Economically Optimal Values and Decisions in Iranian Forest Management

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Abstract

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Stumpage price processes are estimated via regression analysis (with alternative autoregressive models) with data from the Iranian Caspian forests. The parameter estimates indicate that the stumpage price may be regarded as a stationary stochastic process.

The optimal harvest decisions were calculated via stochastic dynamic programming. The harvest decisions that maximize the expected present value of all profits over time are made adaptively, conditional on the latest available price and stock level information. The results show that it is possible to determine the optimal harvesting level for different price and stock states. We may increase the expected present value by more than 26% when we let optimal adaptive decisions replace optimal deterministic planning decisions.

Dynamic game theory is applied to analyze the timber market in northern Iran as a duopsony. The Nash equilibrium and the dynamic properties of the system based on marginal adjustments are determined. When timber is sold, the different mills use mixed strategies to give sealed bids. It is found that the decision probability combination of the different mills follow a special form of attractor and that centers should be expected to appear in unconstrained games. Since the probabilities of different strategies are always found in the interval [0,1], the boundaries of the feasible set are sometimes binding constraints. Then, the attractor becomes a constrained probability orbit. In the studied game, the probability that the Nash equilibrium will be reached is almost zero. The dynamic properties of timber prices derived via the duopsony game model are found also in the real empirical price series from the north of Iran.

Dynamic duopoly game theory was also used to analyze the sawnwood and pulpwood markets in northern Iran. The differential equation system governing the simultaneous optimal adjustments of the decision frequencies of the two players gives cyclical solutions.

Keywords: Iranian Caspian forests, stumpage price, growth function, stochastic dynamic programming, dynamic game theory, Nash equilibrium.

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Contents

Appendix

Papers I- IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Mohammadi, L. S., Lohmander, P. Stumpage prices in the Iranian Caspian forests (submitted).
II. Lohmander, P., Mohammadi, L. S. Optimal continuous cover forest management in an uneven-aged forest in the north of Iran (Forthcoming in *Journal of Agriculture Science*, Abstract, Forthcoming in *Proceedings of the 2nd meeting of the EURO-Working group on OR in Agriculture and Forest Management, Extended abstract, EURO XXI, 2006*).
III. Mohammadi, L. S., Lohmander, P. A game theory approach to the Iranian forest industry raw material market (Forthcoming in *Scandinavian Forest Economics*, No 41, *Proceedings of the Scandinavian Society of Forest Economics, 2006*).
IV. Mohammadi, L. S. A game theory approach to the Iranian sawnwood and pulpwood markets (submitted).

Introduction

The optimal values and decision in forest management may be studied from many different perspectives. We may consider different constraints, different kinds of objective functions and risk or uncertainty. In most cases, the introduction of new considerations affects the optimal decision rules in one way or another. The decisions are usually classified according to whether they are made under conditions of certainty, uncertainty or risk. Certainty is defined as the case when each decision alternative is known to lead invariably to a specific outcome. Risk is the case when each alternative leads to one of a set of possible outcomes and the probabilities of the possible outcomes are known. Uncertainty refers to the situations where there are such alternatives, each having as its consequence a set of possible outcomes, but the probabilities of the possible outcomes are unknown. Depending on the degree of the decision makers knowledge of the outcome, different decision criteria for evaluating and comparing decision alternatives have been suggested.

In the different studies reported in this thesis, the firms maximize the expected present values. In forest management, stochastic dynamic programming (SDP) is used as a tool. In the forest industry mills, game theory models are used based on the assumption that the players maximize the expected profits over time.

The optimal harvest decisions calculated in paper II are based on the stochastic stumpage price process estimated in paper I. The SDP method was used in the optimization. The second part of the thesis contains game theory. Papers III and IV cover this subject. In paper III, dynamic game theory is applied to analyze the timber market in northern Iran as a duopsony situation. In paper IV, a dynamic duopoly game was used to analyze the sawnwood and pulpwood markets in northern Iran.

Objectives

General objectives:

* To investigate how economically optimal harvest management should be performed in the north of Iran.

* To investigate the properties of the forest industry raw material and product markets in the north of Iran.

Specific objectives:

* To determine the optimal harvest policy in an uneven aged forest in the north of Iran via the SDP technique. The decisions of harvesting would be adaptively optimized to the latest price and stock information.

* To develop and evaluate dynamic game theory to analyze the timber market and products (sawnwood and pulpwood) markets as duopsony and duopoly situations, respectively.

Forests and forestry in Iran

The forests of Iran with an area of about 12.4 million hectares represent 7.5 percent of the total area of the country and are divided into five regional forest types as follows (Fig. 1).

1- The Caspian broadleaved deciduous temperate forests:
These forests are also called the Hyrcanian or Northern forests. They are located on the south coast of the Caspian Sea and the northern slopes of the Alborz Mountain which ranges from sea level to 2800 m altitude. The Caspian forests area is about 1.9 million ha. These forests grow, like a thin strip (800 km long and 20-70 km wide). These are the most valuable forests in Iran. Plentiful rainfall, a mild climate, and a long growing season have combined to create a dense forest of high-quality timber in the Caspian region. The species are hardwoods including: oak (*Quercus sp*), beech (*Fagus orientalis*), hornbeam (*Carpinus sp*), maple (Acer sp), ash (*Fraxinus excelsior*), alder (*Alunus sp*), basswood (*Tilia begonifolia*) and etc.

2- Arasbaran forests: These forests, located in north-western Iran, look like the Hyrcanian forest but some species are different.

3- Irano-Toranian forests: These cover an area of about 3 .5 million ha in the central plateau and mountainous part of the country. The climate is arid to semi-arid.

4- Zagrosian forests: The main species of these forests is oak. They are subject to over-exploitation and degradation due to intensive human activities and overgrazing.

5- The Khalijo-Ommanian forests: This region comprises the entire southern part of Iran .The climate is subtropical with hot summers.

All Iranian forests were nationalized in 1962 and the Forests and Ranges Organization (FRO) of Iran under the Ministry of Jihad-e-Agriculture is in charge of rehabilitation, harvest scheduling and supervision of forests. Industrial harvesting occurs only in the Caspian forest. Because of the severe climatic conditions and forest degradation, forests in other regions are not exploited for industrial wood production.

For the importance of Caspian forests in industrial harvesting this research is focused on these forests. Forest industries in these regions produce sawnwood, wood-based panels, as well as pulp and paper from hardwood species. The total stock at the Caspian forest is about 405 million m^3, average stock is about 213 m^3/ha and annual growth is about 3.5 m^3/ha (Saeed, 1992). Fig. 2 and 3 show the percent area of different inventory classes, volume and stem number in these forests (Research Institute of Forest and Rangelands of Iran).

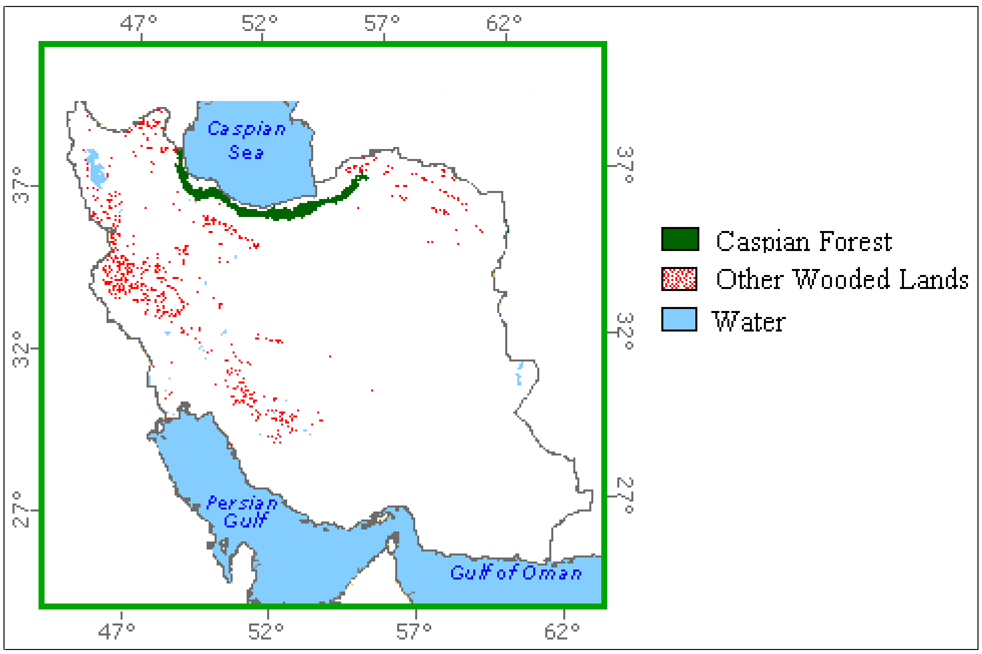

Fig. 1. Iranian forests distribution map (extracted from Global Forest Cover map, Rome, 1999).

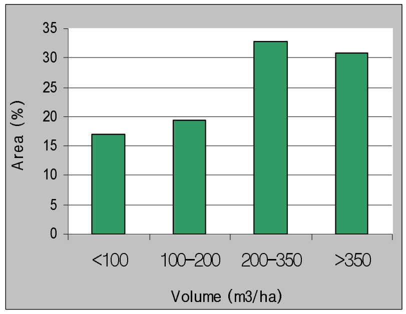

Fig. 2. Area percentage of volume per ha classes.

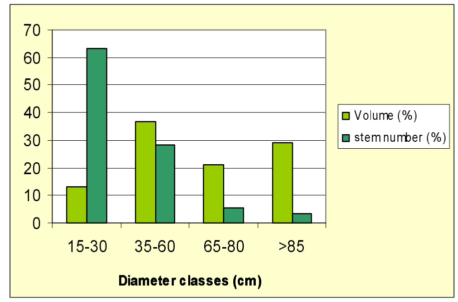

Fig. 3. Volume and stem number percentage in each diameter classes.

The economic role of forests became important in the nineteenth century when the exploitation of the northern forests of the country, mainly for timber for export, was transferred to foreign contractors.

Two types of forest management systems are currently utilized:
Shelterwood: A silvicultural program which creates an even aged stand.
Selection: A silvicultural program which creates and maintains an uneven-aged stand.

The first forest management plan was prepared based on the shelterwood method in 1959. This method is suitable for even-aged oak and beech forests in central Europe and without enough study this method was introduced in the Iranian Caspian forest which suffered from domestic animals (cows, sheep and goats) in the forest (Heshmatol Vaezin, 2000). Rapid urbanization and industrialization, intensive grazing, over-utilization of forests for firewood production and farming in wooded areas are amongst the main causes of deforestation in this area. Over the last few decades, swift forest degradation has brought about a number of environmental, social and economical impacts including soil erosion, floods, degradation of farmlands and habitats, reduction of biodiversity and natural resources and air and water pollution. Studies on animal husbandry indicate that there are 33,100 traditional animal husbandry units with 5.7 million domesticated animals in these forests (Shamekhi, 1993).

914,000 hectares representing 45% of the northern forests are currently managed by governmental, private sector and cooperative contractors in 392 districts (Sagheb-Talebi, Sajedi & Yazdian, 2003). 55% of these forests are outside the management plans and the state is trying to prepare forest management plans for this area. In this area the forests are used by the local people for grazing and fuel collection and the forests are continuously at risk of deterioration.

Statistical data show that during the last decades the forest area decreased and the number of heavy floods increased in north of Iran (Sobhani, 2000). During the past decade, considerable changes have been made in forest management plan principles due to the reinforcement of the ecosystem point of view. According to an approved rule by the Iranian FRO in 1997, the selection system is the only acceptable forest management method in the Iranian Caspian forests (Technical Office of FRO of Iran, 1997). Currently 80% of the forest management plans are shelterwood systems and 20 % are selection systems. The percentage of selection systems is increasing, because all of the new forest management plans are prepared based on selection system principles. There is a transfer from shelterwood to selection.

The selection system creates an uneven-aged forest. In forest management terms, uneven-aged forestry or continuous cover forestry (CCF) is called close to nature forest management. It has less visual impact than other methods, increases species diversity and reduces the soil erosion (Mason, Kerr & Simpson, 1999).

In order to keep the uneven-aged stand structures in these forests, it is important to determine the optimal extraction schedule. For this reason we study optimal CCF management.

There are sawmills in the north of Iran that compete in timber and product markets. The historical timber and product prices show that they fluctuate over time. It is important to investigate the behaviour of sawmills companies located in this area, competing in the timber and product markets. For that reason, dynamic game theory is used in this thesis.

Methods:

Optimal harvest volume

The SDP technique was used to determine the optimal harvest policy in CCF. In CCF environmental, recreational, aesthetic and other objectives are as important as timber production or timber and non timber products are important factors. In particular, CCF is seen as a means of reducing the impact of clear felling and the associated changes that this produces in forest landscapes and habitats.

Several past studies of uneven-aged forest management have dealt with the problem of finding the best cutting schedule that maximizes economic returns. The pioneering studies were based on deterministic approaches such as:

Duerr and Bond (1952), Duerr and et al (1956), Chang (1981), Hall (1983), Michie (1985). Because of the importance of taking risk into account in forestry decisions, in the past few decades, there have been a large number of studies dealing with risk in forest management decisions. Most of the studies have dealt with harvest decisions when the timber growth and/or timber prices are stochastic. Due to the nature of the problem, the most commonly used optimization technique is SDP.

Research on optimal harvest of uneven-aged forest with stochastic price and / or growth: Kaya and Buongiorno (1987) studied economic harvesting of uneven-aged Northern hardwood stands under risk. Their method determined the harvesting policies under uncertain stand growth and prices. Haight (1990) studied feedback thinning policies for uneven-aged stand management with stochastic prices. Buongiorno (2001) developed a generalization of Faustmann's formula for stochastic forest growth and prices with a Markov decision process model. Benedict *et al*. (1999) used the nonlinear programming method to determine the optimal forest management in a Loblolly pine (*Pinus taeda*) stand that maximizes the soil expectation value, average annual sawtimber production, and biodiversity. Francois *et al.* (2005) investigated the management strategy for uneven-aged forest in France with stochastic growth and price.

The previous studies are focused on European and American forests. You can not find any earlier study of the optimal harvest decisions via SDP in the Iranian northern forests. For that reason, we investigated the optimal harvest policy in the Iranian northern forests.

Here we use adaptive optimization. The most important differences between adaptive optimization and traditional deterministic optimization are the following: It is explicitly accepted that there are conditions in the environment that can not be perfectly predicted. Furthermore, decisions can take place over time and that later decisions should be based on the best and latest information concerning the exogenous conditions. The tradition of long term planning in forestry is based on the assumption that long term predictions with high precision are possible. Here we can mention that the traditional forestry assumption is not rational. Timber prices are difficult to predict accurately, since many thing may influence the markets. Therefore we can regard the stumpage price as a stochastic process. Many studies of optimal adaptive forest harvesting under influence of stochastic prices exist. Among them, we find Lohmander (1985, 1987a and 1987b), Brazee and Mendelsohn (1988) Brazee and Bulte (2000) and Rollin and *et al.* (2005).

Some other phenomena, such as the growth of the forest, may also be stochastic. Mostly, the price variation is the most important source of risk. The question under investigation is whether or not the present extraction level should increase or decrease under the influence of increasing risk in the stochastic price process.

In this thesis, the following first order autoregressive (AR) model was used to estimate the stumpage price processes:

$$P_{t+1} = \alpha + \beta P_t + \varepsilon_{t+1} \quad , \quad 0<\beta<1 \qquad (1)$$

We assume that ε_{t+1} is a series of normally distributed errors with mean zero and autocorrelation zero. Empirical data was used from the Iranian northern forests to estimate the parameters values of the first order AR model. The parameter values indicate that the price is a stationary AR process.

To estimate the forest growth, the following function was used:

$$G_i = \alpha_1 V_i + \beta_1 V_i^2 + \varepsilon_i \qquad (2)$$

G_i = growth (m^3/ha/year).

α_1 and β_1 are estimated parameters.

V_i = stock level (m^3/ha).

We assume that ε_i is a series of normally distributed errors with mean zero and autocorrelation zero.

By using the price and growth functions, the optimal harvest decision is determined via SDP, in discrete time. In the SDP, the periods are denoted t. $t \in \{0,1,2,.,T\}$. The final period, the horizon, is denoted T.

$f_t(m)$ is the optimal expected present value (in the beginning of period t) of all profits (revenues – costs) when m is the entering state of the system in period t. $R_t(m,u)$ is the profit in period t as a function of the entering state in the same period and the control (or decision and action) u.

$U(m)$ denotes the set of feasible controls as a function of the entering state. In a generalized setting, $U(.)$ could also be defined as function of time, which is however not necessary in this problem. In the final period, T, the optimal decisions and expected present values are determined from:

$$f_T(m) = \max_{u \in U(m)} \left\{ R_T(m,u) \right\} \quad \forall m \in M \qquad (3)$$

M is the set of states. The optimal decisions and expected present values in the earlier periods $t, t \in \{0,1,2,.,T-1\}$, are determined recursively via the backward algorithm of stochastic dynamic programming:

$$f_t(m) = \max_{u \in U(m)} \left\{ R_t(m,u) + d \sum_n p(n|m,u) f_{t+1}(n) \right\} \quad \forall m \in M \qquad (4)$$

$p(n|m,u)$ is the conditional probability of reaching state n in the next period if your entering state in this period is m and the control is u. d is the one period discounting factor.

$d\sum_n p(n|m,u) f_{t+1}(n)$ is the expected present value (expected in the beginning of period t) of all profits in the periods after period t in case the entering state in period t is m and decision u is made in period t.

In this analysis, the state space is two dimensional. The general problem description using state index m is still relevant. One state dimension is the stock level (m^3/ha) and the other dimension is the price level (€/m^3). The stock level grows according to a deterministic growth function. If harvesting takes place, the stock level is reduced accordingly. The price is assumed to follow a stochastic Markov process. Decisions are sequentially optimized based on the latest information concerning the state, which means that the stock level and the price level are correctly observed and known in the beginning of each period.

Game theory application

Game theory is the study of interacting decision makers. Game theory has applications in a variety of fields, including, operation research, economics, political sciences, military strategy, psychology and biology. Game theory seeks to find rational strategies in situations where the outcome depends not only on one's own strategy and "market conditions", but upon the strategies chosen by other players with possibly different or overlapping goals. The ambition in a game theory is to select an optimal strategy (that is, an optimum decision or a sequence of decisions) in the face of an opponent who has a strategy of his own.

Game theory has received much attention in economics.
Nash (1950) introduced the concept of Nash equilibrium. Schelling (1960) gave a good survey of the field of conflict strategy. Kalai and Smorodinsky (1975) present a wide spectrum of game models from economics and related

fields. Gibbons (1992) described different kinds of games. Basar & Olsder (1995) present static and dynamic noncooperative game theory in their book. Aumann and Hart (1992, 1994 and 2002) represent three volumes of a useful handbook of game theory with economic applications.

The dynamic games have been studied by Flåm (1990, 1996, 1999 and 2002), and Flåm & Zaccour (1991). The research presented in this paper is based on a similar approach, in the sense that the decisions are continuously adjusted. In this thesis, however, the decisions concern mixed strategy frequencies, not output volumes and prices directly. Lohmander (1994) studied the dynamics and non cooperative decisions in stochastic markets with a pulp industry application. Lohmander (1997) contains a general investigation of the constrained probability orbit of mixed strategy games with marginal adjustment. A general two person non-zero sum game (with zero as a special case) is analyzed. A doupsony application where two sawmills are competing in the timber market is included and the dynamic properties of the system are determined.

This research is rather similar to the earlier studies by Lohmander (1994 and 1997), but he did not use empirical data. Here the empirical data from the north of Iran was used to investigate the dynamic games in the timber market as (a duopsony) and in the products market (as a duopoly).

Koskela & Ollikainen (1998) studied a game theoretic model of timber prices in the Finnish pulp and paper industry. They considered special sets of hypotheses concerning the determination of timber price and quantity via negotiations. Carter and Newman (1998) examined the impact of reservation prices on timber revenues from federal timber sale auctions in North Carolina from a game-theoretic perspective by recognizing the effect of competition on optimal bid strategies

A game can be classified on the basis of several criteria. Depending on the number of players, we may have two-person, three-person or n-person games. Depending on the payoff situation a game can be classified as either constant-sum or nonconstant-sum. A constant sum game can be classified as a zero-sum or non-zero-sum games.

In the present studies, each player uses the latest and locally available frequency information in the decision process. We will deal with dynamic two person or non-zero-sum games. When players interact by playing a similar game numerous times, the game is called a dynamic or repeated game.

Two sawmills competing to buy raw material and sell their products in the market. Each sawmill (player) has in the example two different possible decisions: A high (H) or a low (L) bid. How much one player should give a bid? How much the other player will give a bid? This problem will be addressed in this thesis. The dynamic game will be applied to analyze the timber market as a duopsony and products market as a duopoly. The payoffs to the players in this dynamic game will be functions of the stage-game payoffs. We will find Nash equilibrium of this game. We will not assume that the players know exactly how the other players respond to by different decision combinations. Each player however observes the frequencies of the decisions taken by other player.

Results and discussion

This thesis gave the following results:

Stumpage price processes are estimated via first order AR model with data from the Iranian Caspian forests. The parameter estimates indicate that the stumpage price may be regarded as a stationary stochastic process. There are many things that affect the stumpage prices which are not predictable and depend on socio-economic conditions in the future. Changes in forest policies and regulations also have influences on future supply and/ or demand for stumpage. Since these conditions and economic parameters are stochastic, it is reasonable to handle future stumpage price as stochastic variables.

The optimal cutting rule for different price and stock levels are determined via the backward algorithm of SDP in discrete time. We assume that the stock level grows according to a deterministic growth function. If harvesting takes place, the stock level is reduced accordingly. The price is assumed to follow a stochastic Markov process. Decisions are sequentially optimized based on the latest information concerning the state, which means that the stock level and the price level are correctly observed and known in the beginning of each period.

The results show that the optimal harvest level is an increasing function of the net price and of the stock level. The expected present value is an increasing function of the net price and of the stock level. The expected present value was determined for deterministic and the real stochastic cases. Under deterministic assumptions, the optimal harvest interval is 6 (9) years, if the set up cost is 50 € (100 €) per hectare, and the present value is 2757.56 € (2551.62 €) per hectare. It is possible to take the fact that future price and growth are not yet known into account in the planning of forest harvesting. We can expect to gain from adaptive harvesting this way. The expected present value increased by 26.54%.

Dynamic two person non-zero-sum game was applied in a duopsony situation in the timber market and duopoly situation in sawnwood and pulpwood markets. The trajectories of the decision probability combination were investigated. It was found that a large number of initial conditions make the decision probability combination follow a special form of attractor and that centers can be expected to appear in typical games. The probability that the Nash equilibrium will be reached is almost zero. The differential equation system governing the simultaneous optimal adjustments of the decision frequencies of the two players give cyclical solutions. Real world games are complicated. Hopefully, the reader has found the analysis in this publication to be a step in the right direction. When we find a game in reality where the players use mixed strategies and change the frequencies over time, we have an indication that the present theory is relevant.

The properties of the empirical observations should be expected if our game model is relevant. Our interpretation is that the game model results closely match the real world data. Since we have not found any other model that gives more realistic results, we conclude that our game approach may be the best choice.

Conclusions

This thesis includes the following conclusions:

-Forest management:
We have found the optimal adaptive forest management rules using relevant parameters from Iranian Caspian forests. The optimal harvesting is a function of the price and stock level. The optimal expected present value is also a function of the price and stock levels.

-Raw material market:
We have found that the forest industry raw material market can be described as a duopsony. The time path of the raw material price difference between different mills shows cycles. Such cycles should be expected if the two competing mills use mixed strategies and continuously adjust the probabilities of different strategies to the frequencies used by the other mill.

-Forest industry product market:
We have also found that the forest industry product market can be described as a duopoly. The time path of the product price difference between different mills shows cycles. Such cycles should be expected if the two competing mills

use mixed strategies and continuously adjust the probabilities of different strategies to the frequencies used by the other mill.

-Functions:
We have also estimated volume growth functions for uneven age stands in the north of Iran. We have estimated the parameters of the stochastic stumpage price processes in the north of Iran. These functions were used in the forest management optimization model. Furthermore we analyzed the cycles of the raw material prices and product prices relevant to two forest industry mills. This analysis was used in connection to the duopsony and duopoly game model studies.

Suggested research

In paper II price risk is the only risk considered to determine the optimal harvesting rule. Growth is assumed to follow a deterministic model. Growth risk is also an important factor. Future research should contain both price and growth risk.

In the dynamic game model in paper III, the expected payoffs were calculated on the basis of two levels of timber and product (sawnwood and pulpwood) prices. It may be interesting to use more price levels and compare the expected payoff.

The dynamic game theory applications in this thesis concern duopsony and duopoly (two person non-zero sum game) situations. It can be interesting to use oligopsony and oligopoly (multi person game) cases in the future.

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