the introduction of bioenergy production would increase the profitability of forest stands and reduce the risk of catastrophic disturbances, the unsustainable use of forest biomass for bioenergy can lead to negative ecological impacts, increase GHG emissions and adverse effects on communities. Lal et al. (2009) proposed a set of indicators such as land use change, biodiversity conservation, soil and water quality, profitability and community benefits for a sustainable production of forest biomass for bioenergy. On the other hand, forest landowners would be better positioned as certification systems such as the American Tree Farm System (ATFS), the Sustainable Forestry Initiative (SFI), or schemes recognized by the Programme for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) develop standards or incorporate specific guidelines for bioenergy production.

This research can be extended in several ways to address different issues. The incorporation of certain silvicultural activities to produce bioenergy allows other commercial activities to be undertaken. For example, silvopastoral activities can be developed and environmental services such as recreation can be incorporated. These factors can increase further the profitability of forest stands. On the other hand, the optimal thinning age was arbitrarily set at year 16 for the bioenergy market model regarding nonindustrial private forest management. A dynamic optimization model such as the reservation price approach is a plausible extension of the bioenergy market model to determine the optimal thinning age.

Understanding present and future individual preferences for bioenergy is an important tool for policymakers. Findings suggested that individuals were willing to pay a premium for biofuels reflecting environmental and social benefits from using forest biomass for bioenergy production. These findings would provide a scientific basis to formulate policies that stimulate biomass production for energy. Thus, the implications of assessing public preferences for bioenergy are in concordance with policy incentives for forest landowners to undertake sustainable forest practices for bioenergy production. In addition, this positive willingness for bioenergy would facilitate the development of appropriate educational programs that enhance the public support for forest biomass for energy. Particularly, education campaigns might be carried out in certain areas where renewable energy systems are not internalized by the community or fossil fuels industry is a key support for the economy and people are not likely to switch to bioenergy. Thus, clean energy communities might play a significant role in convincing people to choose renewable energy systems.

Periodic revisions of these studies are needed to evaluate the validity and consistency of the results and formulate improved policies based on changing public perceptions and preferences. In addition, the use of meta analysis is a possible approach to explore variation of willingness to pay to transfer information to another location or context. Another extension of this model is to include spatial variation in people's views. Thus, preferences for the use of biofuels might be influenced by geographical conditions or other people's preferences.

Current U.S. energy policies aim to decrease the dependency on foreign oil and the greenhouse gas emissions. The search for environmentally friendly sources of energy and improvement of efficiency of current technologies would be needed to meet this goal. We have pointed out the use of forest biomass as a plausible option to switch to green energy. Our dynamic partial equilibrium model showed that an increased demand for biomass for bioenergy would benefit bioenergy firms and forest landowners. A subsidy for the bioenergy sector that induces an increased consumption of forest biomass would reduce the cost of bioenergy production. This might allow for further advances in research and development to find more efficient energy conversion techniques. The other conventional sectors, pulp and sawmill would be adversely affected. However, because of the absence of data, our results have to be taken with a certain degree of caution. Pulp and sawmills can create synergy acting strategically. Sawmills might establish joint ventures with bioenergy sector by selling low value sawmill residues at competitive prices. On the other hand, potential competition between pulpmills and bioenergy sector might be reduced pulpmills position themselves as integrated forest biorefineries. Furthermore, bioenergy firms might also sell electricity to pulpmills at competitive prices.

This dynamic model could be further improved by incorporating of cross sectional data in light of data availability would provide a more complete assessment of the impacts of bioenergy markets. Further, the assumption of capital stocks adjusting over time to explore the long run responses regarding change in input and output prices also deserves further research.

APPENDIX A
LIST OF VARIABLES

Variables	Definition
S	stumpage price ($ ton^{-1})
$V(T)$	merchantable volume at time T (ton)
$N(d)$	cumulative normal density function
X	forest exercise cost ($ ton^{-1})
R	risk free interest rate
T	harvest date
$N(d1)$	probability that a normal variable takes on values less than or equal to *d1*. Also known as the option delta; the degree to which an option value will change given a small change in the price
$N(d2)$	probability that a normal variable takes on values less than or equal to *d2*. Probability that the option will be exercised (forest will be harvested) or the change of the price at expiration time
$val(T)$	expected value of the timber ($ $acre^{-1}$)
$Nval(T)$	net expected value of the timber ($ $acre^{-1}$)
$Npv(T)_{timber}$	expected net present value of the timber for the first rotation ($ $acre^{-1}$)
δ	discount rate
$LEV(T)$	land expectation value at time T ($ $acre^{-1}$)
Yn	net land rent time ($ $acre^{-1}$)
K	salvageable portion
$E\left[e^{-\delta x_n} Y_n\right]$	expected value of a single rotation
λ	average probability per unit of time of a catastrophic event that follows a Poisson distribution
St	sawtimber
Pw	pulpwood
Cs	chip and saw
Fbb	forest biomass for bioenergy
σ_{st}	volatility for sawtimber
σ_{cs}	volatility for chip and saw
σ_{pw}	volatility for pulpwood
σ_{fbb}	volatility for forest biomass for bioenergy
U_{ij}	utility for each respondent *i* to choose among different *j* alternatives
V_{ij}	deterministic part of the utility of respondent *i* when choosing among different *j* alternatives
ε_{ij}	disturbance term of respondent *i* when choosing among different *j* alternatives

P_{ij}	probability that individual *i* will choose alternative *j* over *k* alternatives
L	likelihood function
Reco2	percentage reduction of CO2
Biomp	percentage improvement of biodiversity
Prem	additional payment at the pump (\$ gallon^{-1})
Member	membership of an environmental organization
Knowledge	knowledge of other sources of renewable energy
Ownership	ownership of a car
Age	age of respondent
Miles week	miles driven weekly
Less high	condition of a respondent with exclusively less than high school level
High	condition of a respondent with exclusively high school level
Some college	condition of a respondent with exclusively some college level
Bachelor	condition of respondent with exclusively bachelor degree or higher level
Lincome	household Annual Income less than \$24,9999
Mincome	household Annual Income between \$25,000 - \$74,999
Hincome	household Annual Income greater than \$75,000
Gender	gender of respondent
Head	head of the household
Size	number of people in the household
Work	work of respondent
WTP	willingness to pay (\$ gallon^{-1})
TE	total expenditures (\$ year^{-1})
P_g	average price of gasoline (\$ gallon^{-1})
Ed_e	price elasticity of the demand for biofuels
Q_e	quantity of gallons of ethanol
π^f	profit function for the forest landowners (\$ year^{-1})
π^s	profit function for the sawmill sector (\$ year^{-1})
π^p	profit function for the pulpmill sector (\$ year^{-1})
π^b	profit function for the energy sector
w_{sv}	price of sawtimber (\$ m^{-3})
w_{pv}	price of pulpwood (\$ m^{-3})
w_{bv}	price of biofuels (\$ m^{-3})
w_{fl}	labor wage in forestry (\$ hour^{-1})
K_f	capital in forestry (million m^3)
w_{sl}	labor wage in sawmills (\$ hour^{-1})

w_{se}	price of energy in sawmills ($ KWh^{-1})
P_s	price of lumber ($ m^{-3})
K_s	capital in sawmill sector (million ton year^{-1})
w_{pl}	labor wage in pulpmills ($ hour^{-1})
w_{pe}	price of energy in pulpmills ($ KWh^{-1})
P_p	price of sbk pulp ($ ton^{-1})
K_p	capital in pulpmills (million ton year^{-1})
w_{bl}	labor wage in energy sector ($ hour^{-1})
w_{be}	price of input energy in energy sector ($ KWh^{-1})
P_p	price of electricity ($ KWh^{-1})
K_p	capital in energy industry (million KWh year^{-1})
Y_{sv}	quantity of sawtimber (million m^3)
Y_{pv}	quantity of pulpwood (million m^3)
Y_{bv}	quantity of biofuels (million m^3)
$\varepsilon_{ii}{}^{s}$	own price elasticity of the supply
$\varepsilon_{ii}{}^{d}$	own price elasticity of the demand
$\varepsilon_{ij}{}^{s}$	cross price elasticity of the supply
$\varepsilon_{ij}{}^{d}$	cross price elasticity of the demand

APPENDIX B
SURVEY INSTRUMENT

The University of Florida School of Forest Resources and Conservation, with the support of the U.S. Department of Agriculture, U.S Department of Energy, Virginia Polytechnic Institute and State University and the University of Arkansas is conducting a survey at household level about the use of energy coming from renewable resources. You have been selected to receive the following questionnaire in order to know your preferences about this type of energy.
To understand public preferences for the use of renewable resources based energy better, we would like to ask you some questions about your opinion of using forest biomass (wood, branches and bark) to generate energy (liquid biofuels and electricity). The questionnaire is not difficult to answer and should only take about 10 minutes to complete. Your responses will be very helpful in determining the best way to understand the potential of bioenergy.

Your participation in this survey is voluntary, but we sincerely hope that you will help us with this study. You are not required to answer any question that you do not wish to answer. Your answers will be kept entirely confidential. We will not release any information that can be used to identify any individuals participating in this survey. There is no direct benefit or compensation to you for participating in this study, and returning the completed questionnaire will be interpreted as your consent to participate in the survey. There is no risk to any human beings, animals or the environment from this questionnaire. If you have any questions concerning your rights as a survey participant, please feel free to contact the UFIRB office, PO Box 112250, University of Florida, Gainesville, Fl 32611-2250; (352) 392-0433.

Forests are not only a source of wood products. In addition, forest biomass (branches, wood and bark) can also be utilized to produce energy: fuel ethanol which is blended with fossil fuels (typically gasoline) to be used by different types of automobiles. For example a "10%

blend" (E10) is a mixture of 10% of ethanol and 90% of gasoline (one tenth of the gallon is ethanol and nine tenths of the gallon are gasoline); a "85% blend" (E85) is a mixture of 85% ethanol and 15% gasoline and so on. The greater the blend, the lesser the emission of carbon dioxide in the atmosphere.

Growing trees to generate forest biomass based energy would absorb CO_2 and reduce the global warming caused by human activities such as the use of fossil fuels and deforestation use so can provide environmental benefits such as reduction in global warming and wildfire occurrence risk and improvements in air quality and biodiversity which are explained on the following screens. Loss of habitat because of wildfires or pest outbreaks could result in a decrease or the extinction of some species that live in the forest. Overstocked forest areas are susceptible to wildfires and also show a lack of vigor (poor forest health).

However, silvicultural practices such as thinnings have been used to reduce the excessive amount of biomass and, thus, risk of wildfire and pest infestations. This practice also produces small diameter wood that has an additional market value.

The price of ethanol will be variable and highly dependent of the location of the ethanol plant, the availability of woody biomass and the local forestry infrastructure. This price is likely to be passed onto you in the form of an increase of the price of gasoline you currently use at the pump.

In the next pages several alternative implementation plans are described to you and you will be asked to evaluate them as if you were voting in a local referendum. Please go through them carefully and vote for the plan that best reflects your preference for the use of fuel ethanol.

In the next section we want you to evaluate 6 different scenarios. These scenarios consist of several plans for implementing forest biomass based production of fuel ethanol, in this particular case, a 85% blend or E85. The plans differ based on the extent of changes in the following:

- REDUCE CO_2 EMISSIONS (50-60%, 61-70%, 71-90% reduction of CO_2 per mile traveled)
- IMPROVE BIODIVERSITY (1-25%, 26-50%, 51-75% improvement of biodiversity by reducing wildfire risk & improving forest health)
- INCREASE PRICE OF THE FUEL AT THE PUMP (an additional extra payment of $0.3, $0.6, $1 and $1.5 per gallon).

Each scenario describes 2 alternative plans (A and B). Please indicate whether you choose Plan A or B and how certain you are with that choice (i.e., how easily it was to make). Plans A differ between scenarios, so please read them carefully. Plan B will always reflect the status quo, which is the current situation of having no change regarding the emissions of CO_2 and biodiversity improvement.

Which of the plans would you choose?

Please choose	Plan A	Plan B
Reco2	Reduction of CO_2 between 61-70% per mile traveled	No reduction (0%)
Biomp	Improvement of biodiversity between 1-25%	No improvement (0%)
Prem	Additional payment of $0.60 per gallon at the pump	No extra payment ($0)

APPENDIX C
COMPLETE HISTORICAL DATA SET

Table C-1. Yearly dataset

Year	Y_{sv} million m^3	Y_{pv} million m^3	Y_{bv} million m^3	w_{sv} \$ m^{-3}	w_{pv} \$ m^{-3}	w_{bv} \$ m^{-3}	w_{fl} \$ hour^{-1}	K_f million m^3
1970	39.64	57.41	12.97	35.42	28.90	9.48	3.43	2524.63
1971	43.50	53.65	16.12	41.40	28.98	8.33	3.77	2573.38
1972	44.05	54.60	17.57	46.92	29.06	7.56	4.11	2622.14
1973	44.05	55.59	20.36	52.71	30.04	6.26	4.41	2670.89
1974	38.54	57.34	20.69	47.86	31.78	6.55	4.75	2719.65
1975	38.54	49.52	19.74	39.36	30.09	7.07	5.11	2768.40
1976	45.31	52.59	24.88	46.61	29.94	5.86	5.83	2817.15
1977	48.43	52.59	27.57	52.04	29.30	4.95	6.36	2865.91
1978	48.91	53.76	27.42	62.94	29.70	4.46	7.01	2868.45
1979	47.96	58.17	28.89	75.70	29.74	4.52	7.71	2870.99
1980	40.05	62.07	26.88	59.35	27.73	5.88	8.36	2873.53
1981	37.65	61.64	26.35	53.17	27.10	6.95	8.81	2876.07
1982	29.84	58.18	26.26	40.73	28.21	7.58	9.47	2878.61
1983	34.93	58.74	29.97	44.68	28.23	7.43	9.84	2881.15
1984	36.28	59.75	31.13	43.13	24.77	7.68	10.35	2883.69
1985	34.59	56.38	31.08	32.26	28.64	7.90	10.56	2919.34
1986	62.30	60.54	31.12	31.57	28.84	7.31	10.46	2954.99
1987	65.49	62.67	32.12	40.36	29.60	6.86	10.33	2990.64
1988	67.62	61.38	30.57	42.42	29.37	7.32	10.43	2971.63
1989	65.49	60.39	29.06	42.45	29.55	7.62	10.76	2952.61
1990	67.09	68.34	28.14	44.23	28.74	7.69	10.85	2933.60
1991	67.96	70.00	27.52	46.98	31.48	7.98	10.70	2914.58
1992	73.02	68.27	30.30	53.50	32.87	6.92	10.80	2923.63
1993	86.50	64.16	29.26	64.75	33.43	5.45	11.00	2932.68
1994	89.87	66.26	30.24	77.32	28.72	5.02	11.06	2941.73
1995	86.01	68.08	29.22	88.00	32.73	5.95	11.26	2950.77
1996	76.46	65.45	27.66	76.00	29.43	5.42	11.37	2959.82
1997	76.80	71.39	29.47	91.04	34.04	5.26	11.76	2968.87
1998	76.82	71.69	30.60	92.10	36.16	5.63	12.07	2986.85
1999	81.09	68.14	29.84	82.75	30.93	4.83	12.80	3004.84
2000	79.67	61.29	30.19	83.28	26.76	5.67	13.25	3022.83
2001	77.33	58.10	29.01	73.70	26.70	5.57	13.93	3040.82
2002	80.13	59.31	29.02	79.16	27.80	5.63	14.27	3058.80
2003	81.86	64.10	24.52	71.07	26.86	6.06	14.46	3118.00
2004	87.38	67.15	24.76	71.50	25.56	4.83	14.54	3177.19
2005	91.01	64.87	26.17	68.79	25.80	5.31	15.22	3236.38
2006	75.52	65.93	26.58	70.79	25.78	5.75	15.56	3295.58

Table C-1. Continued

Year	w_{pe} \$ KWh^{-1}	w_{pl} \$ hour^{-1}	P_p \$ ton^{-1}	K_p million ton year^{-1}	w_{se} \$ KWh^{-1}	P_s \$ ton^{-1}
1970	0.050	3.51	127.26	30.79	2.97	38.77
1971	0.049	3.68	129.23	32.32	3.10	45.34
1972	0.048	3.85	133.67	32.38	3.23	51.28
1973	0.049	4.09	143.53	33.98	3.50	63.53
1974	0.051	4.42	178.56	35.00	3.77	62.39
1975	0.054	4.88	200.26	35.57	4.13	59.36
1976	0.055	5.33	211.11	36.13	4.58	73.50
1977	0.055	5.81	219.49	37.15	4.95	88.78
1978	0.057	6.36	229.85	37.97	5.43	103.06
1979	0.058	6.95	257.97	40.50	5.89	109.75
1980	0.057	7.64	292.99	41.18	6.36	100.66
1981	0.059	8.38	322.09	42.15	6.78	98.76
1982	0.060	9.08	339.85	43.07	7.21	96.74
1983	0.060	9.68	350.70	44.07	7.57	108.23
1984	0.055	10.15	374.87	44.31	7.79	108.23
1985	0.055	10.56	384.73	45.05	7.98	101.79
1986	0.053	10.90	394.60	44.36	8.09	101.54
1987	0.052	11.14	413.83	45.59	8.15	110.38
1988	0.052	11.40	442.94	46.71	8.35	108.74
1989	0.050	11.66	468.09	47.44	8.58	104.57
1990	0.047	12.00	479.44	47.82	8.81	107.60
1991	0.044	12.40	485.35	49.33	8.97	107.48
1992	0.043	12.74	493.25	49.38	9.16	126.29
1993	0.044	13.08	500.15	49.23	9.32	163.30
1994	0.043	13.42	517.91	51.06	9.55	176.56
1995	0.041	13.87	584.99	50.85	9.82	161.53
1996	0.041	14.31	573.15	50.06	10.13	171.89
1997	0.040	14.68	570.00	51.16	10.44	180.08
1998	0.040	15.12	580.06	51.32	10.77	171.20
1999	0.040	15.57	591.40	49.06	11.12	179.71
2000	0.041	15.84	624.30	47.57	11.58	155.81
2001	0.041	16.44	628.04	44.93	11.90	147.58
2002	0.039	17.06	632.12	46.40	12.13	140.52
2003	0.041	16.88	645.71	46.50	12.33	140.71
2004	0.043	17.45	665.08	45.69	12.64	172.84
2005	0.045	17.53	688.53	45.47	12.77	167.74
2006	0.044	18.36	713.34	45.66	13.32	156.32

Table C-1. Continued

Year	K_s million ton year^{-1}	w_{bl} \$ hour^{-1}	w_{be} \$ ton^{-1}	K_p million KWh year^{-1}	P_b \$ KWh^{-1}
1970	13.90	22.59	0.00346	0.070	127.40
1971	17.23	22.03	0.00347	0.068	139.53
1972	20.56	24.85	0.00342	0.068	156.22
1973	23.89	24.65	0.00321	0.068	172.91
1974	25.25	20.79	0.00403	0.067	189.60
1975	26.60	18.95	0.00389	0.070	202.80
1976	27.96	19.07	0.00428	0.070	210.50
1977	28.94	18.22	0.00467	0.070	222.50
1978	29.91	18.10	0.00481	0.071	233.30
1979	30.89	17.96	0.00507	0.073	238.10
1980	31.86	16.18	0.00545	0.071	237.40
1981	32.22	15.61	0.00586	0.074	250.00
1982	32.57	15.27	0.00583	0.075	266.70
1983	32.93	15.76	0.00588	0.075	261.40
1984	33.28	15.84	0.00576	0.071	267.60
1985	33.64	16.10	0.00560	0.071	278.10
1986	34.00	16.61	0.00537	0.069	283.00
1987	34.35	17.38	0.00541	0.069	285.70
1988	34.71	17.86	0.00535	0.069	290.10
1989	35.06	17.81	0.00529	0.068	295.39
1990	35.42	18.05	0.00524	0.066	295.39
1991	35.78	17.67	0.00526	0.064	296.84
1992	36.13	17.88	0.00527	0.063	300.76
1993	36.49	18.35	0.00514	0.063	304.79
1994	36.84	19.07	0.00492	0.063	309.68
1995	37.20	19.28	0.00487	0.061	312.99
1996	39.40	19.76	0.00474	0.061	318.95
1997	40.30	20.59	0.00458	0.060	320.39
1998	42.30	21.74	0.00466	0.061	322.42
1999	42.70	22.53	0.00470	0.061	325.96
2000	43.30	22.89	0.00483	0.062	342.72
2001	43.90	22.39	0.00465	0.062	361.09
2002	44.40	23.03	0.00452	0.060	392.85
2003	45.20	23.08	0.00462	0.062	414.07
2004	46.40	23.52	0.00455	0.064	422.94
2005	48.20	23.37	0.00483	0.066	428.46
2006	48.60	22.24	0.00495	0.067	429.01

APPENDIX D
VOLUMES AND PRICES OF SAWTIMBER, PULPWOOD AND BIOMASS FOR BIOENERGY 1970-2006

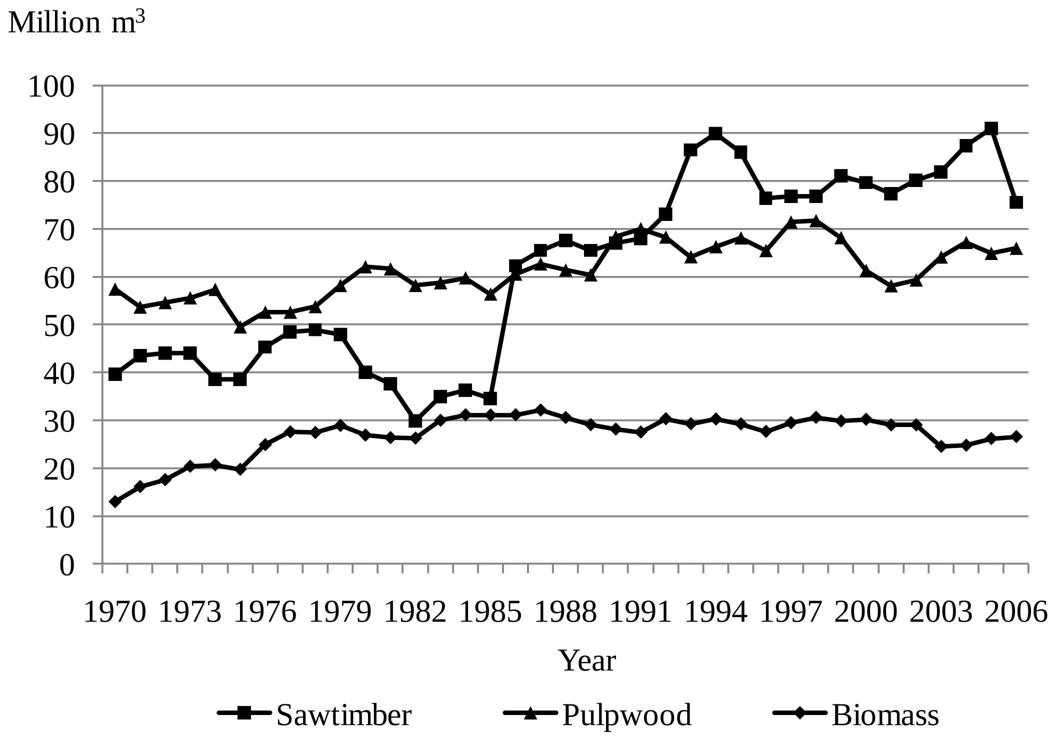

Figure D-1. Volume (Million m^3) of sawtimber, pulpwood and biomass for bioenergy 1970-2006

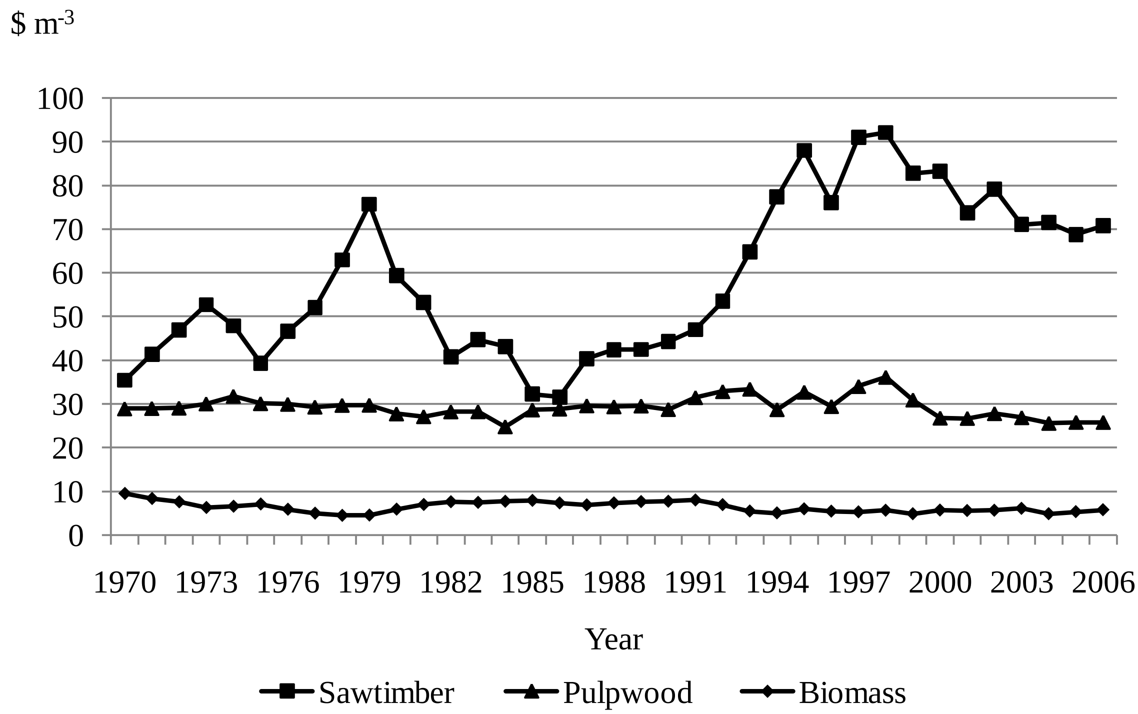

Figure D-2. Stumpage Price ($ m^{-3}) of sawtimber, pulpwood and biomass for bioenergy 1970-2006

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BIOGRAPHICAL SKETCH

Andres Susaeta was born in Santiago de la Nueva Extremadura, aka Santiago, Chile. He earned a Forestry Engineering degree with a specialization in Forest Management at the University of Chile in 1999. In 2003 and after working three years in National Center for the Environment and Faculty of Forest Sciences at the University of Chile as a research assistant, Andres was awarded the New Zealand Aid International Development (NZAID) Scholarship to pursue a Master of Forestry Science focused on forest economics in the land of the Lord of the Rings. After graduating in 2005 and working for an environmental NGO in Chile, Andres was offered a scholarship to start his Ph.D. at the University of Florida focusing on forest economics and policy.