Dissertationes Forestales 46

Econometric models of Finnish non-industrial private forest owners' timber supply and timber stock

Ibrahim Moulifla Favada

Department of Forest Economics
Faculty of Agriculture and Forestry
University of Helsinki

Academic Dissertation

To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki, for public criticism in Auditorium XIV of the Main Building, Fabianinkatu 33, October 19, 2007, at 12:00 noon.

Title:
Econometric models of Finnish non-industrial private forest owners' timber supply and timber stock

Author:
Ibrahim Moulifla Favada

Series title and issue number:
Dissertationes Forestales 46

Supervisor:
Prof. Jari Kuuluvainen; Department of Forest Economics, University of Helsinki.

Co-supervisor:
Prof. Jussi Uusivuori; Finnish Forest Research Institute (METLA).

Pre-examiners:
Dr. Anne Toppinen; Program Manager, European Forest Institute.

Dr. Sjur Baardsen; Department of Ecology and Natural Resource Management, Norwegian University of Life Sciences.

Opponent:
Prof. Jeffrey P. Prestemon; Forestry Sciences Laboratory, SRS, USDA Forest Service, Research Triangle Park, NC 27709.

ISSN 1795-7389
ISBN 978-951-651-181-4 (PDF)

(2007)

Publishers:
Finnish Society of Forest Science
Finnish Forest Research Institute
Faculty of Agriculture and Forestry of the University of Helsinki
Faculty of Forestry of the University of Joensuu

Editorial office:
Finnish Society of Forest Science
Unioninkatu 40 A, 00170 Helsink, Finland
http://www.metla.fi/dissertationes

Favada, I.M. 2007. Econometric models of Finnish non-industrial private forest owners' timber supply and timber stock. Dissertationes Forestales 46. 31 p. Available at http://www.metla.fi/dissertationes/df46.htm

ABSTRACT

This dissertation examines the short- and long-run impacts of timber prices and other factors affecting NIPF owners' timber harvesting and timber stocking decisions. The utility-based Faustmann model provides testable hypotheses of the exogenous variables retained in the timber supply analysis. The timber stock function, derived from a two-period biomass harvesting model, is estimated using a two-step GMM estimator based on balanced panel data from 1983 to 1991. Timber supply functions are estimated using a Tobit model adjusted for heteroscedasticity and nonnormality of errors based on panel data from 1994 to 1998. Results show that if specification analysis of the Tobit model is ignored, inconsistency and biasedness can have a marked effect on parameter estimates. The empirical results show that owner's age is the single most important factor determining timber stock; timber price is the single most important factor in harvesting decision. The results of the timber supply estimations can be interpreted using utility-based Faustmann model of a forest owner who values a growing timber *in situ*.

Keywords: Timber supply modeling approaches, short-run and long-run price elasticities, partial adjustment, inverse hyperbolic sine Tobit model, sawlog, panel data.

PREFACE

The present dissertation focuses on two reciprocal issues, timber supply and timber stock, concerning non-industrial private forestland in Finland. These issues are relevant to Finnish forest policymakers concerned with structural changes in forest ownership and the roundwood market and to international policy regarding forest certification and conservation of biodiversity. The findings of this dissertation provide insight into the harvesting and timber stocking behavior of non-industrial private forest owners in Finland.

This dissertation is part of the “Economics of Non-industrial Private Forestry in Finland” project led by Jussi Uusivuori, who co-supervised this work along with Jari Kuuluvainen. I am greatly indebted to Jari and Jussi for their guidance, encouragement, and fruitful comments, without which this dissertation would not have been possible. My fervid thanks and appreciation go to Heimo Karppinen, Jarmo Mikkola, and Corinne Stavness for their collaboration.

I am also grateful to Sjur Baardsen and Anne Toppinen for their constructive comments as pre-examiners of this dissertation. My sincere gratitude extends to Steven Yen of the University of Tennessee for providing his GQOPT source codes, which inspired me.

Finally, I wish to extend my sincere gratitude to the Academy of Finland (project 48795) and the Graduate School in Forest Sciences for funding my studies. My sincere gratitude goes to the faculty and staff of the Department of Forest Economics of the University of Helsinki for their support. I dedicate this work to the “one who has two eyes”.

Helsinki, October 2007

Ibrahim Moulifla Favada

LIST OF ORIGINAL ARTICLES

This doctoral dissertation is based on the following articles, which are referred to by their Roman numerals:

I. Kuuluvainen J., **Favada, I. M.**, and Uusivuori, J. 2006. Empirical behaviour models on timber supply. *In* The theory and practice of environmental and resource economics. Essays in honour of Karl-Gustaf Löfgren, Edward Elgar, Cheltenham, UK. pp. 225-245.

II. **Favada, I.M.**, J. Kuuluvainen, and J. Uusivuori. 2007. Optimal timber stock in Finnish nonindustrial private forests. Forest Policy and Economics 9: 527-535.

III. **Favada, I.M.**, J. Kuuluvainen, and J. Uusivuori. 2007. Consistent estimation of long-run nonindustrial private forest owner timber supply using micro data. Canadian Journal of Forest Research (In press).

IV. **Favada, I.M.**, H. Karppinen, J. Kuuluvainen, J. Mikkola, and C. Stavness. The effects of prices, owner characteristics and ownership objectives on timber supply (Submitted manuscript).

The first two articles are reprinted with permission.

Studies **I** and **III** were jointly developed by Favada, Kuuluvainen and Uusivuori. Favada analyzed the data and wrote the manuscript which was extended and jointly revised by the authors. In study **II,** Favada developed the study idea, analyzed the data and wrote the manuscript, which was jointly revised by the authors. In study **IV,** Karppinen, Mikkola and Stavness did the principal component analysis and wrote the first manuscript. This manuscript was modified and extended by Favada and Kuuluvainen. Favada re-analyzed the data and rewrote the manuscript which was jointly revised by the authors.

TABLE OF CONTENTS

ABSTRACT 3
PREFACE 4
LIST OF ORIGINAL ARTICLES 5
TABLE OF CONTENTS 6

1. INTRODUCTION 7
   1.1. Background 7
   1.2. Study objectives 8

2. NIPF OWNERS IN FINLAND 9
   2.1. Ownership characteristics and objectives 9
   2.2. NIPF owners in the Finnish forest sector 9
   2.3. Institutional changes affecting forest owners 12

3. THEORETICAL FRAMEWORK AND TIMBER SUPPLY LITERATURE 12
   3.1. The optimal rotation problem 12
   3.2. Short- and long-run timber supply 12
   3.3. Previous theoretical models 13
   3.4. Previous empirical models 16

4. EMPIRICAL MODELS AND DATA 18
   4.1. Dynamic panel data model 18
   4.2. Tobit model 19
   4.3. Data 21

5. MAIN RESULTS OF SEPARATE STUDIES 21
   5.1. Empirical behavior models on timber supply (I) 21
   5.2. Optimal timber stock in Finnish non-industrial private forests (II) 22
   5.3. Consistent estimation of long-run non-industrial private forest owner timber supply using micro data (III) 22
   5.4. Effects of prices, owner characteristics, and ownership objectives on timber supply (IV) 23

6. DISCUSSION AND CONCLUSION 23
   6.1. Contribution of the dissertation 23
   6.2. Factors affecting timber supply and timber stock 24
   6.3. Limitations and policy implications 25
   6.4. Conclusion and areas of future research 25

REFERENCES 27

SUBSTUDIES (I-IV)

1. INTRODUCTION

1.1. Background

Non-industrial private forest (NIPF) owners control less than 16% of the world's forestland, but this is steadily increasing due to continuing privatization, especially in transitional economies (FAO 2005).[1] In temperate boreal forest resource assessment (TBFRA) countries (UN-ECE/FAO 2000), NIPF owners account for 39% of the total forests available for wood supply and about 26% of the total forest area under management. At the national level, NIPF owners' shares of the total forests available for wood supply are especially important, e.g., in Portugal (79%), Norway (78%), and Finland (62%).

NIPF ownership and management information is essential for understanding the choice of forest production on private forestland. The need for such information becomes an overarching issue when NIPF owners' forestland base is the main source of a nation's timber production. Forest ownership involves owner and holding characteristics as well as ownership objectives, while forest management involves silvicultural and harvesting activities. The literature on NIPF owner behavior is vast, mostly appeared in North America (e.g. Romm et al. 1987, Dennis 1989, Kline et al. 2000) and in the Scandinavia (e.g. Lönnstedt 1989, Kuuluvainen 1989, Bolkesjø and Baardsen 2002).

In Finland, researchers have studied ownership structure (e.g. Ovaskainen and Kuuluvainen 1994, Ripatti 2000), ownership objectives (e.g. Kuuluvainen et al. 1996), harvesting decisions (e.g. Koskela 1989a), and reforestation decisions (e.g. Järveläinen 1971, Ovaskainen et al. 2006). The two-period biomass harvesting model (e.g. Koskela 1989a, 1989b, Kuuluvainen 1989, Ovaskainen 1992) has been widely used as the theoretical framework in the analysis of timber supply from non-industrial private forests in Finland. Recently, however, the utility-based rotation model has been increasingly used (e.g. Tahvonen 1998, Kuuluvainen and Tahvonen 1999, Tahvonen and Salo 1999, Tahvonen et al. 2001, Salo and Tahvonen 2002, Uusivuori and Kuuluvainen 2005).

Kuuluvainen and Tahvonen (1999) were the first to present the intertemporal and parametric effects of price on the timber supply using a utility-based rotation model. They apply a two-stage estimation method in which the first stage provides a short-run effect using a fixed effects model. In the second stage, the long-run effects are estimated by assuming that the individual constant terms obtained from the fixed effects Tobit model represent the location of the long-run timber supply functions of individual forestland owners. Their results show that the short-run price effect is positive, while the long-run price effect is negative; both effects are statistically significant. However, the Monte-Carlo simulations show that the second stage estimates have a large variance from sample to sample. Because of this inefficiency, the long-run price elasticity is unrealistically large, and there are few cross-sectional observations in the panel data.

Specification analysis of the Tobit model has received little attention in the literature on NIPF timber supply. Carlén (1990, p. 65) discusses the likelihood ratio test of the assumption of the Tobit model that the discrete and continuous decisions are explained by the same set of explanatory variables, but their marginal impacts on the two decisions are

---

[1] The 2005 Global Forest Resources Assessment by FAO gives only a global share of the total private ownership of forestland, including private individuals, companies and other groups. Private individuals account for a higher proportion of all privately owed and managed forests in the temperate boreal forest zone (UN-ECE/FAO 2000).

allowed to vary. Kuuluvainen (1989) tests the homoscedastic assumption of errors by examining the Tobit residuals. Testing the distributional assumptions of the Tobit model is important, because the maximum likelihood (ML) produces inconsistent and biased estimates when the assumptions of homoscedasticity and normality of errors are violated (Maddala 1983).

In addition, few studies have addressed NIPF owners' timber stocking decisions. Using pooled data, Kuuluvainen (1989) estimates a dynamic linear regression model for growing timber stock (m^3/ha). The findings show that the economic factors determining annual timber sales influence the short-run variation in timber stock. Kuuluvainen and Tahvonen (1997) explore factors affecting long-run equilibrium levels of NIPF timber stock using cross-sectional data and the static linear regression model. The results show that forest owners follow some long-term harvesting policies and keep the average timber stock at a fairly constant level. However, the short-run dynamic adjustment of the timber stock and factors affecting the optimal timber stock level have not been explored using statistically consistent estimation methods.

1.2. Study objectives

This dissertation explores the impact of cross-sectional and intertemporal variations in price and other factors affecting NIPF owners' timber harvesting and timber stocking decisions using a consistent estimation method. This research examines previous empirical studies on NIPF owner behavior and attempts to link theoretical and empirical models on NIPF timber supply and timber stocking. The specific objectives of this dissertation, which translate into separate studies, are as follows:

- To examine the link between the theoretical models of timber supply and the data used in the econometric analyses (Study **I**);
- To analyze the factors affecting NIPF owners' timber-stocking behavior and the short-run adjustment of the observed timber stock to the optimal timber stock level (Study **II**); and
- To explore short- and long-run timber price effects, owner characteristics, and ownership objectives (Studies **III** and **IV**).

Study **I** presents a literature survey of econometric studies using individual forest and forest-owner observations. Study **II** focuses on timber stock to determine the gap between short-term observed and optimal stock levels. Study **III** tests the Faustmann hypotheses of the effects of timber prices and other relevant exogenous variables on timber supply using a Tobit model, allowing corrections for heteroscedasticity and nonnormality of errors. In Study **IV**, ownership objectives are used to group forest owners into objective categories for timber supply analysis using the consistent estimation method. In Studies **III** and **IV**, the effects of the exogenous variables on the mean annual per hectare harvest are divided into the effects on the conditional mean and the probability of a non-zero harvest. This makes interpreting the effects of exogenous variables on harvests using the rotation model more straightforward.

The results of this study provide more insight into NIPF owners' harvesting and stocking behavior. Findings on short- and long-run effects of timber price on the timber supply are useful for understanding the economic behavior of NIPF owners. Findings on owner age reveal the bequest motive and *in situ* preferences of NIPF owners.

The remainder of this dissertation is presented as follows. Chapter 2 discusses owner characteristics, ownership objectives, the role of NIPF owners, and changes affecting forest owners. Chapter 3 provides a selected literature review of previous theoretical and empirical models on timber supply. The empirical models, econometric specifications, and data are described in Chapter 4. Chapter 5 summarizes the separate studies, and Chapter 6 presents the discussion and conclusion.

2. NIPF OWNERS IN FINLAND

2.1. Ownership characteristics and objectives

The main ownership characteristics are occupational status, age, place of residence, sex, number of holdings, area of holdings, number of owners, possession of holdings, owner education, possession of management plan, and objective of holding (Ovaskainen and Kuuluvainen 1994, Karppinen and Hänninen 2006). In Finland, about 443,000 forest holdings have at least 2 ha and are classified as small holdings (about 125,000) having less than 4 ha; middle holdings (about 315,000) having 31 ha on average; and large holdings (about 4,000) having 86 ha on average. Figure 1 shows that about 31% of forest holdings range from 20 to 49 ha (Finnish Statistical… 2006). There are at least twice as many owners as holdings, because a forest holding may be owned by a single owner, by families, or by heirs (Karppinen and Hänninen 2006).

In Finland, NIPF survey for 1990 indicate that there are more male farmers than female farmers and that women are usually older than men (Ripatti 1997). A study using 1999 NIPF survey also reports a larger proportion of male forest owners (Karppinen and Hänninen 2006). The forecast of ownership characteristics for 2020 shows an increase in the number of non-farmer, female, and non-resident owners (Ripatti and Järveläinen 1997, Ripatti 2000). Despite these structural changes in forest ownership, there is no evidence of a possible reduction in harvests from private forests.

NIPF owners have diverse objectives that influence their forest management behavior; these objectives are influenced by owner and forest characteristics (Karppinen 2000). In Finland, the first study on ownership objectives and timber supply identified four groups of forest owners: multi-objective owners, recreationists, self-employed, and investors (Kuuluvainen et al. 1996). However, Study **IV** reports the emergence of the fifth group of owners, indifferent owners, who do not have specific objectives for their forest holdings.

2.2. NIPF owners in the Finnish forest sector

NIPF owners have the largest share of forestland (60%), growing stock (64%) and annual increment of growing stock (68%). Figure 2 shows that non-industrial private forestlands are the main source of domestic roundwood supply in Finland. In 2005, these forestlands accounted for 84% of domestic roundwood sales (about 53 million m^3). NIPF owners shared 83% of domestic roundwood sales from 1990 to 2005. Annual domestic roundwood sales of NIPF owners plummeted in 1991 due to a recession (Figure 3). NIPF owners shared 87% of gross stumpage earnings for 2005 (about 1.6 billion Euros), with an average of 86% for the entire period. The gross stumpage earnings of NIPF owners tend to level off due to imports of roundwood from Russia (Figure 4).

Figure 1. Forest holdings classified bu forest land (as of January 1, 2005)

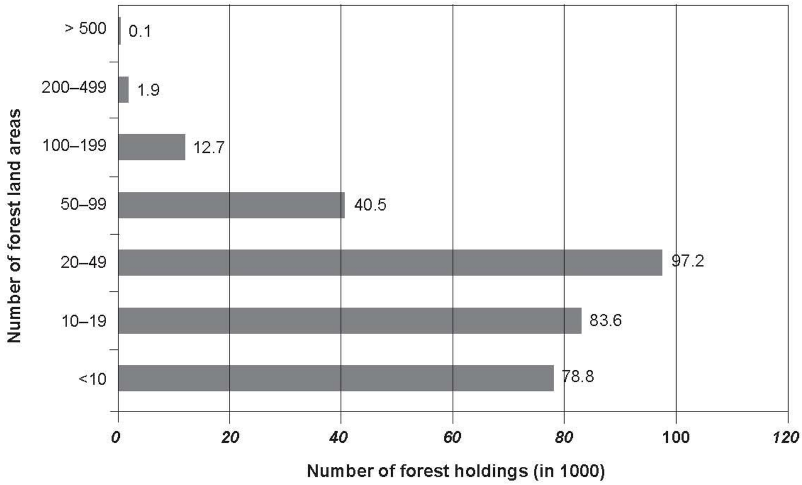


Figure 2. NIPF owners' share of forestland, growing stock and anual incremental growth.

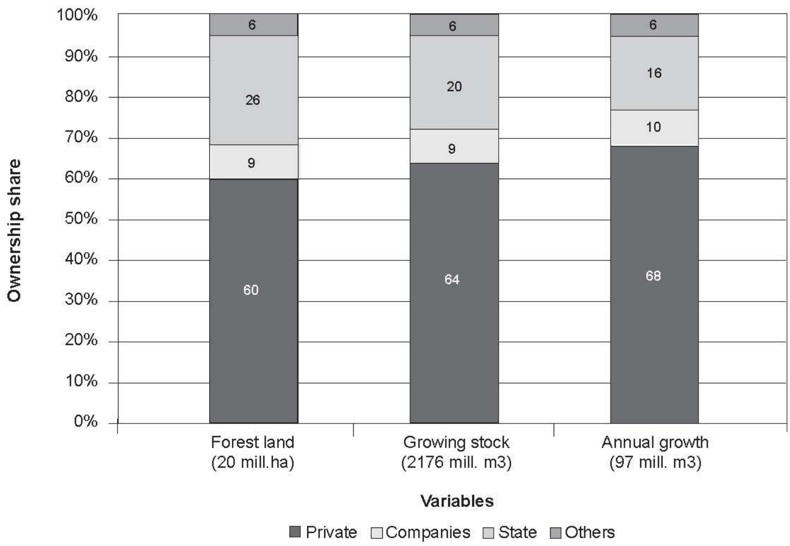


Figure 3. Domestic roundwood sales (1990–2005)

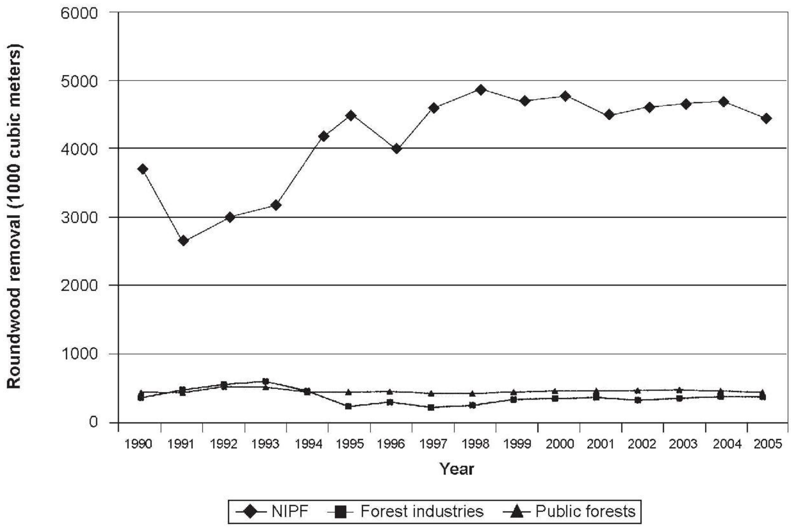
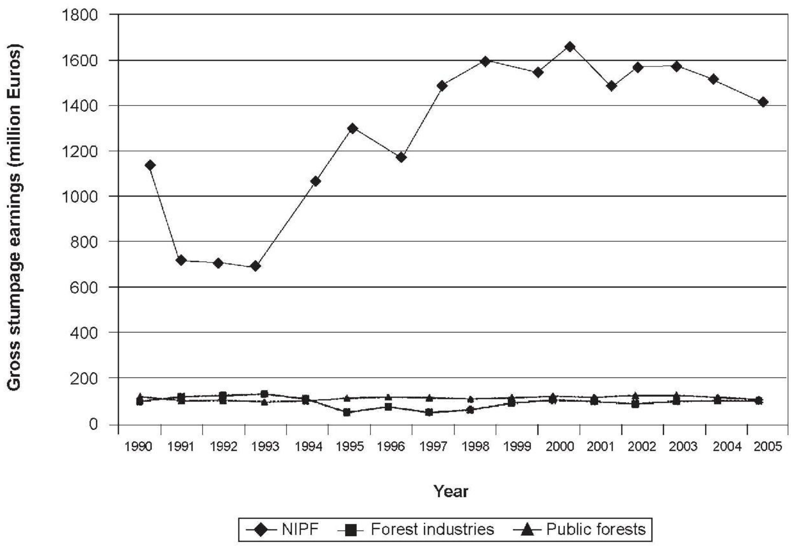


Figure 4. Gross stumpage earnings (1990–2005)



2.3. Institutional changes affecting forest owners

In the 1990s, significant structural changes occurred in the Finnish roundwood market that might have influenced the panel dataset used in this dissertation. These changes include mergers and acquisitions of forest industry companies, the abolition of stumpage price negotiation system, a surge in roundwood imports, and tax regime changes. Only the forest tax regime change was measured in the study data.

As a result of the consolidation of Finnish forest industry companies, three main buyers (UPM-Kymmene, Enso, and Metsä-Serla) accounted for 80 to 90% of the total pulpwood harvests (Toppinen 1998). In 2006, the main forest industry companies based on turnover were Stora Enso, UPM-Kymmene, Metsäliitto, and Myllykoski (Finnish Forest... 2007).

The stumpage price negotiation system instituted in the 1960s was abolished in 1991 due to disagreements between the forest industry and the association of forest owners over the national stumpage price level. It was reinstituted in 1994, without restrictions on wood imports, for regional price level negotiation. As a result of the lack of barriers, the quantity of wood imports as well as domestically produced wood increased significantly (Toppinen 1998). The stumpage price negotiation system was abandoned in 1999 due to European Union competition regulations.

In 1993, Finland implemented a tax reform, moving from area-based site productivity tax to a proportional profit tax. Forest owners were given a transitional period to avoid double taxation. After 2005, only the proportional tax remained in effect (Mutanen and Toppinen 2005).

3. THEORETICAL FRAMEWORK AND TIMBER SUPPLY LITERATURE

3.1. The optimal rotation problem

Timber growing as an economic enterprise entails investment decision-making. Consider a forest owner with 1 ha of bare land who plans to grow timber. He must prepare the land, plant the selected tree crops, and consider when to schedule harvests. Faustmann's (1849) solution to this problem is traditionally known as the Faustmann model (see survey of Newman 2002). An alternative approach introduced in the 1980s is based on biomass harvesting and forest owner consumption-saving decisions (e.g. Binkley 1980, Johansson and Löfgren 1982, Lohmander 1983). Recently, a third approach that blends the advantages of the other two perspectives has emerged (e.g. Hyberg and Holthausen 1989, Tahvonen 1998). These approaches will be discussed in detail in Sections 3.3.

3.2. Short- and long-run timber supply

Before discussing the theoretical and empirical models of this dissertation, it is important to distinguish between the short- and long-run timber supply. The neo-classic distinction is that the short-run relates to feasible immediate production plans in which some factors are fixed; the long-run relates to feasible eventual production plans in which all factors can vary (Varian 1996, p. 313). Following this distinction, the production period in forestry is longer than those in most industries and may generally extend beyond the lifetime of the capital employed for forest management and often longer than the forest owners' lives (Williams and Nautiyal 1990).

In applied forest economics, the short-run timber supply refers to optimal harvest timing, given an initial mature timber stock (Ovaskainen 1992, Binkley 1987a, Jennings and Matysek 2000). The long-run timber supply refers to the average sustainable harvest level beyond the adjustment period of timber stock (Clark 1976, Binkley 1987a). In panel data econometrics, annual fluctuations in timber prices, for instance, represent short-run responses, while the long-run responses refer to differences between cross-sectional units (Baltagi and Griffin 1984, Pirotte 1999).

3.3. Previous theoretical models

The basic Faustmann model assumes that a forest owner maximizes the present value of bare forest land $V(t)$:

$$\max_t V(t) = \left[pq(t)e^{-rt} - w\right]\left(1 - e^{-rt}\right)^{-1}, \tag{1}$$

where p is the stumpage price, $q(t)$ is the volume of stand that depends on age t, r is the real market interest rate, and w is planting cost. Under the assumptions of strict concavity of growth function $q(t)$, perfect markets and certainty, the equilibrium condition for optimal rotation age for an infinite rotations (e.g. Johansson and Löfgren 1985, Montgomery and Adams 1995) is

$$pq'(t^*) = rpq(t^*) + rV(t^*). \tag{2}$$

This states that the marginal benefit from letting a stand grow $pq'(t^*)$ must equal the opportunity cost of capital in timber $rpq(t^*)$ and land $rV(t^*)$.

Differentiating totally Equation (2), we find that the optimal rotation t^* is a function of stumpage price p, planting cost w, and interest rate r:

$$t^* = t^*(p, w, r). \tag{3}$$

The certainty assumption implies that stumpage price, planting cost, and interest rate are constant over time. Therefore, the comparative static effects must be interpreted as once-and-for-all changes in the levels of the exogenous variables. The implicit equation for the long-run equilibrium harvest $h(t^*)$, obtained by dividing the stand volume by optimal rotation age t^* in Equation (3), is expressed as follows:

$$h(t^*) = q(t^*)/t^*(p, w, r), \tag{4}$$

where p and r have a negative effect and w has a positive effect on the long-run equilibrium optimal rotation age t^*. The effects of these variables on the equilibrium per land unit harvest depends on whether the initial rotations are under or above the maximum sustained yield (MSY) rotation; in this case, they are under the MSY.

Two important assumptions of the basic Faustmann model are constant and known prices and perfect capital markets. The assumption of a perfect capital market precludes owner's preferences (e.g. Lohmander 1983, Kuuluvainen 1989). The assumption of price certainty is untenable; several studies (e.g. McConnell et. al. 1983, Newman et al. 1985, Brazee and Mendelsohn 1988, Brazee and Bulte 2000) show that timber price change is an important determinant of harvest timing. These limitations have sparked interest in the two-period model, which allows timber prices to vary between periods and incorporates owner's preferences when market imperfection or non-market amenities of forests are considered.

Lohmander (1983) introduces a Fisherian consumption-saving model of a forest owner assumed to maximize his utility of consumption over two periods. His model is known as the basic two-period model of timber supply analysis (see also Binkley 1980, Johansson and Löfgren 1982). In Finland, the basic two-period model has been extended to include, for example, owner consumption decisions, market imperfections, non-market amenities (e.g. Kuuluvainen 1989, 1990, Kuuluvainen and Salo 1991), and taxation (e.g. Koskela 1989a, 1989b, Ovaskainen 1992). The equilibrium condition of the basic two-period model is

$$q_1(1+r) = (p_2 / p_1)q_2, \tag{5}$$

where p_1 and p_2 are present and future timber prices, respectively; r is the interest rate; and q_1 and q_2 ($q_1 = q_0\text{-}H_1$, $q_2 = q_1[1+F'(q_1)]$) are the first and second period timber volume per unit of land area, respectively, after harvest. The initial timber volume is q_0. Forest growth as a function of the stock, $F'(q_1)$, is strictly concave. The implicit short-run function for the first period harvest H_1 is written as

$$H_1 = H(p_2 / p_1, r, q_0), \tag{6}$$

where p_1, r, and q_0 have an increasing impact and p_2 has a decreasing impact on the first period timber supply. The planting cost w in Equation (4) does not appear in Equation (6), because the basic two-period model ignores land allocation between the present and future stands as well as the age-class structure of growing timber.

In comparison (see Ovaskainen 1992 p. 10–13), the basic Faustmann model addresses present value maximization with age dependent growth, whereas the basic two-period model addresses utility maximization with volume dependent growth. The equilibrium state and comparative statics of the basic Faustmann model yield the long-run harvest, while those of the two-period model yield the short-run[2] harvest, which is described by the first period harvesting decision. However, Equation (4) also has short-run supply implications due to the immediate adjustment to the observed once-and-for-all change in relative prices

[2] The short-run effect of the two period model depends on the length of the perceived periods. Uusivuori and Kuuluvainen (2005) show that, when the two-period model is extended to multiple periods, it becomes a discrete-time version of the Faustmann model (1849) or the Hartman model (1976).

or the interest rate (Clark 1976). Equation (6) has long-run implications through the stock remaining after the first period harvest (Ovaskainen 1992).

The advantages of the basic Faustmann and the two-period model sparked interested in the utility-based rotation model (Tahvonen 1998, see also Hyberg and Holthausen 1989). Tahvonen (1998) developed different versions; we examine the model having *in situ* preferences:

$$\max_{\{c\geq 0\}} W = \int_{t_1}^{T} \left[U(c) + A(x)\right] e^{-\delta t} dt \tag{7}$$

$$s.t.\ \dot{a} = \rho a + m - c \tag{8}$$

$$a(t_1) = a(t_1^-) + px(t_1^-) - w \tag{9}$$

$$\dot{x} = F(x) \tag{10}$$

$$x(t_1) = x^0 \tag{11}$$

$$a(T) \geq 0, \tag{12}$$

where W is the maximized value of utility of consumption $U(c)$, c is consumption, and *in situ* preferences $A(x)$ is a function of the standing timber volume x. Denote the annual interest rate ρ, the level of non-forest assets a, non-forest income m, stumpage price p, subjective time preference δ, planting cost w, the date when the stand is cut t_1, and the length of a decision maker's life cycle T. The date when the stand is cut $t_1 = t_1^-$ when t_1 approaches t_1^- from below. Equation (8) is the change in the level of non-forest assets, and Equation (9) the value of non-forest assets after the stand is cut, which equals the level of assets before cutting $a(t_1^-)$ plus the income from the cut $px(t_1^-)$ less planting cost w. The forest growth function $F(x)$ is concave and $F(x) = F(\bar{x}) = 0,\ \bar{x} > 0$.

The comparative statics of the optimal rotation age (Tahvonen 1998) are expressed as follows:

$$t_1^* = t_1^*(\overset{\pm}{p}, \overset{+}{\dot{p}}, \overset{\pm}{w}, \overset{+}{m}, \overset{+}{a_0}, \overset{\pm}{\rho}, \overset{-}{T}). \tag{13}$$

The implicit timber supply function (Kuuluvainen and Tahvonen 1999) from Equation (13) can be derived as:

$$h(t_1^*) = x(t_1^*(\gamma)) / t_1^*(\gamma), \tag{14}$$

where $x[t_1^*(\gamma)]$ the volume of standing timber in m^3 and γ represents the terms in parenthesis of the right hand side of Equation (13). By differentiating Equation (14) with respect to γ, we obtain:

$$\partial h(t_1^*) / \partial\gamma = \partial t_1^* / \partial\gamma \left(\dot{x}(t_1^*) t_1^*(\gamma) - x(t_1^*)\right) / t_1^*(\gamma)^2. \tag{15}$$

The term $\dot{x}(t_1^*) t_1^*(\gamma) - x(t_1^*)$ is negative (positive) if the rotation period is longer (shorter) than the MSY rotation (Binkley 1987b). For a detailed discussion on the comparative statics in Equation (14), see Kuuluvainen and Tahvonen (1999) and Studies **III** and **IV**.

It should be noted that the basic Faustmann model is widely used in theoretical studies on timber supply, especially in North America. In Scandinavia, the two-period model was more popular in the 1980s and 1990s, but now the utility-based rotation model is increasingly used. Differences in the assumptions about NIPF owners explain the choice of a particular approach. In North America, NIPF owners are usually assumed to be profit maximizers, whereas in Scandinavia, utility maximizers under market imperfections. This dissertation follows the Scandinavian tradition, since forest owners are assumed to derive utility from consumption and *in situ* preference of forests. The theoretical framework for Study **II** is the two-period model presented by Kuuluvainen et al. (1996). This model was chosen to examine the short-run adjustment of the observed stock level to the optimal stock level. By nature, the two-period model yields short-run impacts of exogenous variables. The utility-based rotation model presented by Kuuluvainen and Tahvonen (1999) underpins Studies **III** and **IV**. This model allows us to investigate both the short- and long-run impacts of timber prices.

3.4. Previous empirical models

In the empirical literature on NIPF owners' harvesting decisions, the theoretical background is based on the two-period model and the utility-based rotation model. Study **I** provides a detailed discussion on the lack of testing of the Faustmann hypotheses**.** Empirical studies using individual forest-owner and forest-level data can be grouped into reduced form models and structural models. The reduced form models can be further divided into binary choice models and limited dependent variable models (Table 1). This dissertation focuses on the latter.

This section presents previous studies on NIPF owners' harvesting behavior using the Tobit model as well as the data used and limitations of each study. The type of data used determines what the empirically estimated coefficients of exogenous variables describe. Cross-sectional data have often been used in Tobit models to analyze NIPF owners' harvesting behavior. Some studies, however, have used cross-sectional time-series data (e.g. Hyberg and Holthausen 1989, Carlén 1990, Prestemon and Wear 2000). Recently, the use of panel data has become more common (e.g. Kuuluvainen and Tahvonen 1999, Bolkesjø and Baardsen 2002, Bolkesjø and Solberg 2003, Bolkesjø et al. 2007).

In surveys on NIPF owner behavior, either harvest measured in m^3/year or the qualitative binary information on whether the owner has harvested or not is recorded. Unfortunately, neither the harvested area nor the stand age at the time of harvest has been recorded in past surveys on NIPF owners.[3] In contrast, stand age at the time of harvest is often recorded in forest inventory data, which provide little or no information on owner characteristics. Moreover, the distributional assumptions of the Tobit model have been seldom tested in previous studies on NIPF owners' behavior (Kuuluvainen 1989). This questions the reliability of the estimated coefficients using ML estimation which yields inconsistent and biased estimates in the presence of heteroscedasticity and nonnormality of errors (Nelson 1981, Arabmazar and Schmidt 1981, 1982, Maddala 1983).

[3] The datasets used in this dissertation do not have information on harvested area and stand age at the time of harvest. This has serious implications for testing the Faustmann hypotheses. Therefore, we divide harvest per m3/year by forestland area to obtain harvest per m3/year/ha.

Table 1. Reduced and structural form models of harvesting decisions.

Study	Location	Reduced form		Structural form	Topic
		BVM[a]	LDVM[b]		
Binkley (1981)	Canada	Logit model			Harvest choice
Carlén (1986)	Sweden		Tobit model		Harvest quantity
Loikkanen et al. (1986)	Finland		Tobit model		Harvest quantity
Jamnick and Becknett (1988)	USA	Logit model			Harvest choice
Dennis (1989)	USA		Tobit model		Harvest quantity
Hyberg and Holthausen (1989)	USA		Tobit model		Harvest quantity
Kuuluvainen (1989)	Finland		Tobit model		Harvest quantity
Aronsson (1990)	Sweden		Tobit model		Harvest quantity
Carlén (1990)	Sweden		Tobit model		Harvest quantity
Dennis (1990)	USA	Probit model			Harvest choice
Provencher (1995a)	USA			Structural estimation	Harvest choice
Provencher (1995b)	USA			Structural estimation	Harvest choice
Kuuluvainen et al. (1996)	Finland		Tobit model		Harvest quantity
Lee (1997)	USA	Probit model			Harvest choice
Provencher (1997)	USA			Structural estimation	Harvest choice
Kuuluvainen and Tahvonen (1999)	Finland		Tobit model		Harvest quantity
Prestemon and Wear (2000)	USA	Probit model			Harvest choice and quantity
Bolkesjø and Baardsen (2002)	Norway		Tobit model		Harvest quantity
Bolkesjø and Solberg (2003)	Norway		Tobit model		Harvest quantity
Bolkesjø et al. (2007)	Norway		Tobit model		Harvest quantity

[a] BVM: Binary variable model.
[b] LDVM : Limited dependent variable model.

4. EMPIRICAL MODELS AND DATA

4.1. Dynamic panel data model

A dynamic panel data model is used in Study **II** to analyze the adjustment of the observed timber stock s_{it} to the optimal timber stock level s_{it}^{*} in non-industrial private forests. To motivate the dynamic panel data model, consider a representative forest owner who, seeing a deviation between his observed and optimal stock levels, partially adjusts so that the change in observed stock level may be only a fraction δ of the desired change (see Maddala 2001, p. 408):

$$S_{it} - S_{it-1} = \delta\left(S_{it}^{*} - S_{it-1}\right),\ 0 \le \delta \le 1 \qquad (16)$$

where δ is the adjustment coefficient assumed to be constant over forest owners and time. The optimal stock level for owner *i* in year *t* s_{it}^{*} can be written as:

$$s_{it}^{*} = \alpha_0 + \alpha' V_{jit} + u_{it}\ , \qquad (17)$$

where i = 1...N; t = 1...T; V_{jit} = J x 1 vector of exogenous variables; α = J x 1 vector of coefficients; and α_0 is constant.

Solving for the observed stock S_{it} in Equation (16), substituting the expression for S_{it}^{*} in Equation (17), and adding up error terms yields an estimable timber stock function as follows:

$$S_{it} = \gamma S_{i,t-1} + \gamma_0 + \gamma_j V_{it} + \gamma_i Z_i + \gamma_t Z_t + \varepsilon_{it}\ , \qquad (18)$$

where $\gamma = (1-\delta)$, $\gamma_0 = \delta\alpha_0$, $\gamma_j = \delta\alpha_j$, $\gamma_i = \delta\alpha_i$, $\gamma_t = \delta\alpha_t$, the owner-specific effect is denoted as Z_i, and the time-specific effect is denoted as Z_t. The error term ε_{it} is assumed to be IID with mean 0 and variance σ.

The vector of exogenous variables V_{jit} is obtained from the implicit timber supply function derived by Kuuluvainen et al. (1996). Excluded from this vector are credit limit, subjective rate of time preferences, and amenity preferences of the forest owner, because these variables are not available in the study data and cannot be directly observed. Owner debt and age are included, based on findings in the previous empirical studies on timber supply discussed in Section 3.4. The effects of the omitted variables are captured by the fixed effects model (Hsiao 2003, p. 30). In addition, the use of the fixed effects model is justified, since the dataset only contains information on farmer owners (Judson and Owen 1999).

In dynamic panel data estimation, both fixed and random effect models may lead to biased and inconsistent estimators when the lagged dependent variable is correlated with the error term, which may be serially correlated. Therefore, Arrelano and Bond's (1991) two-step GMM estimator is used.

4.2. Tobit model

The Tobit model is used to analyze quantitative harvesting decision of NIPF owners. It suits to analyze a problem with censored dependent variable (zero harvest in this study; see Tobin 1958). First introduced by Loikkanen et al. (1986), the Tobit model has been widely applied in several studies to understand the harvesting behavior of NIPF owners (see also Carlén 1986). The standard Tobit model presents a forest owner's harvesting problem in reduced form as

$$\begin{aligned} h_j &= h_j^* = \beta' x_j + u_j \quad if\ h_j^* > 0 \\ h_j &= 0 \quad otherwise \end{aligned}, \tag{19}$$

where h_j* is the latent variable (propensity to harvest), h_j is the observed harvest for the j^{th} forest owner, β is a k x 1 vector of unknown constants, and x_j is a k x 1 vector of explanatory variables. In the standard Tobit model, the error term u_j is assumed to be normally and independently distributed with mean zero and constant variance σ^2.

To account for heteroscedasticity of errors, the standard deviation of the residual is parameterized as a function of continuous explanatory variables that are potential sources of heteroscedasticity (e.g. Su and Yen 1996, Yen et al.1996):

$$\sigma_j = exp(\alpha' z_j), \tag{20}$$

where z_j is a vector of continuous explanatory variables and α represents the heteroscedasticity parameters to be estimated. To correct for the nonnormality of errors, the dependent variable is transformed using an inverse hyperbolic sine (IHS) as follows:

$$h_j^T = log\left[\Omega h_j + (\Omega^2 h_j^2 + 1)^{1/2}\right] / \Omega = sinh^{-1}(\Omega h)/\Omega, \tag{21}$$

where Ω , defined over all values, is the unknown nonnormality parameter to be estimated (Burbidge et al. 1988, Reynolds and Shonkwiler 1991, Yen et al. 1996). Hence, a standard Tobit model adjusted for heteroscedasticity and nonnormality of errors using the IHS transformation becomes a heteroscedastic IHS Tobit model:

$$\begin{aligned} h_j^T &= h_j^{T*} = \beta' x_j + u_j \quad if\ h_j^* > 0 \\ h_j^T &= 0 \quad otherwise \end{aligned}, \tag{22}$$

where h_j^{T*} is the transformed latent variable, h_j^T is the transformed observed harvest for the j^{th} forest owner.

Under the assumption of normality of the error term u_j, the sample log-likelihood function for an independent sample of n observations (in the case of heteroscedastic IHS Tobit model) is

$$
\begin{aligned}
\log L = & \sum_0 \log\left[1-\Phi\left(\frac{X_j{}'\beta}{\sigma_j}\right)\right] \\
& + \sum_1 \left[-\log \sigma_j + \log \phi\left(\frac{h_j^T - X_j{}'\beta}{\sigma_j}\right) - \frac{1}{2}\log(1+\Omega^2 h_j^2)\right].
\end{aligned}
\tag{23}
$$

We estimate Equation (23) and the corresponding cases for the heteroscedastic and homoscedastic Tobit model and homoscedastic IHS Tobit model using GQOPT 7.10 software (Studies **III** and **IV**).

The probability of observing a noncensored outcome (positive harvests) is

$$
P\left(h_j^T > 0\right) = \Phi\left[\frac{X_j{}'\beta}{\sigma_j}\right] \tag{24}
$$

and the expected mean harvest of all outcomes is

$$
E\left(h_j^T\right) = \int_0^\infty \left[\frac{h_j}{\sigma_j\sqrt{1+\Omega^2 h_j^2}}\phi\left(\frac{h_j^T - X_j{}'\beta}{\sigma_j}\right)\right] dh_j. \tag{25}
$$

In Equations (24) and (25), Φ and ϕ are cumulative standard normal distribution and standard normal density functions, respectively. The expected unconditional mean harvest can be obtained by dividing Equation (25) by Equation (24).

In censored regression models, the estimated coefficients represent only the impacts of the explanatory variables on the linear index $(X_j{}'\beta)$. Hence, we calculate the elasticities and discrete effects to assess the impacts of the explanatory variables on the probability of harvest, conditional and unconditional mean harvest. For example, the elasticities of expected mean harvest for each k^{th} continuous explanatory variable are calculated as follows:

$$
\left[\frac{\partial E\left(h_j^T\right)}{\partial x_{jk}}\right] \cdot \left[\frac{x_{jk}}{E\left(h_j^T\right)}\right]. \tag{26}
$$

For statistical inferences, we compute the standard errors of the elasticities and discrete impacts using the delta method. Denote $\varphi = [\beta,\alpha,\Omega]$ as a vector of parameters, e.g., of the heteroscedastic IHS Tobit model, with ML estimator $\hat{\varphi}$ and variance-covariance matrix $\hat{\Sigma}$. Let the k^{th} elasticity scalar be $\hat{\xi}_k = \hat{\xi}_k(\hat{\varphi})$ and the Jacobian of transformation from $\hat{\varphi}$ to $\hat{\xi}_k$ be G_k.We then approximate the variance of $\hat{\xi}_k$ by

$$Var\left(\hat{\xi}_k\right) = G_k \hat{\Sigma} G_k', \qquad (27)$$

where G_k is evaluated at $\hat{\varphi}$ and at the sample means of all explanatory variables. The first-order derivatives G_k are complicated, but can be evaluated with numerical differentiation.

4.3. Data

In this dissertation, two datasets are employed. The first dataset consists of Finnish NIPF owners' survey data from 1982 to 1991. A two-stage area cluster sampling is used, where a farm's probability of entering the sample is proportional to its total land area. The dataset includes 122 farmer forest owners interviewed in 1985, 1986, and 1991 in Southern Finland. This dataset is used in Study **II**, because it has a longer survey period. Kuuluvainen and Tahvonen (1999) use the first dataset, but their estimation was based on 119 forest owners (non-farmers).

The second dataset covering the period of 1994 to 1998 was collected in 1999 by the Finnish Forest Research Institute using a random sample of 8800 farmers and non-farmers (Karppinen et al. 2002, Karppinen and Hänninen 2006). From this dataset, we constructed two subdatasets consisting of 7440 observations over a four-year period (used in Study **III**) and 9070 observations over a five-year period (used in Study **IV**). It should be noted that only harvest and timber price vary.

5. MAIN RESULTS OF SEPARATE STUDIES

5.1. Empirical behavior models on timber supply (I)

In this survey, empirical studies on NIPF owners are reviewed and synthesized. In particular, we examine the link between theoretical models of timber supply, the data used in the empirical analysis, and the interpretations of the empirically estimated coefficients.

The survey finds three main timber modeling approaches: the Faustmann model, the two-period biomass harvesting model, and the utility-based rotation model. The basic Faustmann model has widely underpinned various theoretical studies on NIPF management behavior but has not been empirically tested. The use of the basic two-period models is declining, while the age-class utility-based rotation model is increasingly used in Scandinavia (e.g. Salo and Tahvonen 2002, Uusivuori and Kuuluvainen 2005). Empirical studies using individual forest and forest-owner level observations are classified into two broad categories: reduced form models (binary and censored) and structural harvesting decision models. The reduced form models such as logit, probit, and Tobit have been widely employed to examine NIPF owners' harvesting decisions.

The findings show timber price, whether discrete or continuous, is the single most important variable in NIPF owners' harvesting decision making. The results on the short-run transitional effects of prices on supply are consistent in most studies reviewed, while the policy-relevant quantitative measures on the long-run effects of price, cost, and interest rate are largely missing or inconsistent.

5.2. Optimal timber stock in Finnish non-industrial private forests (II)

This study analyzes the factors affecting NIPF owners' timber-stocking behavior and the short-run adjustment of observed to optimal timber stock level. A timber stock function is specified and estimated using Arrellano and Bond's (1991) two-step GMM estimator for balanced panel data of 1098 observations from 1983 to 1991.

The empirical results support partial adjustment of the observed timber stock level to the optimal level, but the speed of adjustment is relatively slow (0.151). This means that, on average, forest owners were faced with upward adjustment that involved either increasing silvicultural efforts or allowing the stands to grow for a longer period. In either case, the cost of making an adjustment is greater than the cost of being in disequilibrium for older forest owners who value their forests *in situ*. Therefore, they let the stands to grow for a longer period, thereby adjusting slowly. The owner's age and timber price were the two most important determinants of timber stock; with short-run impact[4] of 0.7 and -0.1 and long-run impact of 4.3 and -0.4, respectively.

5.3. Consistent estimation of long-run non-industrial private forest owner timber supply using micro data (III)

Despite vast theoretical studies based on the Faustmann model, empirical testing is rare. This is due mainly to difficulty in collecting relevant data on timber prices, reforestation cost, and interest rates. Previous empirical studies using the Tobit model have seldom tested distributional assumptions; the violation of these assumptions renders the ML estimates biased and inconsistent. This study tests the hypotheses of the utility-based Faustmann model and distributional assumptions of the Tobit model using panel data from 1994 to 1998. The analysis is based on the assumption that cross-sectional variation of the data (Baltagi and Griffin 1984, Pirotte 1999) can be used to study the long-run effects of the exogenous variables on timber supply.

The results confirm that ignoring specification analysis may lead to inconsistent ML estimates and misinterpretation of the theoretical hypotheses. The findings support positive price and income effects on timber supply under the utility-based Faustmann model when forest owners value standing timber *in situ*. The results further suggest that the long-run effect of timber price on the per-land-unit harvest rate is not statistically significant. This is a plausible result in light of the numerically computed long-run supply functions by Kuuluvainen and Tahvonen (1999). The empirical results can be related to the theoretical rotation model, assuming constant forestland area and exogenous regeneration costs. Forest

[4] The short- and long-run impacts differ from those discussed in Section 3.2. In the partial adjustment model, the short-run impact is the change that occurs in each period, while the long-run impact is the total change over the whole period (Greene 2000, p. 722).

owners who stayed in the area-based lump-sum taxation during the transition period (1993 to 2005) clearly harvested more than those who accepted the proportional profit tax in 1993. Thus, the transitional effects of taxation policy changes are important.

5.4. Effects of prices, owner characteristics, and ownership objectives on timber supply (IV)

The present study examines the short-run effects of stumpage price with other factors on NIPF timber supply in Finland, using the Tobit model and dataset similar to that described in Study **III**, The dataset in Study **IV** includes ownership objective variables.

The results suggest that annual variation in timber prices is an important determinant of the per-hectare harvest levels in the short-run. Estimated results of different model specifications also show that, if the distributional assumptions of the Tobit model do not hold, biased elasticities are obtained. No *a priori* predictions about the sign or the magnitude of the bias can be made (Maddala 1983).

The study corroborates earlier findings by Kuuluvainen et al. (1996) that ownership objectives have a statistically significant effect on timber supply. Those owners who value recreational opportunities most strongly or do not have any particular objectives for their forest ownership harvest about 2 m^3 per hectare per year less than multi-objective and self-employed owners. Per hectare timber volumes do not differ markedly between ownership objective groups. The lower harvest levels of recreationists may indicate that they are in a transition period and are adjusting to longer rotations, and therefore currently harvesting less.

Ownership objective groups identified in this study based on a survey conducted in the late 1990s were similar to those groups identified at the end of 1980s, indicating some consistency in ownership objectives. This is important for forest and forest-related environmental policy planners, such as forestry extension services providers. However, another group of owners, indifferent owners, do not have specific interests in their forest property. In addition, the difference in timber harvest levels between multi-objective owners and recreationists seems to have doubled since the late 1980s, while the difference between multi-objective owners and investors has stayed the same. These comparisons must be considered with caution, as Kuuluvainen et al. (1996) did not test the distributional assumptions and used a standard Tobit model with a smaller dataset.

6. DISCUSSION AND CONCLUSION

6.1. Contribution of the dissertation

This dissertation examines both the short- and long-run impacts of timber prices and other factors affecting NIPF timber harvesting and timber stocking decisions. It attempts to build a closer link between the theoretical and empirical models on timber supply and timber stock using a consistent estimation method in the econometric analyses. The utility-based Faustmann model (Kuuluvainen and Tahvonen 1999) provided hypotheses of exogenous variables, which were tested using a heteroscedastic IHS Tobit model for timber supply and a dynamic fixed effects model for timber stock. The effects of the exogenous variables on the mean annual per hectare harvest were divided into the effect on the conditional mean of a non-zero harvest and the effect on the probability of a non-zero harvest. The motivation for this dissertation is that timber price and owner age are important variables in NIPF owner's harvesting and stocking decisions (Beach et al. 2005). Hence, a consistent estimation of their short- and long-run effects yields reliable results that serve as the basis for effective policy recommendations.

6.2. Factors affecting timber supply and timber stock

In previous empirical studies on timber supply from private forests, timber price was the single most important variable in the NIPF owners' harvesting decision making. Its short-run effect was reported consistently, while its long-run effects were largely missing or inconsistent (see Study **I**). Empirical data do not seem to capture the long-run effect of timber prices, because forest owners may not have adjusted their harvest levels to equilibrium price levels.

This dissertation confirms the short-run effects of timber prices reported in previous studies on NIPF owners' timber supply (e.g. Carlén 1990, Bolkesjø and Baardsen 2002, Bolkesjø and Solberg 2003). The short-run effects of timber prices results from annual variation in timber prices. Most data used in previous empirical studies on timber supply from private forest have intertemporal variation in prices (Study **IV**). The long-run effect of timber price (measured by elasticity) on the per-land unit harvest rate is statistically insignificant. This result is supported by the numerically computed long-run supply functions by Kuuluvainen and Tahvonen (1999). However, Bolkesjø et al. (2007) find a positive and statistically significant high elasticity of price (4.677). In this study, the statistical insignificance of the long-run effect of timber price may be explained by less variation between cross-section units, as forest owners in the same commune perceive the same price level (Study **III**). This means that only intercommunal differences are considered, which may not be important.

The results confirm that ignoring specification analysis may lead to inconsistent ML estimates and misinterpretation. Misleading policy implications may have resulted from previous studies on timber supply using the Tobit model without specification analysis (see Studies **III** and **IV**). In this study, ownership objective groups identified based on survey data collected in the 1990s were similar to those groups identified in the 1980s. This indicates that the objectives of forest holdings have not changed over the study period (Study **IV**).

The effect of tax regime change is that forest owners who stayed in the area based lump-sum taxation harvested more than those who accepted the proportional profit tax. For owners in the area-based lump sum tax, taxation year 2006 meant a known timber price decrease in the future (Studies **III** and **IV**). The findings support the partial adjustment of the observed timber stock level to the optimal short-run level, with slow speed of adjustment (0.151). This means that forest owners adjust only about 15% of the gap between the actual and desired stock during the year. The owner's age is the single most important variable in the timber stocking decision making of NIPF owners (Study **II**).

6.3. Limitations and policy implications

The limitations of this dissertation are as follows. The annual timber stock at the beginning of each year was recursively calculated instead of being observed directly. Information on reforestation costs and individual interest rates were not available (Study **II**). The omission of non-farmer owners in Study **II** limits the interpretation of the results to farmer forest owners. In Studies **III** and **IV**, the theoretically correct measure of the size of the harvested areas in woodlots was not available, so a proxy (m^3/ha/yr.) was used. This approach, however, yields lower m^3/ha/yr if only a portion of the stand in the 60 to 100 age class was harvested. Consequently, the elasticities and discrete effects may be biased downward. There was also a lack of information on individual forest owner interest rates and reforestation costs. Because of these limitations, the results apply only to the samples under study. The impacts of institutional factors such as consolidation on the demand side, abolition of national stumpage price negotiation, and elimination of restrictions on import of wood and wood chips were not considered.

The theoretical frameworks, data, and econometric techniques applied produce results relevant to different policy settings. Therefore, policymakers must be aware of the particular theoretical framework, data, and econometric technique that produced results relevant to a particular forest policymaking; otherwise, the effectiveness of that forest policy may be greatly reduced.

The findings of this dissertation are relevant to the Finnish National Forest program 2015, in particular to the goals of increased commercial roundwood removal, biodiversity conservation, recreation, and multiple uses. Extension services and policies aimed at influencing timber harvest and biodiversity conservation on Finnish non-industrial private forestlands are more efficient when directed at particular groups of forest owners with knowledge of their ownership objectives. Forest banking as a means of ensuring sustainable forest management under discussion in North America (Sullivan et al. 2005) may not be needed in Finland for those forest owners who have *in situ* preferences and bequest motives. Given that price elasticity of the expected mean harvest is statistically insignificant, the long-run effects on the per ha timber supply of forest taxes and subsidies are difficult to measure. In contrast, transitional effects, such as tax regime changes, imply that a yield tax to all owners may not be a strong incentive to harvest.

6.4. Conclusion and areas of future research

In conclusion, timber price is the single most important variable affecting NIPF owners' harvesting decisions. The forest owner's age is important in timber stocking decisions among Finnish NIPF owners. Therefore, harvesting and non-harvesting decisions may not be a joint decision, as normally assumed. Given that the forest owner's age is important in timber stocking decision-making, possible structural changes in forest ownership with respect to owner age may have a great impact on projecting the timber supply from the Finnish non-industrial private forestland. The data used and the method of analysis yield results that are relevant to a particular forest policy decision making. Ignoring specification analysis of the Tobit model may result in misleading policy recommendations based on elasticities.

Further research is needed on NIPF owners' timber harvesting and timber stocking behavior. The availability of a suitable panel data including relevant variables is a prerequisite for a successful replication of this study. In particular, the long-run impacts of stumpage price, reforestation cost, and interest rate should be explored. As discussed by Provencher (1997), structural estimation of the Tobit or probit model is another promising area for future research. Because the assumption of the standard Tobit is restrictive (Smith and Brame 2003), its possible generalizations, such as double hurdle or infrequency of harvest models, should be employed. In timber stocking decision analysis, differences between forest owners should be explored to yield results that may increase understanding of forest holding objectives.

REFERENCES

Arabmazar, A. & Schmidt, P. 1981. Further evidence on the robustness of the Tobit estimator to heteroscedasticity. Journal Econometrics 17: 253-258.

__ & Schmidt, P. 1982. An investigation of the robustness of the Tobit estimator to non-normality.Econometrica. 50: 1055-1064.

Aronsson, T. 1990. The short-run supply of roundwood under nonlinear income taxation – Theory, estimation methods and empirical results based on Swedish Data. University of Umeå, Umeå Economic Studies No. 220, 166 p.

Arrellano, M. & Bond, S. 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an application to Employment Equations. Review of Economic Studies 58: 277-297.

Baltagi, B.H. & Griffin, J.M. 1984. Short and long run effects in pooled models. International Economic Review 25: 631-645.

Beach, R.H., Pattanayak, S.K., Yang, J.-C., Murray, B.C. & Abt, R.C. 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Policy and Economics 7: 261-281.

Binkley, C.S. 1980. Economic analysis of the allowable cut effect Forest Science 26: 633-642.

__ 1981. Timber supply from private forests. Bulletin. No 92, Yale University, School of Forestry and Environmental Studies, 97 p.

__ 1987a. Economic models of timber supply. In: The Global Forest Sector: an Analytical Perspective. (Kallio, M., Dykstra, D.P. & Binkley, C.S. eds.). John Wiley and Sons, Great Britain.

__ 1987b. When is the optimal economic rotation longer than the rotation of maximum sustainable yield? Journal of Environmental Economics & Management 14: 152-158.

Bolkesjø, T.F. & Baardsen, S. 2002. Roundwood supply in Norway: Micro-level analysis of self-employed forest owners. Forest Policy Economics 4: 55-64.

__ & Solberg, B. 2003. A panel data analysis of nonindustrial private roundwood supply with emphasis on the price elasticity. Forest. Science 49: 531-538.

__, Solberg, B. & Wangen, K.R. 2007. Heterogeneity in nonindustrial private roundwood supply: Lessons from a large panel of forest owners. Journal of Forest Economics 13: 7-28.

Brazee, R. & Mendelsohn, R. 1988. Timber harvesting with fluctuating prices. Forest Science 34: 359-372.

Brazee, R.J., & Bulte, E. 2000. Optimal harvesting and thinning with stochastic prices. Forest Science 46: 23-31.

Burbidge, J.B., Magee, L., & Robb, A.L. 1988. Alternative transformation to handle extreme values of the dependent variable. Journal of American Statistical Association 83: 23-127.

Clark, C.W. 1976. Mathematical Bioeconomics, New York, Wiley Interscience, 352 p

Carlén, O. 1986. The Swedish private non-industrial forest owner's cutting behavior –An econometric study based on cross-section data. Department of Forest Economics, Swedish University. of Agricultural Sciences; Umeå, Report 66, 53 p.

___ 1990. Private nonindustrial forest owners' management behavior: An economic analysis based on empirical data. Department of Forest Economics, Swedish University of Agricultural Sciences, Umeå, Report 92, 104 p.

Dennis, D. 1989. An econometric analysis of harvest behavior: Integrating ownership and forest characteristics. Forest Science 35: 1088–1104.

___ 1990. A probit analysis of harvest decisions using pooled time-series and cross-sectional data. Journal of Environmental Economics & Management, 18:176-187.

Hsiao, C. 2003. Analysis of Panel Data, 2nd ed., Cambridge University Press, Cambridge, 366 pp.

Faustmann, M. 1849. Calculation of the value which forest land and immature stands possess for forestry. Reprinted in Journal of Forest Economics 1: 7-44.

Forest Industry Cluster in Finland. 2007. Finnish Forest Industry Federation.

Finnish Statistical Yearbook of Forestry. 1994-1998, Finnish Forest Research Institute. [In Finnish with English summary]

___ 2006. Finnish Forest Research Institute. [In Finnish with English summary]

FAO 2005. Global forest resources assessment 2005. FAO, Rome.

Hartman, R. 1976. The harvesting decision when a standing forest has value. Economic Inquiry 81: 8-38.

Hyberg, B.T. & Holthausen, D.M. 1989. The behavior of nonindustrial private forest landowners. Canadian Journal of Forest of Research 19: 1014–1023.

Jamnick, M.S. & Beckett, D.R. 1988. A logit analysis of private woodlot owner's harvesting decisions in New Brunswick. Canadian Journal of Forest of Research 18: 330-336.

Jennings, S.M. & Matysek, A.L. 2000. Modelling private timber supply - a survey of approaches. Austrialian Forestry 63:53-50.

Johansson, P.O. & K.G. Löfgren. 1982. Six different results on the properties of the timber supply function. Report 39, Swedish University of Agricultural Sciences, Umeå. 14 p.

___ & K.G. Löfgren. 1985. The economics of forestry and natural resources, London, Basil Blackwell, 292 p.

Järveläinen, V-P. 1971. Factors influencing silvicultural activity. Communicationes Instituti forestalis Fenniae 73(2). 107 p.

Karppinen, H. 2000. Forest values and the objectives of forest ownership. Doctoral dissertation. University of Helsinki, Department of Forest Economics. 51 p. + Appendix.

___ & Hänninen, H. 2006. Monitoring Finnish family forestry. The Forest Chronicle: 82: 657-661.

Karppinen, H., Hänninen, H., and Ripatti, P. 2002. Suomalainen metsänomistaja 2000. Metsäntutkimulatoksen tiedonantaja 852, 83 p. [Finnish Forest owners 2000, In Finnish].

Kline, J.D., Alig, R.J., & Johnson, R.L. 2000. Fostering the production of nontimber services among forest owners with heterogeneous objectives. Forest Science 46: 302-311.

Kokela, E. 1989a. Forest taxation and timber supply under price uncertainty: Perfect capital markets, Forest Science 35: 150-159.

___ 1989b. Forest taxation and timber supply under price uncertainty: Credit rationing in the capital markets, Forest Science 35: 160-172.

Kuuluvainen, J. 1989. Nonindustrial private timber supply and credit rationing: Microeconomic foundations with empirical evidence from the Finnish Case. Department of Forest Economics, Swedish University of Agricultural Sciences. Report 85.

___ 1990. Virtual price approach to short-term timber supply under credit rationing. Journal of Environmental Economics & Management 19: 109-126.

___ & Salo, J. 1991. Timber supply and life cycle harvest of nonindustrial private forest owners: An empirical analysis of the Finnish case. Forest Science 37: 1011-1029.

___ & Tahvonen, O. 1997. Testing the forest rotation model: evidence from panel data. Finnish Forest Research Institute, Research Paper 644. 36 p.

___ & Tahvonen, O. 1999. Testing the forest rotation model: Evidence from panel data. Forest Science 45: 539-551.

___, Karppinen, H. & Ovaskainen, V 1996. Landowner objectives and nonindustrial private timber supply. Forest Science 42: 300-309.

Lee. K.J. 1997. Hedonic estimation of forest amenity values of nonindustrial private landowners, Doctoral Dissertation, North Carolina State University, Forestry and Economics, 80 p.

Lohmander, P. 1983. Optimal harvest policy under the influence of imperfections and uncertainty. Report 22, Swedish University of Agricultural Sciences, Umeå, 75 p.

Loikkanen, H.A., Kuuluvainen, J. & Salo, J. 1986. Timber supply of private nonindustrial forest owners: Evidence from Finland. Institute of Economics, University of Helsinki Research Report No. 50.

Lönnstedt, L. 1989. Goals and cutting decisions of private small forest owners. Scandinavian Journal of Forest Research 4: 259-265.

McCornnel, K.E., Daberkow, J.N. & Hardie, I.W. 1983. Planning timber production with evolving prices and costs Land Economics 59: 292-299.

Maddala, G.S. 1983. Limited dependent and qualitative variables in Econometrics. Cambridge University Press, New York. 401 p.

Maddala, G.S. 2001. An Introduction to Econometrics. 3rd Ed. John Wiley & Sons. 664 p

Montgomery, C. A., and D.M. Adams. 1995. Optimal timber management policies, in D.W. Bromely (ed.), Handbook of Environmental Economics, London, Basil Blackwell, p. 379-404.

Nelson, F.D. 1981. A test for misspecification in the censored normal model. Econometrica 49: 1317-1329.

Newman, D.H. 2002. Forestry's golden rule and the development of the optimal forest rotation literature. Journal of Forest Economics. 8: 5-27.

___, Gilbert, C.B. & Hyde, W.F. 1985. The optimal forest rotation with evolving prices. Land Economics 61: 347-353.

Ovaskainen, V. 1992. Forest taxation, timber supply and economic efficiency. Acta Forestalia 233, 88 pp.

___ & Kuuluvainen, J. (eds.). 1994. Yksityismetsänomistuksen rakennemuutos ja metsien käyttö. Metsäntutkimuslaitoksen tiedonantoja 484, 122 p. [Structural changes in non-industrial private forest ownership and the use of forests. In Finnish].

___, Hänninen, H., Mikkola, J.& Lehtonen, E. 2006. Cost-sharing and private timber stand improvements: A two-step estimation approach. Forest. Science 52:44-54.

Pirotte, A. 1999. Convergence of the static estimation toward the long run effects of dynamic panel data models. Economic letters. 63:151-158.

Prestemon, J.P. and D.N. Wear. 2000. Linking harvest choices to timber supply. Forest Science 46: 377-389.

Provencher, B. 1995a. Structural estimation of the stochastic dynamic decision problems of resource users: An application to the timber harvest decision, Journal of Environmental Economics & Management 29: 321-338.

___ 1995b. An investigation of the harvest decisions of timber firms in the South-East United States. Journal of Applied Econometrics 10: 57-74.

___ 1997. Structural versus reduced-form estimation of optimal stopping problems. American Journal of Agricultural Economics 79: 357-368.

Reynolds, A. & Shonkwiler, J.S. 1991. Testing and correcting for distributional misspecifications in the Tobit model: An application of the information matrix test. Empirical Economics 16: 313-323.

Ripatti, P. 1997. Profile of Finnish female owners and their timber sales behaviour.Scandinavian. Forest Economics 36: paper number 24.

___ 2000. Use of log-linear models in forecasting structural changes in Finnish non-industrial private forest ownership. Silva Fennica 34: 275-283.

___ & Järveläinen,V-P. 1997. Forecasting structural changes in non-industrial private forest ownership in Finland. Scandinavian Forest Economics 36: 215-230.

Romm, J., Tuazon, R. & Washburn, C. 1987. Relating forestry investment to the characteristics of nonindustrial private forestland owners in northern California. Forest Science 33: 197-209.

Judson, R.A. & Owen, A.L. 1999. Estimating dynamic panel data models: a practical guide for macroeconomists. Economics Letters 65 9-15.

Salo, S. & Tahvonen, O. 2002. On the optimality of a normal forest with multiple land classes. Forest Science. 48: 530-542.

Smith, D.A. & Brame, R. 2003. Tobit Models in Social Science Research: Some Limitations and a More General Alternative. Sociological Methods & Research 31: 364-388.

Su, S.B. & Yen, S.T. 1996. Microeconometric models of infrequently purchased goods: An application to household pork consumption. Empirical Economics 21: 515-533.

Sullivan, J., Amacher, G.S. & Chapman, S. 2005. Forest banking and forest landowners forgoing management rights for guaranteed financial returns. Forest Policy and Economics 7: 381-392.

Tahvonen, O. 1998. Bequests, credit rationing and in situ values in the Faustmann-Pressler-Ohlin forestry model. Scandinavian Journal of Economics 100: 466-492.

___ & Salo, S. 1999. Optimal forest rotation with in situ preferences. Journal Environmental Economics & Management 37: 106-128.

___, Salo, S. & Kuuluvainen, J. 2001. Optimal forest rotation and land values under borrowing constraint. Journal of Economic Dynamics &. Control 25: 1595-1627.

Tobin, J. 1958. Estimation of relationships for limited dependent variables. Econometrica 26: 24-36.

Toppinen, A. 1998. Econometric models on the Finnish roundwood market. Doctoral dissertation. University of Helsinki, Department of Forest Economics. 52 p. + Appendix.

UN-ECE and FAO 2000. Forest resources of Europe, CIS, North America, Australia, Japan and New Zealand, industrialized temperate/boreal countries, Geneva

Uusivuori, J. & Kuuluvainen, J. 2005. The harvesting decisions when a standing forest with multiple age-classes has a value. American Journal of Agricultural Economics 87: 61-76.

Varian, H.R. 1996. Intermediate Microeconomics: a Modern Approach, 4th ed. W. W. Norton & Company, Inc., New York, 650 pp.

Williams, J.S. & Nautiyal, J.C. 1990. The long-run timber supply function. Forest Science 36: 77-86.

Yen, S.T, Liu, S. & Kolpin, D.W. 1996. Analysis of nitrate in near-surface aquifers in the midcontinental United States: An application of the inverse hyperbolic sine Tobit model. Water Resources Research 32: 3003- 3011.