HELSINGIN YLIOPISTO
METSÄEKONOMIAN LAITOS
JULKAISUJA 7

THE PROFITABILITY OF SCOTS PINE (*PINUS SYLVESTRIS L.*) AND SILVER BIRCH (*BETULA PENDULA ROTH*) NEXT-GENERATION SEED ORCHARDS IN FINLAND

MÄNNYN (*PINUS SYLVESTRIS L.*) JA RAUDUSKOIVUN (*BETULA PENDULA ROTH*) SEURAAVAN POLVEN SIEMENVILJELYSTEN KANNATTAVUUS SUOMESSA

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ACADEMIC DISSERTATION

ISBN (NID.) 951-45-9459-2
ISBN (PDF) 951-91-2327-2
ISSN 1236-6226
Yliopistopaino
Helsinki 2000

To Anne and Roope

PREFACE

Since the early beginning of Finnish tree breeding, the main emphasis in the studies has been on biological and genetical aspects of the phenomenon. There has been a shortage of economic assessments on the subject. In all sincerity, I hope that my work might cater for this deficiency.

Over the past years, there have been several persons who have contributed towards my thesis, and now is the right time to pay respects for their efforts. First of all, I am most grateful to my supervisor Professor Matti Keltikangas - in brief, without his encouragement and guidance I would not have been able to finish this thesis. I would also like to thank Professor Pertti Pulkkinen for supporting me along the way. His ideas were integral for the development of the research theme in the first place (dating back to 1994). Dr. Pirkko Velling and Professor P.M.A. Tigerstedt are also sincerely acknowledged for their insights and comments on tree breeding. Further, I am indebted to Jarmo Leskinen (M.For.) who kindly introduced me to the simulation world of MELA, and who has helped me a great deal in the process. Thanks are also due to Mr. Kari Lahtinen, Hannu Kukkonen (M.For.), Martti Venäläinen (M.For.), Matti Haapanen (M.For.),Teijo Nikkanen (M.For.), Jouni Mikola (Lic. For.), Risto Hagqvist (M.For.), Juhani Hahl (M.For.), Martti Lepistö (Lic.For.), Anne Pakkanen (M.For.), Jukka Antola (M.For.), and Acting Professor Lauri Valsta for sound advice, helpful comments and collaboration over the course of the process.

I'm also grateful to Professor Jaakko Pehkonen, Dr. Matti Estola, and Dr. Kari Heimonen at the University of Jyväskylä for inspiring discussions concerning economics in general and modelling practice. For the rich interdisciplinary conversations over the past years, I would like to thank Professor Timo Takala (the supervisor of my wife's upcoming thesis). I would also like to express my deepest gratitude for the insightful comments and constructive critisim provided on my thesis by the official pre-examiners. Special thanks go to Kimmo Hyrsky (MA) whose support (in form of English revision) has become more and more important towards the end of this work.

The grants received from Suomen Luonnonvarain Tutkimussäätiö, the Ministry of Agriculture and Forestry, Niemi-Säätiö and Suomen Metsätieteellinen Seura are warmly acknowledged. Through this funding it has been possible for me to conduct research in a continouos fashion.

My deep gratitude is due to my parents - for the mental legacy they've passed on, and for the everlasting love which has given me space and motivation in pursuing my goal. Last but not least, I express my sincere thanks to my wife, Anne, who has been there for me through thick and thin. She has given me the life worth living - let alone our son, Roope whose impact on us has been "beyond words". And, finally those who have followed the different phases of my work might go along with the following latin phrase:

" *Dignus est enim operarius mercede sua* "

Jyväskylä
June 2000
Anssi Ahtikoski

ABSTRACT

The thesis consists of a theoretical section and five empirical studies analyzing the profitability of Scots pine (Pinus sylvestris L.) and Silver birch (Betula pendula Roth) breeding in Finland with special emphasis on the next-generation seed orchards. The profitability was calculated for three *a priori* chosen agents (government, orchard seed producer and private forest owner) by applying the so-called differential approach. In this approach, differential benefits of tree breeding (compared to stand seed acquisition) were weighted against the differential costs of tree breeding. Differential benefits were evaluated by incorporating genetic gains into widely-used growth and yield models (Scots pine: MELA and Vuokila & Väliaho, Silver birch: Oikarinen), and differential costs (compared to stand seed acquisition) were derived from, e.g., the cost data of the Forest and Park Service and the Foundation for Forest Tree Breeding. The net present value (NPV) was chosen as the investment criterium. The purpose of the assessments was to determine the so-called threshold values for the profitability, and further to examine whether these values would be obtainable, given the prevailing conditions of each agent. Specific shadow pricing procedure was adopted in the assessments made from the society's viewpoint (i.e. government), whereas simple financial analyses were conducted for the private forest owners and orchard seed producers.

The NPVs were positive for Scots pine even with *six* per cent discount rate (genetic gain 12%), and for Silver birch with *four* per cent discount rate (genetic gains being 20% for South and 14% for central Finland). In addition, the main results implied that there might even be some welfare improvements when breeding proceeds from the present to next generation. The analysis of market environment demonstrated that there are still economies of scale to be exploited with the orchard seed production of both species in the present generation. Further, with Scots pine the government subsidy for orchard seed production was found to be essential for the profitability, even at the next generation. For a private forest owner the results indicated that in direct sowing (Scots pine) orchard seed is an economically desirable alternative to stand seed even with as high as *eight* per cent discount rate. The overall results suggested that the subsidy for the next-generation seed orchards is economically justified from the society's viewpoint. At the same time, it provides incentives for private forest owners and orchard seed producers to operate in the tree breeding field. Furthermore, it seems that the next-generation seed orchards established for northern Finland are more dependent on the government subsidy than those established for southern Finland. Redirecting subsidy into the breeding activities, which are more cost-effective than others, will improve the outcome considerably.

KEYWORDS: Cost-benefit analysis, profitability, Net Present Value, shadow pricing, seed orchards, Scots pine, Silver birch, differential approach, next generation, genetic gain

ABSTRAKTI

Väitöskirja koostuu teoreettisesta osiosta ja viidestä empiirisestä osatutkimuksesta, joissa analysoidaan männyn (Pinus sylvestris L.) ja rauduskoivun (Betula pendula Roth) jalostuksen kannattavuutta Suomessa painottaen erityisesti seuraavan sukupolven siemenviljelyksiä. Kannattavuus laskettiin kolmelle *a priori* valitulle agentille (valtio, siemenentuottaja ja yksityinen metsänomistaja) soveltamalla ns. erotuslaskentamenetelmää. Ko. menetelmässä metsänjalostuksen *erotus*hyötyjä (verrattuna metsikkösiemenkeruu-vaihtoehtoon) verrattiin metsänjalostuksen erotuskustannuksiin. Erotushyödyt evaluoitiin sisällyttämällä jalostushyödyt yleisesti käytössä oleviin kasvumalleihin (mänty: MELA ja Vuokila & Väliaho, rauduskoivu:Oikarinen), ja erotuskustannukset (verrattuna metsikkösiemenkeruu-vaihtoehtoon) saatiin mm. Metsähallituksen ja Metsänjalostussäätiön kustannusaineistosta. Investointikriteeriksi valittiin Nettonykyarvo(NNA)menetelmä. Laskelmien tarkoituksena oli määrittää kannattavuudelle ns. kynnysarvot, ja verrata ko. arvoja edelleen vallitseviin olosuhteisiin kunkin agentin osalta. Yhteiskunnan tason laskelmissa sovellettiin erityistä varjohinnoittelua kun taas finanssista analyysia käytettiin laskettaessa yksityiselle metsänomistajalle ja siemenentuottajalle kannattavuuksia.

Nettonykyarvot olivat positiivisia männyllä vielä *kuuden* prosentin (jalostushyöty 12%) ja rauduskoivulla *neljän* prosentin (jalostushyöty 20% Etelä-Suomessa ja 14% Keski-Suomessa) laskentakorkokannoilla. Lisäksi, päätulokset implikoivat mahdollisista hyvinvointiparannuksista jalostuksen edetessä nykyisestä sukupolvesta seuraavaan sukupolveen. Markkinaolosuhdeanalyysi osoitti, että molemmilla puulajeilla skaaletuja voidaan vielä hyödyntää nykyisissä siemenviljelyksissä. Lisäksi, valtion tuki todettiin tärkeäksi jopa seuraavan sukupolven siementuotannon kannattavuudelle männyllä. Männyn siemenviljelyssiemenen käyttö kylvössä havaittiin yksityisen metsänomistajan kannalta taloudellisesti perustelluksi vaihtoehdoksi jopa *kahdeksan* prosentin laskentakorkokannalla. Kokonaisuudessaan tulokset osoittivat valtion tuen seuraavan polven siemenviljelyksiin olevan yhteiskunnallisesti perusteltua. Samanaikaisesti, tuki tarjoaa sekä metsänomistajille että siemenentuottajille taloudellisesti perustellut toimintamahdollisuudet. Laskelmien mukaan Pohjois-Suomea varten perustettavat männyn seuraavan polven siemenviljelykset näyttävät olevan enemmän riippuvaisia valtion tuesta kuin Etelä- ja Keski-Suomea varten perustettavat viljelykset.
Tulokset osoittivat, että kohdentamalla valtion tukea sellaisiin jalostustoimintoihin, jotka ovat muita toimintoja kustannustehokkaampia voidaan jalostuksen taloudellista tulosta parantaa entisestään.

AVAINSANAT: Kustannus-hyötyanalyysi (KHA), kannattavuus, Nettonykyarvo, varjohinnoittelu, siemenviljelykset, mänty, rauduskoivu, erotuslaskentamenetelmä, seuraava sukupolvi, jalostushyöty

CONTENTS

LIST OF SYMBOLS AND FREQUENTLY USED ABBREVIATIONS

a = administration costs incl., e.g., costs of marketing, rents and salaries of supervising personnel

a_i = forest investment

areas= cultivated total area relative to projected area, expressed in decimals (in modelling)

b_i = forest investment

B^{diff} = differential benefits (due to genetic gains)

B_t^g = economic value of a thinning or final cut in an improved stand, FIM (Silver birch)

B_t^0 = economic value of a thinning or final cut in a normal stand, FIM (Silver birch)

c (•) = total cost function

c_o (•) = total cost function for seedlings made of orchard seed

c_N (•) = total cost function for seedlings made of stand seed

CBA= cost-benefit analysis

ccones= collected cones required for 1kg of orchard seed, litres (in modelling)

C^{diff} = differential costs of seed orchards compared to stand seed acquisition (divided further into progeny testing, C^p, annual management of seed orchards, C^m, and administration, C^{ad})

C^{es}= establishment costs of seed orchards (differential as such)

C_g(S)= sowing costs of orchard seed, FIM/hectare (Scots pine)

C_0 (S)= sowing cost of stand seed, FIM/hectare (Scots pine)

C_i^m = coefficient reflecting the prevailing market structure for input i, ≤ 1

colcost= collection costs of Scots pine orchard cones, FIM/litre (in modelling)

constant proportional advantage= genetic gain expressed relative to the diameter and height growth of an unimproved stand over time

constant volume advantage= genetic gain expressed in absolute volume increase (harvesting times unchanged)

costdiff= sowing cost difference between Scots pine orchard seed and stand seed, expressed in FIM/hectare (in modelling)

crop= average annual seed crop, kg/hectare (in modelling)

c, z = given prices for inputs q and x, respectively (formula [2.4])

Δp = change in price

ΔR = change in total revenue

D_p= discount factor, $[1 + p/100]^{-1}$, where *p* presents discount rate (s.t. e.g. 3% corresponds to 3 in the formula)

exp= exponent (e.g. exp (areas) = e^{areas} ; in modelling)

EVT = Empetrum-Vaccinium type forest (classified for northern Finland)

ϵ= error term (in modelling)

ϵ(p) = price elasticity of demand

FV_i = financial value (market price) for input *i*

f_{LAC}= long-run average cost function

f(q, x) = production function

gengain= genetic gain, expressed in percentage

growth region= an area in which annual growth rate for a particular forest site type is assumed to be homogeneous

η_x = price ealsticity of commodity x

improved stand= stand established (either sown or planted) by orchard seed material

IRR= internal rate of return

JT_t = financial value of a thinning or final cut in an improved stand in year *t*

k^*= fixed plant size

KG_t = (produced and) sold amount of orchard seed in year *t*

LAC= long-run average costs

LMC= long-run marginal costs

m = management costs incl., e.g. costs of nursery sowing, fertilization, culling, transport: i.e. direct production costs of seedlings

managcost= annual management cost, FIM/hectare (in modelling)

MES= minimun efficient scale

MR= marginal revenue

MT= Myrtillus type forest

n= time index associated with normal stands

NB = present value of (aggregated) net benefits

normal stand= stand established with stand seed

NPV= net present value

NS_n = financial value of a thinning or final cut in an improved stand

p = price for orchard seed

P_x = price of commodity x

price= sales price of the orchard seed, FIM/kg (in modelling)

P_{sf} = profitability for a single firm

r = a gross rate refleting SOC (formula [2.3])

rate= discount rate, expressed in percentage (in modelling)

q = quantity demanded (formula [2.8]), or labour input (formula [2.4])

RB= relative bias (of modelling)

relprice= relative stumpage price level compared to projected price level, expressed in decimals (in modelling)

s = a rate expected by sharedolders (formula [2.3])

s_o = seed material when using orchard seed

s_N = seed material when using stand seed

SDR= social discount rate

$\sum$ = summation

SOC= social opportunity cost rate

SP_i = shadow price for input *i*

stand seed = seed collected from cones in natural stands

stand seed acquisition= organized large-scale seed collection from cones in natural stands

STPR= social time preference rate

t= time index associated with improved stands , or corporation tax (formula [2.3])

TP_i = transfer payment associated with input i (e.g. tax, social security payments)

x = other inputs used in production (formula [2.4])

$X^1 (\bullet)$ = aggregate market demand for good 1

$x_i^1 (\bullet)$ = consumer *i'*s demand function for good 1

VT= Vaccinium type forest

WTP= willigness to pay

y = output

y_i = i:th simulated value (in modelling)

$\hat{}y_i$ = predicted value (by modelling)

1. Introduction

1.1 Background

According to the National Forest Inventory conducted between 1986-1997 the total forest land in Finland is at present approximately 20.1 million hectares. During the 90s the annual total regeneration area has been fluctuating between 150 (in 1991) and 175 (1994) thousand hectares of which natural regeneration has been approximately 25 to 75 thousand hectares (Finnish Statistical... 1999).

Artificial regeneration of forests in Finland was rather modest until the early 60s, the annually cultivated area varying between 30-60 000 hectares. From the beginning of the 60s, the artificially regenerated areas increased rapidly and achieved the annual level of 120-140 000 hectares within 10 years (Metsäpuiden...1989, Finnish Statistical...1997). The motivation for the ever-increasing artificial regeneration was to secure the wood supply for the expanded forest industry. At the time, artificial regeneration linked with forest tree breeding was seen as an essential means to increase timber production (e.g., Metsäpuiden...1989).

Forest tree breeding in Finland started with the establishment of Scots pine (*Pinus sylvestris L.*) seed orchards in the mid 50s, and large-scale tree breeding took place during 1963-76 when most of the seed orchards were established (Nikkanen et al. 1999). Plus trees were selected as the basis for the seed orchards with most of them being selected during the 50s and 60s (Pitkäntähtäyk-sen...1989, Oskarsson 1995). Scions of the plus trees were grafted to establish clonal seed orchards (Oskarsson 1995). The main responsibility for the grafting operation was handed to the Foundation for Forest Tree Breeding. The former National Board of Forestry (present Finnish Forest and Park Service, the FPS) was obliged to procure the land for the seed orchards, the government being the main financier (Oskarsson 1995).

Birch breeding material was selected using the same principles as with Scots pine plus trees (Sarvas 1953). In the beginning of the 60s, birch breeding (mainly Silver birch, *Betula pendula Roth*) expanded strongly due to the considerable financial assistance of the Finnish Plywood Association (Kukkonen 1991, Viherä-Aarnio 1994).

1.2 Seed orchards

A seed orchard is a manmade tree population which is expected to produce genetically and physiologically high quality seed (Sarvas 1970, Koski 1980). Seed orchards can be situated outdoors (Scots pine and Norway spruce) or in a polythene tunnel (e.g., Viherä-Aarnio 1989, Mikola 1995). They carry forward the results of breeding to practice, i.e. produce seed for reforestation purposes (e.g., Ruotsalainen 1999). An orchard usually contains 50-100 grafts per clone and 25 to 400 different plus trees. The total number of grafts, for example in Scots pine seed orchards, can vary from 1 000 up to 18 000 (Pulkkinen 1994, Pulkkinen 1996), covering from 2 to 61 hectares (Nikkanen et al. 1999). Seed orchards require continuous management which consists of, e.g., fertilization, roguing, weeding and cone collection (e.g., Talbert et al. 1985,Williams & deSteiguer 1990, Byram et al. 1999). Observations on male and female flowering are undertaken to estimate the genetic quality of the seed.

Traditionally, in the national breeding and seed orchard programs there have been three main species, namely Scots pine, Norway spruce (Picea abies (L.) Karst.) and Silver birch (see, e.g., Pitkäntähtäyksen...1989). At present, Scots pine and Silver birch present seed orchards (Scots pine: henceforth denoted also as 1st-generation or present-generation seed orchards) are in full production, but Norway spruce seed orchards have not been successful in producing seed on a regular basis for practical cultivation (e.g., Metsänviljelyaineistotyöryhmän... 1994, Männyn...1997). This combined with the fact that there are only a few progeny trials for Norway spruce (Pulkkinen et al. 1999) resulted in the Norway spruce seed orchards being excluded from the assessments of this dissertation. It should be stressed that it is the seed production of improved material (provided that the material is further cultivated) which generates the economical benefits of tree breeding.

Scots pine seed orchards

In Finland, the number of Scots pine seed orchards is 160, covering 2 492 hectares. All the seed orchards are now in seed production (Nikkanen et al. 1999). It has been assumed that seed production will decrease when the seed orchard is around 40 years old (Metsäpuiden...1989, Hahl 1992). Thus, after the year 2010 the seed production of the present-generation seed orchards will quickly decrease (Mikola 1995) and finally ceases entirely. New, so-called 1.5 generation seed orchards (also called as next-generation seed orchards or first-generation seed orchards of progeny-test screened genotypic plus trees, see Mikola 1995) are to be established between 1997-1999, at the first stage covering approximately 95 hectares (Antola et al. 1996). In practice, the change over from present-generation seed orchards to next-generation seed orchards is planned to proceed so that the seed supply can be kept on a demanded level (Männyn...1997). The new seed orchards will be composed of the best 10-20% of the present-generation plus trees (Mikola 1995). Moreover, they will be established in their target areas (Nikkanen & Antola 1998) which reduces considerably the risk of background pollination (for background pollination, see, e.g., Harju & Muona 1989). At present generation the background pollination has been one of the main drawbacks since it reduces the attainable genetic gain. Especially in the seed orchards established with clones from northern Finland pollen contamination leads to poor adaption in the targeted cultivation zone (e.g., Pulkkinen 1994). This has resulted in the seed being utilized in an intermediate climatic zone instead of the original target area (e.g., Mikola 1995). Further, this has made more difficult to maintain annual orchard seed supply at the desired level.

Another main drawback in the present-generation seed orchards has been the poor soils on which the seed orchards have been established. At the time of the establishment of the present-generation seed orchards (1963-1976) the land for seed orchards had to be procured quickly due to intensive grafting leading to situations where the soil was not "suitable". This has affected on the annual average seed crops by (Nikkanen & Antola 1998, p. 423).

At the next generation the goal is to establish approximately 385 hectares for southern and central Finland and 250 hectares for northern Finland between 1997 and 2015 (Antola et al. 1996, Männyn...1997), which is assumed to be sufficient regarding the annual supply requirements for Scots pine orchard seed (Antola et al. 1996). The need for introducing separate seed orchards for southern and central Finland (385 hectares) and for northern Finland (250 hectares) has arisen primarly from the divergent cilmatic conditions. This has led to different breeding goals for southern and central Finland and for northern Finland. For southern and central Finland the main breeding goals are growth yield and quality while in northern Finland the main focus is on the survival aspect (Nikkanen & Antola 1998). At this point it should be stressed that theoretically there are alternative seed orchards, namely to establish new first-generation seed orchards. However, this option has no relevancy as it would mean a stagnation of genetic enhancement. It would also cost as much as the next-generation seed orchards. The present and next-generation orchard seed can be considered as a concerted effort with respect to that they both possess genetically enhanced qualities *compared to* natural stands. Moreover, the present and next-generation orchard seed will not be competing for market shares in a traditional sense (i.e., they are not substitutes), because at the time of simultaneous orchard seed production the supply can be divided into two parts: seed for nursery sowings and direct sowings. There will most likely be separate prices as well.

Silver birch seed orchards

Abundant flowering and regular yearly seed crops combined with easy crossing in the greenhouse and fast initial growth of birch plants have made it possible to make rapid advances in breeding and applying the results in practice (e.g., Holopainen & Pirttilä 1978, Koski 1991, Viherä-Aarnio 1994). In addition, the genetic variation between individuals in growth properties is large, indicating that selection results in considerable genetic gains (Viherä-Aarnio 1994).

The first (experimental) birch seed orchard was established in 1970 in a polythene tunnel (Kukkonen 1991). At present there are 15 seed orchards (the majority being so-called second generation) in polythene tunnels, the total area being about 1 hectare (Lepistö 1996, Finnish statistical...1997). Approximately 55% of these seed orchards (weighted by the area) produce seed for southern Finland, 37% for central Finland and the rest for northern areas (Männyn...1997). In general, birch seed orchards are much less capital- and labour-demanding than Scots pine and Norway spruce seed orchards. The average life span of a polythene tunnel is between seven and eight years (Koski 1991, Männyn...1997), thus the establishment costs can be kept down concerning the produced output, i.e., orchard seed. Actually, some of the polythene tunnels built in the 70s are still in use (Hagqvist 1994, Männyn...1997). The last new polythene tunnel (2 000m^2) was built in 1991, costing about FIM 0.97 million (Lepistö 1996).

Over the last few years the annual Silver birch orchard seed production has exceeded the demand considerably. This is mainly due to the fact that most of the seed orchards have been simultaneously in their best production age, producing seed for storage. Another reason for this overproduction is that the seed-to-plantable seedling ratio has increased from 1 kg to 170 000 seedlings to 1 kg to 220

000 seedlings during the 90s (Hagqvist 1994, Lepistö 1996). Moreover, the government subsidy for reforestation of arable land was discontinued in the early 90s leading to a divergence between anticipated seed demand and actual cultivation area (e.g., Lepistö 1995).

1.3 Characteristics of Finnish tree breeding

Tree breeding in Finland has been based on national breeding and seed orchard programs which have been scheduled for every 10-year period (Metsäpuiden...1989, Pitkäntähtäyksen...1989, Männyn...1997). The frames for these short-term programs have been set by the long-term breeding program. In the long-term program the general trends of tree breeding are provided for several decades (Pitkäntähtäyksen...1989). Primarily, the breeding programs have been planned with emphasis on the biological and genetical aspects, leaving economical aspects to some extent in the background (Metsäpuiden...1989, Pitkäntähtäyksen...1989).

Among other goals, seed orchard programs have been planned to secure annual seed supply (e.g., Metsäpuiden...1989). In these programs the total annual seed supply usually consists of two parts: one part comprising the amount of seed produced by seed orchards (orchard seed), and the other consists of the seed collected from natural stands (stand seed). One of the main targets has been to supply *all* the seed required for nursery plantings by seed orchards, at least in southern Finland (e.g., Metsäpuiden...1989, Männyn...1997). The establishment schedules of seed orchards have been carefully planned to meet the estimated supply requirements for orchard seed (e.g., Männyn...1997).

In practice, however, the goal of the annual seed supply has not been fulfilled due to biological problems involved with seed orchards (e.g., background pollination, poor soils). This has led to situations where stand seed has been used also in areas where initially, according to breeding programs, orchard seed should have been used. Moreover, in direct sowing (mainly Scots pine) the lower price of stand seed (as compared to orchard seed) has in recent years "provoked" private forest owners to use stand seed instead of orchard seed. Thus, especially in Scots pine direct sowing, the development in recent years has led to the orchard seed and stand seed being considered as perfect substitutes. In nurseries, however, most of the seedlings are still raised from orchard seed reflecting more or less the initial goal of the programs (Metsäpuiden...1989, Ministry of Agriculture...1996).

These above-mentioned facts, among other things, have been taken into account in planning the establishments of the next-generation seed orchards. This has been done by revising the demands of orchard and stand seed for Scots pine and Silver birch. The adjustments have lead to a slight reduction of the originally planned orchard programs (Männyn...1997).

Government subsidy has played a major role in Finnish forest tree breeding (e.g., Pitkäntähtäyksen...1989, Valtion...1998). Due to the long rotation periods of our main commercial tree species (Scots pine, Norway spruce, Silver birch), the national importance of the forestry, and the capital-demanding establishment costs of the seed orchards, financial help of the government has been seen as an important factor to support forest tree breeding in Finland (e.g., Pitkäntähtäyksen...1989, Männyn...1997). In many countries, however, tree breeding programs are financed by private companies (e.g., Talbert et al. 1985, Thomson 1989, Strategi...1995). Traditionally in those countries where the conditions for growth are excellent (i.e.short rotation periods are attainable), forest tree breeding is considered as an economically profitable business action, and large private companies have their own breeding divisions (e.g., Ledig & Porterfield 1981, Talbert et al. 1985, Strategi...1995).

Currently, the Ministry of Agriculture and Forestry monitors tree breeding activities and guides the financing. It grants advances to organizations implementing tree breeding programs (see, e.g., Valtion...1998). Advances are granted annually to the Forest and Park Service (FPS), the Foundation for Forest Tree Breeding (FFTB), the Finnish Forest Research Institute (FRS) and the Forestry Development Centre Tapio (Tapio). A major proportion of the total annual subsidy is directed to the Forest and Park Service and the Foundation for Forest Tree Breeding (Table 1.1). The FPS, FFTB and Tapio are seen to pursue so-called "practical tree breeding", while the FRS is seen to pursue "basic research" including among other things provenance trials, tests concerning genetic variation and maturation tests of seeds. In this work only activities conducted by the FPS and FFTB are taken into account. This is due to the fact that the accuracy of book-keeping in the above-mentioned organizations (FPS and FFTB) are considered as sufficient to trace down the money flows and relate the costs to courses of actions for several decades.

Table 1.1. Annual advances of forest tree breeding planned to be granted to organisations in 1999, millions of Finnish Marks (FIM). (Source: Valtion...1998).

Organisation	The amount, millions of FIM	Proportion, %
Foundation for Forest Tree Breeding	9.00	47%
Forest and Park Service	6.90	36%
Finnish Forest Research Institute	2.94	15%
Forestry Development Centre Tapio	0.43	2%
Sum	19.3	100%

Besides the government (society) which subsidizes tree breeding activities in Finland, there are other agents involved in the tree breeding field. First, a private forest owner is obliged by law to regenerate the forest (as well as he is obliged to follow the silvicultural recommendations in thinnings and final cut). For artificial reforestation a private forest owner can either use improved material or stand seed. Nowadays, however, in planting there is no genuine decision to be made between these two seed qualities because the seeds used for seedlings are in most cases unknown to the private forest owner. Moreover, for instance, in southern Finland almost 100% of Scots pine seedlings are grown with orchard material (e.g., Ministry of Agriculture...1996). Furthermore, the possible price effect of seed origin on seedlings cannot be distinguished with sufficient accuracy; the prices facing private forest owners are more or less identical regardless of whether the seedlings are raised from stand or orchard seed. In direct sowing, on the other hand, there is an actual choice to be made between these two seed qualities, because the prevailing prices are distinctive.

Part of the subsidy granted annually for tree breeding is directed to seed producers in order to contribute to the orchard seed production at the levels determined in the national breeding programs (see, e.g. Männyn...1997). In practice, the annual expenses caused by management (e.g. fertilization, roguing, weeding) in seed orchards are partly (Scots pine: the first 15 years) covered by the subsidy.

In Finland, a few seed producers control the markets of Scots pine and Silver birch orchard seed (Finnish Statistical...1997, Männyn...1997). *A priori* it can thus be argued that the market structures for Scots pine and Silver birch orchard seed are imperfect, implying ,e.g., an oligopolistic competition.

Prior to the outset of this work, there have been only very few studies (e.g., Valtanen 1975, Kärki 1983) where economical aspects related to the Finnish forest tree breeding had been taken into account. However, these studies have focused on specific issues, the former on a relatively small and hypothetical forest tree breeding program (Valtanen 1975) whereas the latter on an approximate evaluation of timber quality and stem wood production in improved stands (Kärki 1983). Thus, there is a lack of an overall economical assessment of the impact of forest tree breeding.

1.4 Problem setting and objectives

The main purpose of this dissertation is to determine the conditions under which the next-generation seed orchards would be profitable from the viewpoint of society. The setting is closely linked to the present day decision-making of tree breeding in Finland. At this juncture, society refers to the Finnish economy which faces limited resources, and where the decisions made by public sector policies change the allocation of the resources. Special emphasis is afforded to differential approach where the standard of comparison is stand seed acquisition. In the assessment differential benefits of tree breeding (compared to stand seed acquisition) are weighted against the differential costs. The same amount of seed is assumed to be produced and further cultivated in both alternatives (seed orchards and stand seed acquisition). The assessments are conducted with reference to national *ongoing* seed orchard programs. The binding to ongoing programs entails an aspect of evaluating a real-world situation rather than determining an economic optimum (see, Lesourne 1975). Each establishment schedule of seed orchards is evaluated as an entity disregarding further analyses which deal with more controversial questions, i.e., how large the amount of total seed production should be or what is the optimum ratio between direct sowing and planting in forest regeneration.

The profitability is evaluated in a cost-benefit framework using net present value (NPV) as an investment criterium, and it is conducted separatively for those seed orchards which are to be established for southern and central Finland (Study 2) and for northern Finland (Study 3). Separate assessments for southern and central Finland and northern Finland are needed due to the discrepancies in climatic conditions which further cause differences in establishment schedules and magnitude of the seed orchards (Männyn...1997). To achieve positive net present values for the next-generation seed orchards certain treshold values of the main variables are required. These values are then confronted with the conditions prevailing in practice in order to examine whether the values are plausible. The unplausibility indicates that next-generation seed orchards could be rejected, and, the required amount of seed should be acquired by collecting from natural stands instead. The main variables to be studied are: genetic gain, annual reforestation area, (trend) stumpage prices, costs, discount rate and total establishment area of the seed orchards.

There are other objectives connected to the main frame. The supporting studies address the profitability of present-generation Scots pine and Silver birch seed orchards (Study 1), the business economical conditions and profitability of orchard seed production (Study 4) and the profitability of using Scots pine orchard seed in direct sowing (Study 5). The profitability conditions are surveyed via a *multilevel analysis* with respect to three agents: government, seed producer and private forest owner. The results are then combined in order to examine the plausibility and possible inconsistencies between the profitabilities. The former (plausibility) entails an aspect of evaluating whether the required profitability conditions for each agent are in general conceivable, given the realities of everyday practice in forestry (e.g. silvicultural recommendations, annual reforestation area, initial growth conditions). The latter (inconsistency between the profitabilities) refers to a situation where seed orchards would be economically profitable from the society's viewpoint, but there were no incentives for possible entrepreneurs to establish firms which produce orchard seed, or in the worst case, there were no incentives for private forest owners to use orchard seed either.

The profitability of the present-generation Scots pine and Silver birch seed orchards is examined by an *ex ante* assessment (Study 1).The purpose of this analysis is twofold. Firstly, to examine the conditions under which the present seed orchards are profitable from the viewpoint of society, and whether these conditions on the whole are met in practice. Secondly, and more importantly, in order to be able to quantify any improvements in social welfare associated with the next-generation seed orchards some standard of comparison is required. An apparent choice is the present-generation seed orchards (provided, of course, that the calculation priciples with regard to evaluation of the differential costs and benefits are identical).

The prevailing market structures for Scots pine and Silver birch present-generation orchard seed are examined by an *ex post* assessment (Study 4). The aim is to quantify the demand and supply conditions of the orchard seed in order to determine whether there are economies to scale still to be exploited in the orchard seed production. This is done by constructing mathematical equations for market demand and long-run average cost curves, and solving them for first-order. The analysis of market environment becomes especially eminent when the outputs (produced by firms) have to be valued from the society's viewpoint. In order to set correct shadow prices prevailing market structures must be first revealed. Severe failures in the shadow pricing might lead to situations causing government to subsidize activities which are socially undesirable, i.e., inefficient. The study provides detailed knowledge on the (financial) profitability of producing orchard seed from the producer's viewpoint.

In the same sub-study, a supplementary *ex ante* calculation is conducted to determine the financial desirability of establishing a next-generation Scots pine seed orchard. The initial purpose is to determine limiting, threshold values of the main variables (e.g. annual management costs, discount rate, collecting costs, seed crop and sales prices) for a profitable outcome, i.e. sales revenue higher than production costs. These values could then be compared to the values reflecting present-generation seed orchards. Once again, the analysis gives further insight into financial aspects as tree breeding proceeds.

An *ex ante* calculation is conducted on the financial desirability of using Scots pine orchard seed in direct sowing (Study 5). Primarily, the aim is to determine the conditions (e.g. genetic gain and sowing costs) under which it is profitable for a private forest owner to use orchard seed instead of stand seed for direct sowing in southern Finland. This study supports the main focus of the dissertation by providing new knowledge concerning the demand site of the improved material -,i.e., whether there is in general any incentive for private forest owners to use orchard seed.

In each study, the nonmarket and market-related uncertainties affecting the results are tested by sensitivity analyses. The analyses are conducted for the net present value (NPV) and in some cases for the spread of internal rates of return (IRRs) separatively.

The outline of this dissertation is as follows: First, in Chapter 2 theoretical frameworks with special reference to chosen viewpoints (a society, seed producer and private forest owner) are formulated and the applied data and time series analyses presented. In Chapter 3 the five above mentioned substudies are presented: detailed objectives, calculation models and results. Finally, in Chapter 4 the results are evaluated and combined into general conclusions on the economic profitability of next-generation seed orchards.

2. Theoretical framework and applied data

2.1 Society's viewpoint

2.1.1 A formula for the profitability

In assessments made from the society's viewpoint the profitability is usually evaluated with respect to Net Present Value (NPV) as a decision criterion (e.g., Dasgupta & Pearce 1978, Pearce & Nash 1989). The NPV as a decision rule for assessments was also adopted in this dissertation. An economic desirability refers to a positive NPV and generally projects with the highest NPV are preferred to alternatives (e.g., Pearce & Nash 1989, Brent 1996). NPV method was considered to be more adept in this context than other methods such as internal rate of return, IRR (for further details see, e.g., Irving 1978, Clutter 1983, Johansson & Löfgren 1985, Brown & Jackson 1991, Sarnat 1994). In this dissertation special emphasis was additionally afforded to so-called differential approach resulting in a formula which can be considered to be somewhat contradictory to conventional formulas. Instead of evaluating the costs and benefits of each alternative separatively, this research concentrated on identifying differential costs and benefits between seed orchards and natural stand seed acquisition. The profitability, expressed in NPV was evaluated by applying the following general formula:

$$NPV = \sum_{t_1}^{T_1} B_t^{diff} * (D_p)^t - \left[\sum_{t_2}^{T_2} C_t^{es} * (D_p)^t + \sum_{t_3}^{T_3} C_t^{diff} * (D_p)^t \right] \qquad [2.1]$$

The factors on the right-hand side are presented in Table 2.1. Specifications of the general formula [2.1] are presented in each empirical study separatively.

Table 2.1 Main factors affecting the profitability

Factor	*Description*
B^{diff}	Differential benefits: genetic gains are assumed to generate faster growth rate resulting in higher present value of the outturns when compared to natural stands
C^{es}	Establishment costs of the seed orchards are considered to be differential costs as such due to the absence of any corresponding activity related to natural stand seed acquisition
C^{diff}	Differential costs can be divided into progeny testing, annual management and administration
$D_p = (1 + \frac{p}{100})^{-1}$	Discount factor with per cent *p*
t_1, t_2, t_3	parameters reflecting different time spots (Note that $t_1 \neq t_2 \neq t_3 \wedge T_1 \neq T_2 \neq T_3$)

At this juncture it should be stressed out that f ormula [2.1] is a simplification; the terms B^{diff}, C^{es} and C^{diff} can be interpreted as aggregations. For example, B^{diff} is in fact the sum of differential benefits of various growth regions. Due to paucity the complete formula is not presented here. The profitability calculations proceeded as follows: first, the differential benefits were evaluated according to genetic gains and the differential costs were formed from the total costs of seed orchards by comparing them to the costs of stand seed acquisition. Then, the differential benefits and costs were adjusted to possible market distortions by shadow pricing them, and these shadow priced values were further discounted to present. Finally, the present values for shadow priced differential benefits and costs were calculated by summing up the annual discounted values (Figure 2.1).

Each step of the calculation procedure is examined in detail so that the underlying assumptions of the profitability concept specific to this dissertation can be comprehended. Prior to examining the steps, however, the differential approach is described in full.

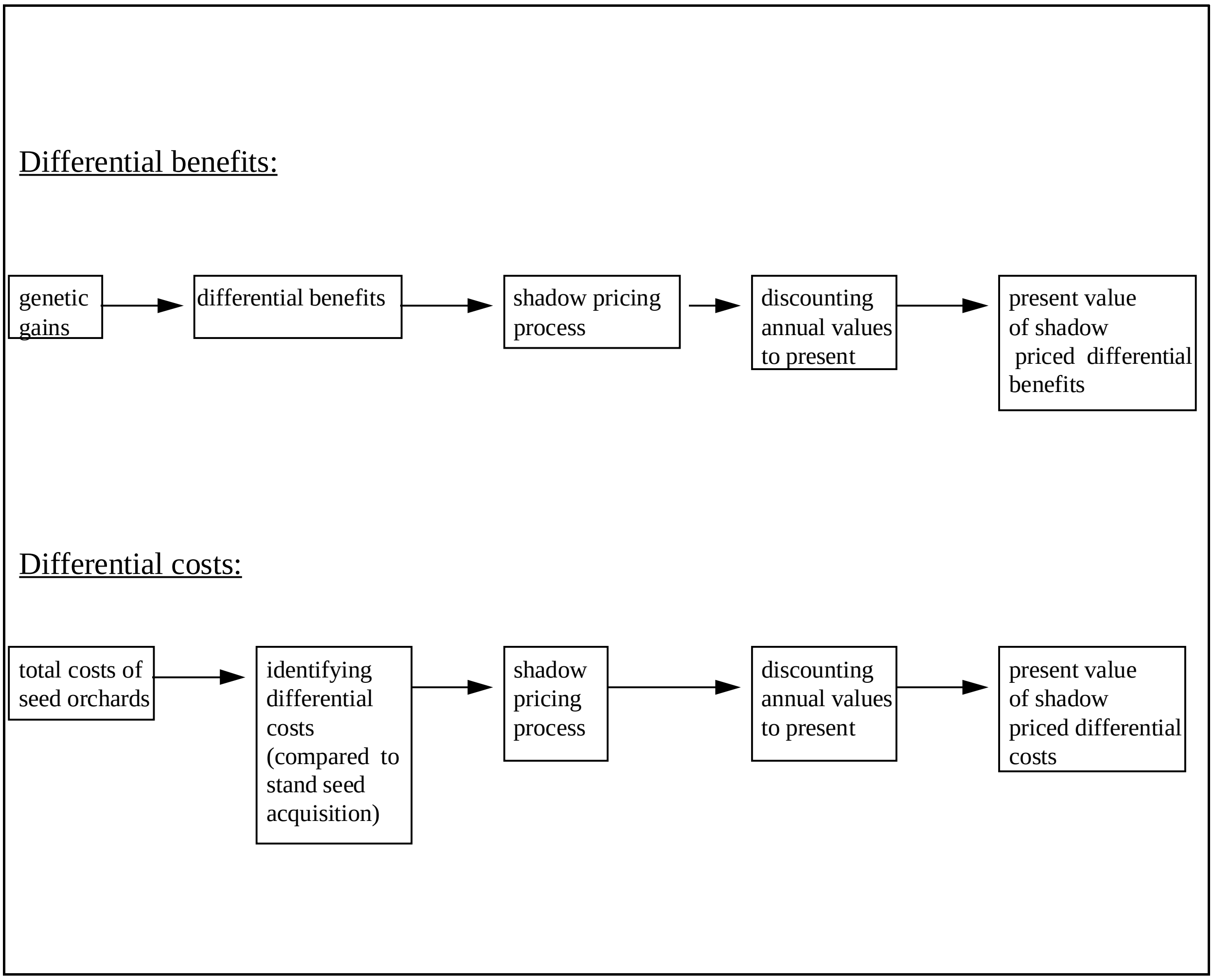

Figure 2.1 Phases of calculation in differential approach.

2.1.2 Differential approach

General

The advantage of differential approach is that it enables the same assessments and methodology as traditional methods, but requires considerably less data to obtain these results. Basically, differential approach implies that those costs and benefits which are different between alternatives (projects) are identified. The sums of differential costs are then confronted with the sum of differential benefits for comparison. Usually this identification of differential costs and benefits requires special expertise on the subject in question. There is no universal method to be applied. In this dissertation the alternatives were natural stand seed acquisition and tree breeding: the differential benefits and costs of tree breeding could be identified with the accuracy relevant to the context.

The differential benefits of tree breeding are generated by genetic gains. The genetic gains in turn result from tree breeding activities which contribute genetical enhancement (see Appendix 1 for further details on genetic gains). Principally, higher genetic gains can normally be expected to be achieved in the next generation, because in practical tree breeding the next generation allways consists of the best present-generation clones with respect to chosen trait (e.g. faster volume growth). Differential costs of tree breeding originate mainly from activities specific to seed orchards; such as annual management, crossings and progeny testing. In the context of the present study both the differential benefits and costs were converted into monetary value.

The pros and cons of the differential approach should be studied in detail, because of its essential role in the assessments. The main advantage of the differential approach is, beyond dispute, that it gives a roundabout method for the often so labourious evaluation of compensated demand curves and further consumers' surpluses. This is done by emphasizing only the differences between the alternatives with respect to demand and supply effects. In the absence of significant differences in demand and supply effects, the price *effects* can also be ignored (in such a way that the analyst does not have to *choose* whether to use initial price; i.e. the price prevailing before the project has been introduced, final price or some combination of the two: see, e.g., Pearce & Nash (1989, p. 89). In this way, a lot of time and effort could be saved - for instance, in a conventional cost-benefit analysis it is precisely the evaluation of consumers' surpluses which requires labourious effort (see, e.g., Dreze & Stern 1994).

In the present study both alternatives (seed orchards and stand seed acquisition) were assumed to generate more or less identical demand and supply effects in, e.g., roundwood and input markets - this is a reasonable assumption, given that the annual artificial regeneration area was fixed in the first place to be the same for both alternatives. Moreover, the differential benefits of seed orchards consisted of the combined effect of earlier thinnings and additional timber. The time effect "reducing" the additional timber with the magnitude that possible differences in demand and supply effects compared to unimproved stands could be ignored. In addition, the differential approach reduces significantly the risk of double-counting. Double-counting is considered to be a common problem in a conventional cost-benefit analysis, CBA (see, e.g., Squire & van der Tak 1981).

The disadvantage of the differential approach is that it requires special expertise on the subject and detailed knowledge on the alternatives - much more detailed data than what is needed in a conventional CBA framework. Moreover, it cannot be applied to assessments where the alternatives are "wide apart" ,e.g., when evaluating the costs and benefits of different transportation methods and different healt care plans. In those cases *total* costs and benefits of each alternative need to be valued (see ,e.g., Layard & Glaister 1994).

Differential benefits and genetic gains

In modelling the genetic gains into tree growth the results of progeny test trials usually need to be extrapolated for the rest of the rotation period. The extrapolation method is needed since progeny test trials are normally done with juvenile trees (e.g., Fins & Moore 1984, Talbert et al. 1985, Haapanen et al. 1993, Jayawickrama & Balocchi 1993, Venäläinen et al. 1994, Dhakal et al. 1996, Haqgvist & Hahl 1998), or at most with trees from midrotation (Carson et al.1999). Then, the results are estimated throughout a rotation.

Basically there are three different methods to formulate the effect of genetic gain on tree growth and further assessing its monetary value. In addition, there are theoretical methods which try to solve (by using mathematics) upper and lower bounds of the present value function when it is a function of biotechnological parameters (e.g., Löfgren 1988, 1992). Characteristically these theoretical studies are embodied with a small case study (e.g., Löfgren 1992, Bhattacharyya & Lyon 1994), but they do not involve genuine tree growth modelling, and are thus ignored in this connection.

The simplest method for estimating the effect of genetic gain is to translate improvement in height into an increased site index (Buford & Burkhart 1987, Williams & deSteiguer 1990). This method, however, does not require actual growth models to be modified. Another applicable method is to assume constant volume advantage with improved stands (e.g., Fins & Moore 1984, Talbert et al. 1985). This generally leaves the harvesting times unchanged increasing only the volumes of removals, and usually results in net present values which can be considered as "lower boundary" for a given genetic gain percentage. Constant volume advantage is applied when existing harvest scheduling models can be used. Both the abovementioned methods (increased site index and constant volume advantage) are more or less hypothetical and should be used only if there are no data available concerning tree characteristics.

In order to be able to evaluate the impact of genetic gains on the harvest scheduling models two kinds of biological information are particularly important. First, the shapes of the growth curves for improved and unimproved material, and second the magnitude of the differences between them over time are needed to be explored (Fins & Moore 1984). In general improved material is said to have higher growth potential than unimproved material (Figure 2.2).

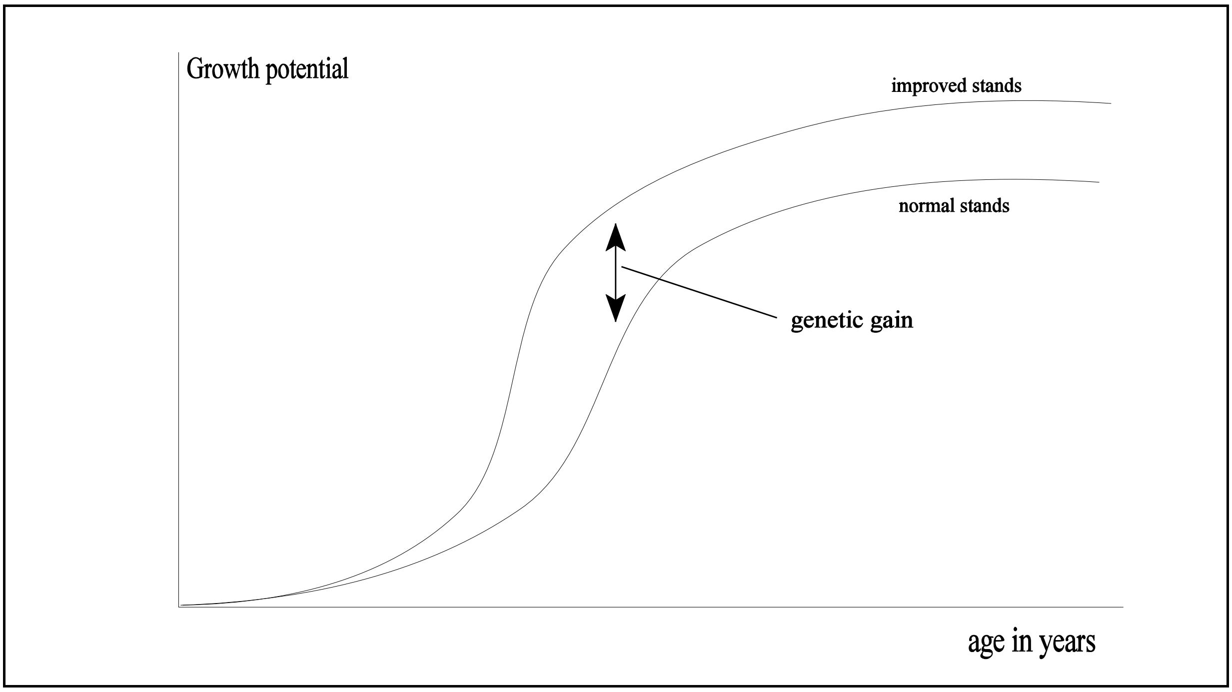

Figure 2.2. Growth potential of normal stands and improved stands**.**

However, in most cases there are no data available concerning growth functions or volumes of improved stands at rotation age (e.g., Fins & Moore 1984, Bhattacharyya & Lyon 1994, Carson et al. 1999), and biological yields must for most tree species be projected for the rest of rotation according to alternative growth models.

Perhaps the most realistic way of evaluating the effect of genetic gains on growth models is to assume constant proportional advantage (e.g., Fins & Moore 1984) which is based on the progeny test results. Principally, the constant proportional advantage is expressed relative to the diameter and height growth of an unimproved stand over time. This method enables to take into account the possible differences in absolute growth rates at different stand ages, because the proportional advantage is adjusted to an absolute growth rate at each time. Stated differently, younger trees are more "sensitive" to react for possible changes in growth conditions (e.g., Jäghagen 1997) than older trees, and thus it can be surmised that the absolute effect of genetic gains on tree growth would vary along the rotation period, although the proportionate advantage is kept constant.

In practice applying a constant proportional advantage to growth functions, as a realization of genetic gains, results in changes in harvesting times and further affects the structure of a stand. The difference between constant volume advantage and constant proportional advantage is presented in Figure 2.3.

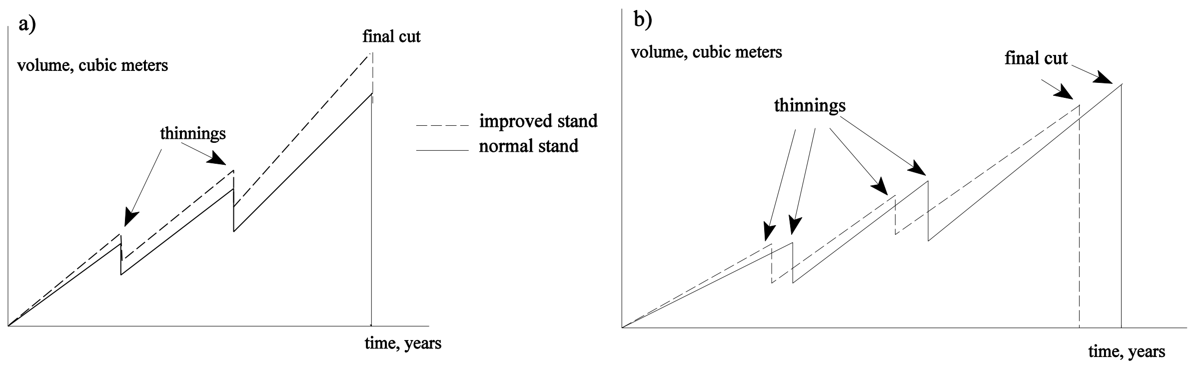

Figure 2.3. The difference between constant volume advantage (a) and constant proportional advantage (b) as a realization of genetic gain in thinnings and final cut. A constant proportional advantage to growth function usually results in changes in both harvesting times and volumes.

It can be argued that faster growth rate (due to genetic gain) is most likely utilized by harvesting earlier. This is especially true in Finland where long rotations might be the most significant single factor bordering the profitability of private forestry (e.g., Ahonen 1970, Keltikangas 1973, Penttinen & Kinnunen 1992).

Genetic gains and MELA program

In Finland the most widely applied forest simulation program is undoubtedly MELA (see, e.g., Hynynen 1996). In MELA program there are two main procedures to change the growth of the trees to depict the genetic gains, and both procedures are adjacent to constant proportional advantage method. First, by changing both the height increment and basal increment model by the percentage reflecting the genetic gain, or second, by changing the annual growth level by the corresponding percentage the genetic gains can be incorporated into tree growth. The latter results in a slightly different change in volume growth of the trees than the genetic gain in percentage due to general structure of the MELA program. The change of the annual growth level is conducted by so-called relative growth increment in which both basal area increment and height increment models are changed. In addition, the predicted stem form is slightly being changed, because the relation between stem diameter and height is changed (in MELA stem form development is predicted according to the taper curve which is based on stem diameter and height). Usually changing annual growth level by certain percentage (e.g. 3%) leads to a little smaller proportional change in volume growth than the initial percentage.

In MELA program the criterium for thinnings is set exogenously, i.e. independently from the actual growth modelling (incorporated with genetic gains). Generally there are various criteria (from, e.g. net present value maximizing to "legitimate" criterion) to be executed in the program. In other words, the same underlying growth function results in different harvest scheduling models depending on the applied harvest criterion. This feature of MELA program is somewhat contradictory to several other widely used forest simulation programs. For example, in linear timber harvest scheduling models the model projections concerning a harvest pattern are conducted so that they are constrained by various profitability and volume restrictions simultaneously in the short term (e.g., Thomson 1989). Moreover, in these models stands are usually simulated according to some optimization criterion, e.g. financial rotation. Then harvest scheduling is executed according to this optimization criterion with respect to chosen discount rates. It can be argued that this is against the realities prevailing in practical forest management, and thus MELA program is more realistic in a sense that it allows also harvest patterns which are based on realized thinnings.

Genetic gains and economic value

The economic impact of genetic gains is usually assessed by converting the volumes of thinning removals in improved and normal stands into monetary value (e.g., Fins & Moore 1984, Talbert et al. 1985). This is done by multiplying the volumes of each timber assortment by a unit price, and then discounting these products to present value with a chosen discount rate. Finally, the present value (PV) of aggregated products for a normal stand is subtracted from the PV of aggregated products for an improved stand. Predominantly, there are two options for a unit of measure of the outturns (i.e. thinning and final cut removals). The outturns can be evaluated at stumpage prices, or alternatively they can be valued at export prices. There is, however, a considerable difference between these two evaluation methods.

The use of stumpage prices as a unit of measure implies that tree breeding is a means for supplying wood material for the industry. Generally, stumpage value is seen as an economic rent, a value attributable not to any cost of production, but to the strength of market demand and favourable natural resource endowments and location (Repetto 1988). Rent, by definition, is a value in excess of the total costs of bringing trees to market as logs or wood products, including the cost of attracting the necessary investment. Theoretically, all rent can be captured by governments as a revenue source stemming from the country's advantageous natural resource assets. In practice, e.g., royalties, land rents, license fees and harvest taxes are all means of converting rent into government revenue (Repetto 1988).

Tree breeding is considered as a "prerequisite" for the wood processing industry indicating that the social costs and benefits of seed orchards need to be separated from wood industry. The underlying principle is to examine whether the forest tree breeding is an economically desirable way of supplying the raw material needed for the wood processing industry, given the conditions with regard to, e.g., discount rates and shadow pricing rules.

If the outturns had been valued at export prices of the final products (paper board, sawn timber) this would have required that forest tree breeding and manufacturing of wood be evaluated together as an "entity". The final products reflect the increases in the value of the material, i.e. value added (see, e.g., Begg et al. 1994). This value added, on the other hand, depends on the production process which can be expected to vary considerably due to, e.g. differences in marginal rates of technical substitution (MRTS: see, e.g., Dasgupta & Pearce 1978) for goods within the wood processing industry. However, without the pre-existing "expedient" of supply there would be no goods whose value would increase (indicating value added) in the process of exploiting the nation's resources. Thus, when using export prices as a unit measure of the outturns it is necessary to combine the economical effects engendered by tree breeding and wood processing industry, since the value of final products reflects the values of both these components. By taking both the tree breeding and wood processing industry into account and further forming an "entity" would involve uncertainties and speculativeness which are beyond the scope of this dissertation. These include, for instance, a) estimating the effect of transfer payments in the wood industry by different branches of industry, b) the future average structure of an additional cubic metre in terms of timber assortments and c) the labour inputs in different stages of the process.

In addition, the effects of stand and orchard seed production on roundwood prices were assumed to be similar. This assumption is justified twofold, and the arguments are closely related. First, due to differential approach applied here only *differences* between the alternatives (i.e. stand vs. orchard seed production) account. For the sake of simplicity the stand seed supply can be expected to cause similar impacts on the roundwood prices as the corresponding of seed orchard activity, although the quantities felled each year are not exactly identical due to differences in harvest scheduling. These divergencies are considered to be insignificant with regard to the initial problem-setting, and furthermore they would be nevertheless especially difficult to evaluate, given the long time horizon of the assessment. Second, the forecasted future prices according to time series modelling always reflect the past development of stumpage prices *including* the possible interrelationships between, e.g. wood quantities, stumpage prices and forest industry products. In the absence of any significant change with respect to past development, as is the case in this dissertation (the future cultivation areas were based on the past development), it can well be argued that through time series modelling the possible effects of wood supply on roundwood prices are transferred to the future. This latter argument entails a "static balance framework" adopted here. The stand and orchard seed options are constrained to reflect past, realized magnitudes of annual seed supply and cultivation area. All the abovementioned led to using identical unit stumpage prices for improved and normal stands.

Relevant differential costs

Generally, only those costs related to courses of actions which further generate benefits should be taken into account in assessments. Moreover, in *differential* approach only the costs which can be distinguished between different alternatives are relevant - usually identical costs are ignored in the analysis. In the identifying process of differential costs a *standard of comparison* need to be established. Stand seed acquisition was chosen to be that standard in this dissertation. Each activity executed within the seed orchards was compared to the corresponding activity related to stand seed acquisition. Then, according to this comparison differential costs were formed. Any absence of corresponding activity in stand seed acquisition brought about a differential cost. The establishment of seed orchards is an example of this absence. The main classes of differential costs, C^{diff} in this work were: annual management of seed orchards, progeny testing and administration (related to seed orchards).

Two separate aspects underlying the differential costs should be addressed in this connection. First, it was assumed that areas where the genetically improved material (i.e. orchard seed) will be used would otherwise be cultivated with stand seed or regenerated naturally. This assumption is critical with respect to that it excludes the possibility that the subsidy (to tree breeding) itself would cause distortions in a form of, e.g. cultivating poorer sites than it is generally profitable (cf. merit goods; Ward & Deren 1991). Stated differently, the annual cultivation area for stand seed and orchard seed was the same.

The second assumption is more restrictive. It is known *de facto* that only relative prices matter in determining demands and supplies (see, e.g., Myles 1995). In the assessments any possibility for a change in relative input price of stand and orchard seed production was ignored - in other words the *differential* costs were only constrained to trend development assuming that they will be fixed within the time horizon adopted here. This is tantamount to saying that there will be no changes in cost functions which could alter resource allocation by the magnitude which would invalidate the initial comparison. Such changes in cost functions could result from, e.g. tightened safety regulations on stand seed collections, new technology for cone extraction of orchard seed or intensified progeny testing.

There is another way of viewing the problem. If there will, in spite of all, be considerable changes in relative input prices (in a sense that resources are moved from one alternative to another), those changes can be considered to favour either stand seed acquisition or seed orchard activity. Viewed in this fashion the results of the assessments can be interpreted as overestimations or underestimations of the profitability of seed orchards, respectively. Presently, however, it seems that there will be no drastic changes in cost functions in the near future (see, e.g., Männyn... 1997). Finally, any attempt to forecast the possible changes in relative input prices involves so much speculativeness that it would be more secure to adopt the abovementioned concepts of over- or underestimation.

The differential approach adopted here somewhat simplifies issues related to forestry in general. For example, tax effects (with regard to relative efficiency, see Ovaskainen 1992) can be assumed to be similar for natural stands and improved stands due to the initial problem confrontation. Moreover, it can be argued that this comparison of two states is less sensitive to possible failures or miscalculations in the main procedures of assessments than an assessment for economic optimum. Because the *difference* between stand seed acquisition and seed orchard activity does not *directly* relate to actual markets, it can be argued that it does not have any significant effect on other markets' prices either. This can also be seen as a drawback which excludes further (formal) examination arising from the fact that the evaluated differential values do not correspond to actual input markets (e.g., compensated demand curves for labour cannot be constructed).

In this problem-setting it was assumed that forest measures, for instance, thinnings of saplings might occur earlier in improved stands than in normal stands, especially with Scots pine (see Ahtikoski 1997). The earlier timings of the thinnings of saplngs in improved stands were assumed to offset the possible higher costs involved, resulting in a zero cost-difference with regard to decision rule, NPV (see Appendix 2). This applies to harvesting costs as well (bearing in mind that the harvesting costs relate to benefits which are discounted earlier than in normal stands). In addition, cultivation costs were presumed to be identical for improved and normal stands and thus have no effect on the analysis (Appendix 2). Further, it can be suggested that there was no significant difference in extraction costs of cones either. This is based on the fact that currently the extraction costs are more or less identical for stand and orchard seed (see, e.g., Ahtikoski 1996a), or alternatively, they cannot be separated with the accuracy needed in this analysis.

2.1.3 Economic efficiency and cost-benefit analysis, CBA

The subsidy to forest tree breeding, considered as a cost of tree breeding, is expected to generate benefits in the far future. Before valuing these costs and benefits two fundamental questions should be answered. First, from whose point of view are the assessments conducted, and second, how are the costs and benefits valued, i.e. what are they compared to ?

In general, two main functions of government can be distinguished. First, "allocative" function consists in the provision of public goods and the removal of externalities on efficiency grounds, subject to Pareto principle. The other, "redistributive" function refers to the redistribution of wealth (through income transfers or services) from one section of society to another (Self 1993). Sometimes another function of government, namely the stabilization function, is brought up. Government pursues a stabilization objective by using instruments of, e.g., fiscal policy in an attempt to aid restoration of general equilibrium (e.g., Peacock & Shaw 1976, Brown & Jackson 1991). Especially, fiscal policy is aimed at internal objectives in order to exert impact on aggregate demand (Stevenson et al. 1988). The fiscal viewpoint, however, is in this dissertation ignored due to following grounds. Fiscal policy implies to relatively short-term balancing of the government: the possible feedback effects of, e.g. salaries and taxes related to a project would influence at most two to three years. On the other hand, seed orchards are commonly regarded as a considerably long-term activity (see, e.g., Talbert et al. 1985, Thomson 1989, Bhattacharyya & Lyon 1994, Carson et al. 1999). Finally, the main emphasis of this research was admittedly on the efficiency aspect. This left the stabilization and redistributive functions of the government for lesser attention.

The state (government) intervention is usually evaluated on efficiency grounds (e.g. Atkinson & Stiglitz 1980). Economic efficiency relates to the value of society's consumption over time: when economy is functioning in a way that maximizes this value, economic efficiency is attained (Ward &

Deren 1991). Broadly speaking, economic efficiency (also referred to synonymously as Pareto efficiency, Pareto optimality or allocative efficiency) is about making the best use of limited resources given people's states (Barr 1987). For a government to be able to restore the requisite conditions for economic efficiency, the projects should be appropriately valued: costs defined relative to their opportunity costs (social costs) and benefits relative to their effect on the fundamental objectives (social benefits). Principally, the government subsidy to seed orchards alters the allocation of resources and further changes the social welfare function (for more detailed information on social welfare functions see, e.g., Dasgupta & Pearce 1978, Honkapohja & Niskanen 1984, Aronsson 1997). This change in the social welfare is measured according to the social costs and benefits.

In this dissertation the assessments concerning the (present and next-generation) seed orchards are conducted from the society's viewpoint in the sense that the economic impacts on social welfare are taken into account with special reference to public decision-making enforced by the Ministry of Agriculture and Forestry. This is in accordance with the viewpoint of a nation as a project-operating entity: could the same benefits derived from the seed orchards be obtained with lower cost or with less use of nation's resources ? Here, as in most cases, the nation is taken as a unit of society (Gregersen & Contreras 1992). In the background of the assessments there is an essential prerequisite: roundwood is assumed to be the main source of material in the wood processing industry also in the future. This assumption specifies somewhat the study context by restricting the possible alternatives to two: stand seed acquisition and tree breeding. In addition, in this connection the following aspects must be emphasized. The possible (and relevant) alternatives to forest tree breeding activity from *the society's point of view* are more intensive silvicultural management (incl. fertilizations, ditching, artificial regeneration) or to import the roundwood. If any comparisons with respect to economic efficiency between these alternatives are to be made, the same calculation principles must be adopted. These principles include, e.g., methods for determining costs and benefits in terms of common denominator (Squire & van der Tak 1981), *a priori* chosen discount rates(s) and expressing the quantities at net present value. However, this work concentrated on determining whether seed orchards are economically justified from the society's viewpoint *per se* - the initial purpose was *not* to find the economically most efficient way to supply roundwood (raw material) to wood processing industry.

In order to be able to ensure that scarce resources are allocated efficiently (i.e. maximizing society's consumption over time: see Ward & Deren 1991) a common methodology is needed. One such methodology which is consistent to restoring the requisite conditions for economic efficiency is cost-benefit analysis, CBA (see, e.g., Brown & Jackson 1991, Layard & Glaister 1994, Brent 1996). Prior to proceeding it should be clarified that there is a difference between the *theory of the economic optimum* and the *theory of the comparison of economic states*. The theory of the economic optimum, generally called *welfare theory (welfare economics)*, tries to determine those conditions in an economy for which an optimum state exists. The theory of the comparison of economic states, generally called *cost-benefit analysis*, on the other hand, attempts to find how to compare any two states of the economy, neither of which need to be an optimum (Lesourne 1975). This is the case here: seed orchards and natural stand seed acquisition are compared to each other. Typically cost-benefit analysis is applied to situations where some (or all) of the benefits and costs are yet to come, i.e. during the project identification and preparation stages (e.g., Layard & Glaister 1994). With this respect CBA is an *ex ante* methodology.

A project brings about a Pareto improvement in welfare if it actually makes some people better off without making anyone worse off (Pearce & Nash 1989) - this is tantamount to saying that the project has met Kaldor-Hicks test (e.g. Pearce 1976). Further, CBA is consistent with the assumption that social objectives can be defined in terms of individuals' preferences (Dasgupta & Pearce 1978). Individuals' preferences can be (indirectly) revealed by valuing the inputs and outputs on the basis of individuals' true willingness to pay (WTP) for them (e.g., Ward & Deren 1991, Gregersen & Contreras 1992). It should be noted that sometimes "value in use" is used to refer to WTP (Gregersen et al. 1995).

WTP can be split into two parts: what the consumer pays, and the excess of what the individual is willing to pay over what is actually paid. The excess is called consumer surplus (e.g., Schmid 1989, Brent 1996). This is one main reason why markets, even if they are competitive, fail to measure social benefits of projects which are large. Consumer surplus is not, however, generally important for small or even medium sized projects in a competitive environment, when the demand curve for the product is fairly elastic (Abelson 1979). This is the case also here: consumer surplus as an indicator for the WTP can be ignored since the demand for roundwood, especially for sawlogs, is elastic both in the long and short term (e.g, Toppinen 1998). In addition, tree breeding can be considered to be a relatively small project. The latter can be well argued by comparing, e.g., the Finnish total budget and the subsidy granted for tree breeding: the ratio for 1999 was approximately 1 000 to 1 (Valtion...1998). As a conclusion, alternative indicators for the WTP were developed for this work.

Traditionally CBA has been a widely applied framework in public project appraisals (see, e.g., Dasgupta & Pearce 1978, Brown & Jackson 1991, Layard & Glaister 1994, Brent 1996). However, it has been adopted less frequently to forestry, at least in its conventional form (see, e.g., Johansson 1987, Pearce & Turner 1989, Pearce 1994). Further, the conventional CBA has been used for assessing tree breeding programs only occasionally during the last decades (see, e.g., Reilly & Nickles 1977, Ledig & Porterfield 1981, Gregersen & Contreras 1992). Reasons are multiple for not applying CBA in tree breeding, but two particular aspects should be pointed out. First, traditional cost-benefit rules are to some extent misleading when applied to non-renewable or renewable natural resources (e.g., Nautiyal & Rezende 1983). For example, multiple uses of natural resources cause significant complications in the conventional CBA framework implying that alternative approaches could tackle the problems better. In particular, it has been demonstrated that socially optimal rotation might differ from the *Faustman* rotation, especially when the economy suffers from market imbalances like unemployment and excess demand for timber (Johansson & Löfgren 1985). Second, and more important, in the majority of countries tree breeding is financed by private companies (see, e.g., Strategi...1995) - thus, there is no actual need to evaluate the profitability of tree breeding from the society's viewpoint. Rather the profitability is calculated, e.g. by studying the conditions under which seed orchards is a profitable *private* investment (see, e.g. Williams & deSteiguer 1990, Lowe et al. 1999). On average, a simple financial analysis suffices for an adequant means to conduct the assessments from the private firm's viewpoint.

In this dissertation, however, CBA is applied on the following grounds. First of all, the harvesting schedules were *not* based on either Faustman rotation (cf. Gong 1991, p. 11) or financial rotation (cf. Fins & Moore 1984, p. 675). Instead, the harvesting schedules were simulated according to prevailing silvicultural recommendations reflecting mainly an assessment of an economic state rather than determining an economic optimum (see Lesourne 1975, p. 3) - so CBA methodology is well justified with this respect. Secondly, the specific feature of tree breeding in Finland is that government has subsidized it practically in full from the early stages - the presence of public funding indicates that the role of economic efficiency should be brought out, and this can be executed with the CBA framework. Finally, due to the strong reliance on empirical context and to *ex ante* approach of this dissertation (e.g. possible differential benefits of tree breeding has not yet occurred) cost-benefit analysis matches for a tenable methodology.

2.1.4 Shadow pricing

Having identified the relevant outputs and inputs the next problem is to determine an appropriate set of prices which is based upon the efficiency criterium (Jackson & Brown 1991). Under perfect competition markets will automatically achieve economic efficiency, and prevailing market prices as such can be used as marginal valuations imputed to inputs and outputs (Pearce & Nash 1989, Ward & Deren 1991). However, due to widespread market failures and imperfections (e.g., monopolistic competition, externalities, public and quasi-public goods) market prices are seldom Pareto-efficient and must, therefore, be adjusted by shadow pricing (e.g., Mishan 1988, Ward & Deren 1991, Brent 1996) before they are used in CBA calculations. Shadow prices are to be used to evaluate the net impact on welfare of public-sector projects; shadow prices are the social opportunity costs of the resources used (Dreze & Stern 1994). Due to limited resources, the use in one project will entail an opportunity cost - the benefit they (i.e. resources) would have yielded in an alternative. Each output has an opportunity cost in terms of some forgone alternative (e.g., Dasgupta & Pierce 1978, Starrett 1988, Gregersen & Contreras 1992). Under market failures the prices that are paid may lead to consumption and production decisions which do not contribute to national economic efficiency (Ward & Deren 1991).

In this dissertation the need for shadow pricing process arises mainly from two sources. Firstly, the prevailing market structures for factor inputs (and also intermediate goods) used in seed orchards are known to be dominated by imperfect competition (see, e.g., Ahtikoski 1995, Männyn...1997). For instance, there have been only a few contractors who collect the cones from Scots pine seed orchards. Secondly, and more importantly, the Finnish labour market is characterized by a centralized wage formation in which trade unions play a crucial role (Kauhanen 1998). The existence of trade unions, among other things (e.g. persistently high unemployment rates), imply that the labour market is influenced by factors which do not reflect the elements of perfect competition. This combined with the fact that in seed orchards the majority of inputs are labour inputs gave rise to make corrections of market wages by shadow pricing. Without shadow priced inputs and outputs the results would have reflected misallocations of the resources directed into seed orchards, and in the worst case might have lead to decisions which are inefficient from the society's viewpoint, and further, which are inconsistent to other socioeconomic assessments.

Theoretically, there are three main methods for calculating shadow prices. The method of Lagrange multipliers is the most general, and can be applied no matter the objective or the constraints, as long as both of these are made explicit. The second methods follows the "Ramsey rule" (e.g., Dreze & Stern 1985). The third method involves a shortcut procedure. It relies on using a particular data source that is direct and simple alternative to suing market price data, i.e. producer price data (Brent 1996).

In order to evaluate the economic impacts of the project there is in general two sets of shadow prices applicable. So-called first-best shadow prices refer to cases in which the shadow prices would have been estimated in terms of equilibria which would exist after optimal correction of all distortions in all sectors (incl. private sector). On the other hand, second-best shadow pricing refers to prices which do not assume that these corrections have occurred, or will occur in all sectors (Ward & Deren 1991). The term second-best shadow pricing derives from the theory of second best which assumes that we can have no assurance that meeting some but not all optimum conditions will make us better of (e.g., Polkinghorn 1979). Second-best shadow prices take into account several inherent conflicts and tradeoff facing managers of the public sector, in other words they leave some sectors intact emphasizing those sectors which are most affected by the project. Especially with a small project assumption (Boadway & Bruce 1984, p. 292) second-best shadow prices are commonly used - so is the case here. First-best and second-best shadow prices are closely related to the distinction of general and partial equilibrium models (for further details see, e.g., Mas-Colell et al. 1995, Dinwiddy & Teal 1996).

In this dissertation the shadow pricing procedure was conducted separatively for differential benefits and costs. Differential costs were divided into three "cost classes" (Figure 2.4) which in most part (app. 90-95%) generate the total differential costs of seed orchards. This division into cost classes is analogous to the basic idea that there are key sectors in the economy (Dasgupta & Pearce 1978, p. 111). Each cost class consisted of subactivities, and the inputs (such as labour) of these subactivities were finally shadow priced (Figure 2.4). Prior to shadow pricing, however, transfer payments

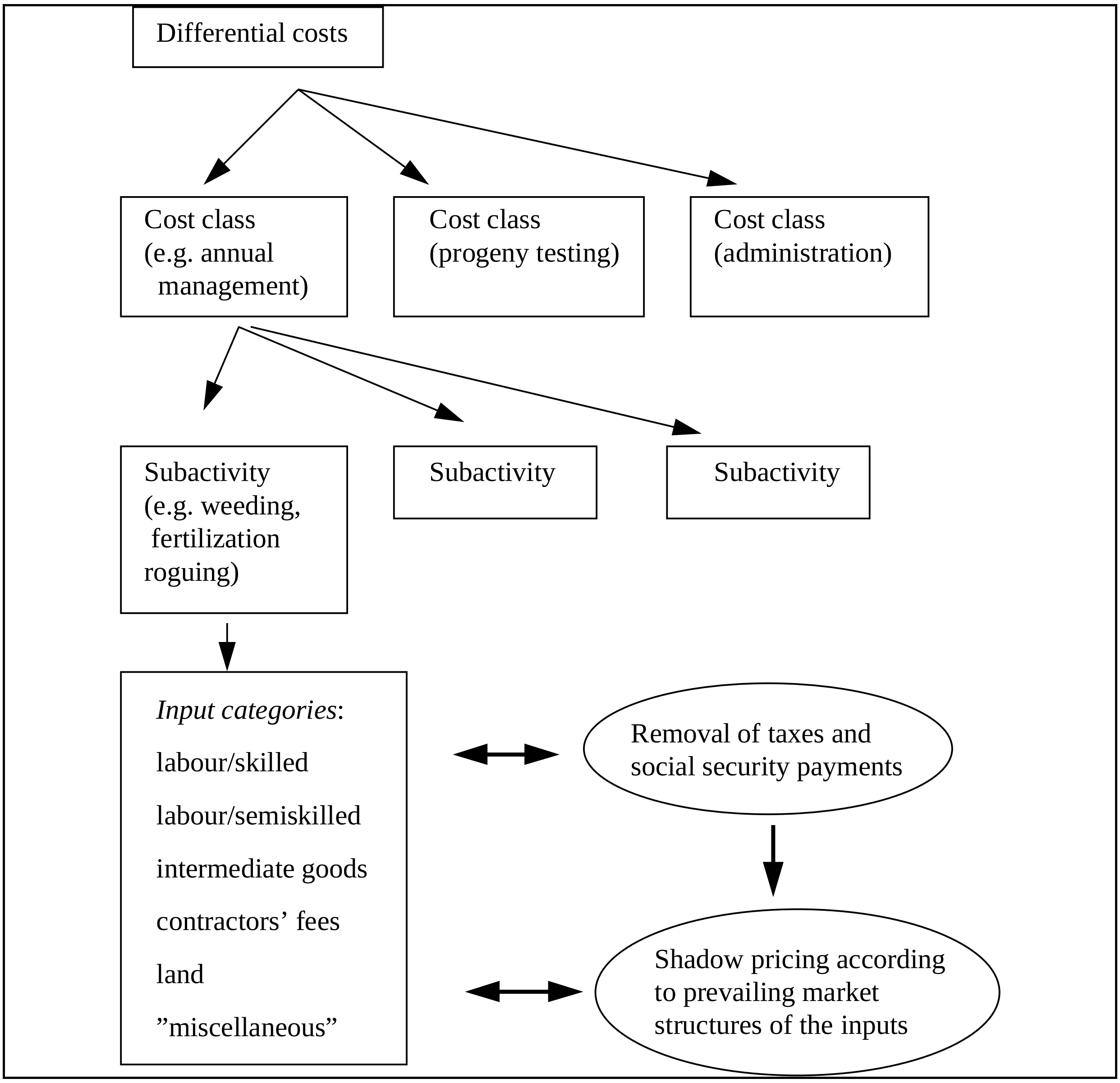

Figure 2.4. General shadow pricing procedure.

such as taxes and social security payments were deleted from the financial values of the inputs (Figure 2.4). This is due to the fact that transfer payments do not represent direct claims on the country's resources but merely reflect a transfer of the control over resource allocation from one member or sector of society to another (Squire & van der Tak 1981, pp. 19-20).

The main shadow pricing procedure of differential costs was conducted by estimating the market structure for each input so that the divergency between prevailing market price and the price reflecting perfect competition (i.e. Pareto-efficient equilibrium prices) could be determined. The initial purpose for this detailed examination was to catch and further quantify the specific features prevailing for each input in seed orchards. In practice this was done by specific coefficients which are analogous to generally applied conversion factors (see, Ward & Deren 1991, p. 75) referring to the ratio of the economic value to the financial value of items in the project cash flow. These coefficients varied between 0.6 and 1.0, and they were study specific. In other words, the coefficients were evaluated separatively in each study (further discussed in empirical studies). To some extent, this empirical approach can be seen as case-sensitive implying a lack of generability, but on the other hand, the detailed examination of market structures supplies important information that can be used as a basis for designing policies to remove the market distortions (see, Squire & van der Tak 1981). Formally, the shadow pricing of the inputs could be presented by formula:

$$SP_i = \left[FV_i - TP_i\right] * C_i^M \qquad [2.2]$$

where SP_i= shadow price for input *i*
FV_i= financial value, i.e. market price for input *i*
TP_i= transfer payment of input *i*
C_i^M= coefficient reflecting the prevailing market structure for input *i* (e.g. oligopolistic competition, monopoly), ≤ 1

The shadow pricing of differential benefits was much simplier than that of differential costs. In short, stumpage prices were assumed to reflect correctly the social costs involved (see Appendix 3 for further details).

2.1.5 Discounting process

Background

After having identified the differential costs and benefits and having them shadow priced properly the next task in the calculation process was to commensurate the future units with current units. This was done by discounting, i.e. "downgrading" the future benefits and costs to present. The applied discount rate was indisputably one of the most decisive factors affecting the profitability. For this reason the discounting process should be examined in detail.

General

The two fundamental causes which determine the rate of interest are time preference (noted as subjective element) and investment opportunity (objective element). Discounting (computing from future to present values) is essential in time valuation, that is, the problem of ascertaining the capital value of future income (Fisher 1930).

The choice of a suitable rate of interest with which future net benefits are to be discounted has occupied a major part of the discussions on CBA, especially when the decision criterion is NPV (although also the IRR method involves a predetermined interest rate to which the calculated internal rate of return is compared; Irvin 1978). Choosing a suitable interest rate is of vital importance for a number of reasons. First, if too low a rate of interest is chosen, socially inefficient projects will be undertaken. Conversely, if too high an interest rate is chosen efficient projects will fail to clear the hurdle of acceptability. Second, what is at stake in the choice of a discount rate is the allocation of resources between the public and the private sectors of the economy (Brown & Jackson 1991). If a unit of resource is extracted from the private sector to build a public project, what is its opportunity cost ? Rates of return on private investment should be observable and relevant. But many such rates can be observed with respect to different industries and financial instruments and these opportunities differ among individuals.

The market value is a function of expected future income and the discount rate, and there is never certainty as to whether the result is a matter of discount rate or differences in expectations. Some analysts (e.g., McKean 1958) suggest that with capital rationing, the relevant opportunity cost for any public project is another public project. Thus, the rate of discount rate should be the rate of return on the marginal project. However, the problem arises when defining the marginal project (Schmid 1989). For a private firm the true cost of capital for an investment should be a function of the risk in the cash flows generated by the investment and the marginal debt capacity of the investment (Fortson 1986), but problems arise when determining the marginal debt capacity from the society's point of view.

Determining the social discount rate (SDR) is analogous to finding the distribution weights. Both distribution weights and the SDR involve attaching coefficients to the benefits and costs. For distribution weights, one values the benefits and costs that go to different individuals at the same point of time; while for the SDR, one values the benefits and costs that go to the same individuals at different points of time (Brent 1996). There are two main candidates to measure SDR, the social opportunity cost rate, SOC (denoted also as SOCC or SOCR) and the social time preference rate, STPR (denoted also as SRTP) (e.g., Pearce & Nash 1989, Brown & Jackson 1991 , Brent 1996). Briefly, the social opportunity cost of capital, SOC, is a measure to society of the next best alternative use to which the resources employed in the public project might otherwise have been put (Brown & Jackson 1991). The STPR, on the other hand, assigns current values to future consumption reflecting society's evaluations of the relative desirability of consumption at different periods of time, i.e. STPR tries to use discount rate to reflect society's valuation of future consumption (Pearce & Nash 1989, Brown & Jackson 1991, Gregersen et al. 1995), or put it differently, to evaluate society's preference for present consumption at the expense of more rapid growth (Gregersen & Contreras 1992). Only if the assumption of optimal investment holds, these two rates will "conflate" to one single rate. But it is precisely because opinion favours the view that economies do not operate at the optimal level of investment that these two divergent rates exist.

Technically, the difference between the SOC and the STPR can be explained by the following reasoning (Baumol 1968). Assume that government can borrow at the rate of s, and assume further this government's borrowing rate is equal to the STPR. Let there be a corporation tax equal to t, which is levied on the profits of private industry. From the private company point of view, shareholders will expect at least s per cent, otherwise they will secure better returns by lending to the government. But to provide them with s per cent or more, companies must earn a *gross* rate (r, SOC) of s/1 -*t* since *t* per cent disappears in corporate tax. Self-evidently,

$$r = \frac{s}{1 - t} > s \qquad [2.3]$$

since *t* is less than unity.

There are two reasons why the rate of return on private investment is relevant to discussion of the social discount rate. First, the notion of a social discount rate arises from the view that the cost of capital in the private sector is an inappropriate measure for evaluating government spending. An opposing view is that government should employ the same measure of capital cost as citizens do. To determine the practical significance of this difference in viewpoint requires both numerical specification of a social discount rate and estimation or measure of the private sector rate. Secondly, if there is a difference between the two rates, a method must be worked out for dealing with the problem of possible misallocation of resources. In other words, to employ a social discount rate as a feature of the government's resource-allocation apparatus requires information about the profitability of private investment that will be displaced or stimulated by the government's investment behaviour. However, the idea of "the" rate of return on private investment is itself an abstraction. The concept follows from equilibrium theory, in which rates of return obtainable from investment in many activities are equalized. Financial information (i.e. empirical counterparts of the theoretic concept), at best, may provide insight only into *average* rates of return. Yet it is the *marginal* rate of return that is relevant to resource allocation. (Stockfisch 1982, p. 258).

The market rate of interest can be used to measure the social discount rate, SDR *only* if so-called "first-best" optimum exists. This indicates that the only constraint affecting welfare maximization is the production function. If there exists some additional constraint, the one is in a "second-best world". In developed countries (such as Finland), transaction costs and capital taxes are imposed that drive a wedge between what investors are willing to pay and savers are willing to receive. As long as there is an additional constraint (e.g. capital taxes), the market rate of interest should not be used as the SDR (Brent 1996).

It would be difficult to mount a decisive case for or against any rate of discount rate governments might to choose, but it is still fair to say that the lower part of the discount rate range would be associated with the STPR approach, and the higher values recommended by the SOC advocated (Brent 1996). Sometimes the case for using a social rate of discount *lower* than the private rate has been argued on the following grounds: super-responsibility argument (the government has also responsibility to future generations), dual-role argument (some members may be more concerned about the welfare of the future generations than their day-to-day market activities) and isolation argument, which states that members of the present generation may be willing to join in a collective contract of more savings by all, though unwilling to save more in isolation (Sen 1982). The last argument is the most controversial which is elaborated on by ,e.g., Harberger (1964).

The variance of the rate of return declines with the duration of the investment and therefore the maximum rate of return also declines with the duration of the investment (Binkley 1981). In addition, there are studies (e.g., Klemperer et al. 1993) suggesting that the appropriate risk premium (and thus the resulting compound discount rate) may decline with lengthening payoff period for many forest investments, although forestry investments in general are not considered risky (Thomson 1989). However, it can be concluded from the above that it is well grounded that with long-term projects such as tree breeding the lower part of the discount rate range should be applied. This view is supported by a recent, technically stressed study (Weitzman 1998). In addition, lower discount rates imply that more resources will be made available to the future than with higher discount rates (Binkley 1981). This is in accordance with the growing concern about sustainability (of natural resources).

There are alternatives to conventional (also den oted as standard) discounting to be applied in public investment calculations. To name few, dual rate approach (Manning 1977), modified discounting (Kula 1988) and logarithmic discounting (Heal 1998) have been suggested. In dual rate approach a "social discount rate" is being used for long range investments affecting future generations, and a more normal rate is being used for harvest scheduling. However, there are some drawbacks with this method. For example, the initial amount of public funding has to be divided in order to commensurate these different results with different discount rates to other projects' net benefits. Usually, this is more or less obscure. In modified discounting method discount factors are weighted according to the structure of the population in terms of its generation. The effect is to give higher weights to future costs and benefits than under conventional discounting (Kula 1988). Logarithmic discounting measures time by equal proportional increments rather than by equal absolute increments. Logarithmic discounting at some given discount rate places very much more weight on the long-term future than does exponential (or conventional geometric) discounting at the same constant rate. This method implies that in discounting we measure distance into the future according to the logarithm of time. The underlying idea is so-called Weber-Fechner law which says that human responses to a change in a stimulus are nonlinear and are inversely proportional to the existing level of the stimulus (Heal 1998).

Before selecting the discount rate(s) in the NPV method, there is one important task to be done. Namely, the effect of inflation must be taken into account. One must either estimate the rate of inflation (assuming that it will be identical for costs and benefits) and add it to the appropriate discount rate or express all flows in constant prices before discounting (Irvin 1978). The latter technique was applied here, and the current prices were deflated by the whole sale price index.

Applicable discount rates for Finnish conditions

In Finland *return on forestry* has exceeded inflation by app. 3% during the last two decades, years 1972-1994 (Penttinen et al. 1996). Thus, it might be advisable to take this 3% as a starting point for the discount rate, although this percentage does not originate from the public-sector forestry investments, but from an "overall" return of forestry. Nevertheless, there is little support to select any particular discount rate for public-sector investment in Finland due to the lack of empirical studies dealing with the issue. An earlier study (Björk 1984) suggested that the range of 3% to 7% is empirically justified in government projects in Finland, depending on the particular theoretical framework applied.

2.2. Seed producers' viewpoint

2.2.1 Profitability conditions for a single firm

In its simplest form, the profitability for a single firm producing orchard seed can be calculated by subtracting production costs from sales revenues. Formally, this can be presented by the following:

$$P_{sf} = pf(q,\ x)\ - cq\ - zx \qquad [2.4]$$

, where P_{sf} = profitability for a single firm

q = labour input

x = other inputs used in production

f(q,x)= production function

p= price for orchard seed produced according to f(·)

c, z= given prices for inputs q and x, respectively

In this dissertation the focuses with regard to financial profitability were *a)* to examine the overall conditions for positive P_{sf} (P_{sf} >0), and *b)* to estimate whether there are possible economies to scale still to be exploited. The solutions for profit maximization conditions were left in the background. These tasks (a, b), however, required first that the definition about the time period had to be made.

2.2.2 Short run and long run

In order to be able to analyse the output decisions made by a single firm (producer) two separate aspects should be underlined. First, output decisions must be analysed with respect to time period, and second the market environment need to be described (Varian 1987). However, in this dissertation the latter issue (market environment) is not examined *as such*. This is due to the established fact that there are only a few orchard seed producers in Finland (see, e.g., Metsänviljelyaineistotyöryhmän...1994, Männyn...1997), indicating an oligopolistic market structure. Rather, the issue is surveyed by quantifying the essential functions determining the orchard seed markets in order to estimate whether there are possible economies of scale still to be exploited.

The short run is defined as that period of time in which there are some fixed factors - factors that can only be used in fixed amounts. In the long run, on the other hand, the firm is free to vary all of the factors of production. In other words, in the long run the firm is free to choose the level of *all* of its inputs (e.g. labour, capital, machines) whiles in the short run it may be very difficult to adjust *some* of the inputs. Fixed costs (due to fixed factors) are the costs that must be paid regardless of what level of output the firm produces. However, there is no rigid boundary between the short and the long run: the exact time period involved depends on the problem under examination. Moreover, there may still be quasi-fixed factors in the long run, for example it may be a feature of the technology that some costs have to be paid to produce any positive level of output (Varian 1987).

Formally, the difference between the short run and long run can be presented by the following:

$$\frac{c(y,k^*)}{y} \geq \frac{c(y)}{y} \qquad [2.5]$$

where k^*= fixed plant size

$c(\cdot)$= total cost function

y= output

This is consistent to saying that the firm must be able to do at least as well by adjusting plant size as by having it fixed (Varian 1987). In this study context long run instead of short run was chosen due to two reasons: the long time horizon involved in seed orchards and technical restrictions; higher-than-annual frequency data on orchard seed sales was not available.

2.2.3 LAC curves, MES, market demand and price elasticity of demand

Generally, after profit maximization condition (also denoted as marginal condition, MC=MR; see Varian 1987, Hirshleifer & Glazer 1992) is satisfied the *perfectly* competitive firm has to check whether it is making losses at that output level (Begg et al. 1994). In the checking process long-run average cost (LAC) curves are essential. They determine whether to shut down or stay in business: if in the profit-maximization output level the selling price (which equals marginal revenue in perfect competition) is higher than long-run average costs, then the firm is making profits. On the other hand, if price is less than long-run average costs, the firm should leave the industry. The checking process applies also to monopoly and imperfect competition, although, e.g. the monopoly price usually exceeds marginal revenue.

One applicable method to reveal the market structure is to examine the LAC curves and minimum efficient scales (MES). Minimum efficient scale indicates the point at which the LAC curve *first* becomes horizontal (Begg et al. 1994). Stated differently, MES is the point where dLAC/dx = 0 (x is output). By comparing the MES *relative* to the output of the industry as a whole, estimates about the prevailing market structure can be made: large proportions indicate imperfect competition, e.g. oligopoly. One approximation of the output of the industry can be given by the market (also denoted as industry) demand curve, because market demand curve reflects the sum of individual demand curves at each price (e.g., Friedman 1976), and also indicates the realized output which has been produced at the prevailing price. The market demand for a good can be presented by the following (Varian 1987):

$$X^1(p_1,p_2,m_1,\ldots m_n) = \sum_{i=1}^{n} x_i^1(p_1,p_2,m_i) \qquad [2.6]$$

$X^1(p_1,\ldots m_n)$ = aggregate market demand for good 1

where $x_i^1(p_1,p_2,m_i)$ = consumer i's demand function for good 1

p_1, p_2 = prices for goods 1 and 2

m_i = consumer i's income

The geometric interpretation of the aggregate demand curve is that individuals' demand curves are summed horizontally (Varian 1987).

The responsiveness of quantity to price changes is measured by the elasticity of demand (e.g., Stigler 1970, Friedman 1976, Parkin 1997). This price elasticity of demand is usually measured by the percentage changes in price and quantity in order to have an elasticity measure that is independent of the units in which price and quantity are expressed (e.g., Friedman 1976, Varian 1987, Hirshleifer & Glazer 1992, Parkin 1997). Formally presented by (Hirshleifer & Glazer 1992):

$$\eta_x = \frac{\partial x/x}{\partial P_x/P_x} \qquad [2.7]$$

where η_x = price elasticity of commodity x

P_x = price of commodity x

Demand is said to be elastic if the price elasticity (denoted by η_x here) is more negative than -1. Demand is inelastic if the price elasticity lies between -1 and 0 (Begg et al. 1994). In words the former (elastic demand) means that the quantity demanded is very responsive to price: if the price is increased by 1 per cent, the quantity demanded decreases more than 1 per cent (Blair & Kenny 1982, Varian 1987). However, it is noteworthy that since elasticity is usually *changing* along a demand curve, it is generally wrong to identify a demand curve as elastic or inelastic; it would be correct to say that in the neighbourhood of some given price, the demand is elastic or inelastic (Hirshleifer & Glazer 1992). In general the elasticity of demand for a good is determined by the closeness of substitutes for it, the proportion of income spent on it and the time lapse since its price changed (Parkin 1997).

One of the most important reasons for employing the elasticity concept (when dealing with demand curves) is that it provides a convenient method of indicating the behaviour of total receipts. The change in total receipts depends on two factors: the change in price and the change in quantity (Friedman 1976). The relationship between (price) elasticity and total revenue can be tested by total revenue test, which is a method of estimating the price elasticity of demand by observing the change in total revenue that results from a price change (with all other influences on the quantity sold remaining unchanged). If a price cut increases total revenue, demand is elastic; if a price cut decreases total revenue, demand is inelastic (Parkin 1997). This relationship can be also discovered from the following formula (Varian 1987):

$$\frac{\Delta R}{\Delta p} = q[1-|\epsilon(p)|] \qquad [2.8]$$

where ΔR = change in total revenue

Δp= change in price

q= quantity demanded

ϵ(p)= price elasticity of demand

2.3 Private forest owner's viewpoint

2.3.1. Decision making environment

The most desirable decision is one which is preferred by the decision maker after taking into account not only monetary value, but also other factors such as the risk associated with the outcomes (Anderson et al. 1994). The risks associated with improved (orchard seed) and unimproved (stand seed) material either in direct sowing or in planting can be considered to be more or less identical, and thus they can be ignored. Also the risk associated with, e.g. fire occurrence (see Caulfield 1988) can *a priori* be expected to be identical for both material. In this connection, however, it should be brought out that previous studies (e.g., Venäläinen et al. 1994, Ahtikoski & Pulkkinen 1999) have indicated that there might be small differences in vitality (measured by survival rates) especially in direct Scots pine sowing. On the other hand, in large-scale (national) silvicultural practice the divergence cannot be converted into monetary value without substantial speculativeness involved in the process.

For a private forest owner there are two artificial regeneration methods: he can sow either seed or plant seedlings. In direct sowing of commercial tree species in Finland (Scots pine, Silver birch and Norway spruce) the seed material costs build up approximately 70% of the total sowing costs (Kinnunen 1997). Thus, for a private forest owner, as a rational decision maker, it is of vital importance to choose the most cost-effective seed. In this connection it is assumed that a forest owner is acting rationally, i.e. maximizing utility (see, Arrow 1992: utility maximization and rationality). For all commercial tree species grown in Finland there are only two alternatives for seed material: (natural) stand seed and orchard (improved) seed. The cost difference between the stand and orchard seed material does exist, and varies between tree species, but in recent years it has been smallest for Scots pine (e.g., Hänninen 1995, Kinnunen 1997).

The orchard seed possesses a potential for higher total outturns compared to stand seed in a form of better vitality and better growth properties. The expectations with regard to higher outturns in the future might be reflected by a higher willingness to pay for orchard seed (WTP_o) than for stand seed (WTP_N) , i.e. $WTP_o > WTP_N$. Thus, it is economically justified for private forest owners (under rationality assumption) to pay more for orchard than stand seed, given that higher outturns can be realized in the future.

In planting, seed material costs form only a very small proportion of the total production costs of seedlings, say 1-3%, and with some species (e.g. Scots pine) these costs cannot even be separated from other production costs. Moreover, it can be argued that:

$$c_o(s_o,\ m,\ a) \approx c_N(s_N,\ m,\ a) \qquad [2.9]$$

,where:

$c_o(\bullet)$ = total cost function for seedlings made of orchard seed
$c_N(\bullet)$ = total cost function for seedlings made of stand seed
s_o= seed material costs when using orchard seed
s_N= seed material costs when using stand seed
m= management costs incl. e.g. costs of nursery sowing, fertilization, culling, transport: i.e. direct production costs of seedlings
a = administration costs incl., e.g. costs of marketing, rents, and salaries of supervising personnel

In words formula [2.9] means that the total costs of production of seedlings are more or less the same regardless of seed material origin. This is coherent to saying that the prices of seedlings facing a private forest owner are identical for seedlings grown from stand seed and seedlings grown from orchard seed.

2.3.2 Difference investment method for profitability calculation

Difference investment method is preferred to the sole comparison of the NPVs under imperfect capital markets (i.e. borrowing rate of the financial market, r_v does not equal to the yield rate on financial market investments, r_s) and when discount rate is changed intertemporarely (Ollonqvist & Kajanus 1992). Moreover, when there are only two alternatives to compare (as is the case of choosing seed material for direct sowing), the difference investment method is preferred to alternatives. In difference investment method the difference of *net* benefits at present value instead of net present values is being (Ollonqvist & Kajanus 1992) examined:

$$\Pi_{diff} = \sum_{i=0}^{\infty} \frac{a_i - b_i}{e^{\sum_{j=0}^{i} r_j}} \qquad [2.10]$$

, where:

Π_{diff} = difference investment (FIM)

a_i, b_i = forest investments

$$e^{\sum_{j=0}^{i} r_j} = e^{r_0} * e^{r_1} * e^{r_2} * \ldots * e^{r_i}$$

In formula [2.10] $\Pi_{diff} > 0$ indicates that investment *a* is to be preferred to investment *b* (Johansson & Löfgren 1985, Ollonqvist & Kajanus 1992). In the difference investment method the discounted costs are subtracted from the discounted benefits resulting in net benefit within *each* time period. These separate time periods constitute the final time horizon relevant to problem setting.

The profitability of using orchard seed in direct sowing was calculated by applying the difference investment method (Ollonqvist & Kajanus 1992), and it was evaluated from the private forest owner's point of view. The present value of the outturns in normal (i.e. unimproved) stand was subtracted from the present value of the outturns in an improved stand. Then, the initial sowing cost difference (between orchard and stand seed) was subtracted from this figure indicating a *net* benefit at present value as the original article suggests (Ollonqvist & Kajanus 1992). Formally,

$$\pi_{tb} = \sum_{t_1}^{tt} JT_t * (D_p)^t - \sum_{n_1}^{nn} NS_n * (D_p)^n - (C_g(S) - C_0(S)) \qquad [2.11]$$

where:

π_{tb}= net benefit, FIM/hectare

JT_t=financial value, FIM/ha (assessed by using trend stumpage price as a unit of measure) of a thinning or final cut in an improved stand

NS_n= financial value of a thinning or final cut in a normal stand without genetic gains

D_p= discount factor (see Table 2.1)

t_1= time (in years) of the first commercial thinning in an improved stand

n_1= time of the first commercial thinning in a natural stand

tt= time of the final cut in an improved stand

nn= time of the final cut in a natural stand

$C_g(S)$= initial sowing cost (FIM/ha) when using orchard seed

$C_0(S)$= initial sowing cost (FIM/ha) when using stand seed

2.3.3 Choice of a discount rate

There is no rigid rule for applicable discount rates to be used in private forest investments, but some principles about the rate can be given. First, a higher rate can be expected to be applied for a nonindustrial private forest owner (NIPF) who operates (e.g. investing forest measures) with loan money than an NIPF who invests with savings. Second, with increasing risks higher returns are commonly required (see, e.g., Megginson 1997). Finally, investments for private forestry are in general considered as low-risk investments when compared to main alternatives (public bonds and real estate) - this can somewhat be interpreted by assuming lower interest rates for forestry. In addition, the roundwood market in Finland has encountered more stable supply and demand conditions than other raw material markets on average (Hannelius 1997).

The starting point in determining applicable discount rate for private forest investments in Finland is evidently past relative returns on forest investments. Recent studies (e.g. Penttinen et al. 1996, Tilli 1998) suggest that only relatively low returns are obtainable from forest investments. Returns of forest investments have exceeded the inflation by approximately 3% (Penttinen et al. 1996) during 1974-1994. The total return (incl. forest asset income and the increase in the value of a forest asset) has varied between 5.8-6.3% during the period 1986-1996 (Tilli 1998). Another study reported that in 1995 the overall profitability (expressed in percentage) of private forestry was 3.78% for the whole country, ranging from 2.26% to 6.91% (Hannelius 1997).

2.4 Applied data and time series analysis

Stumpage prices and time series analysis

The primary idea was to obtain as wide-ranging time series as was possible. This is in accordance with the long time horizon associated with this research.The disadvantage of this procedure was that it did not take into account regional differences in stumpage prices (see, e.g., Toppinen 1998, Vaara 1998) since the longest available time series of stumpage prices are from national level averages (Finnish Statistical ...1999, p. 165). On the other hand, these relatively small regional differences can be considered to be well offset by the advantage of obtaining long time series. The underlying data for time series modelling mainly consisted of deflated stumpage prices between the years 1950 - 1995 (Appendix 4). From 1996 onwards stumpage prices in each study were forecasted according to the equations presented in Appendix 4. The underlying idea was to standardize the division into past and forecasted values across the studies. The deflation rates were calcualted based on the wholesale price index of domestic goods (Statistical Yearbook of Finland 1997, Table 373).

In this research the main purposes for modelling stumpage time series data were to identify a possible trend and to forecast the future values according to this trend. No attempt was made to formulate a behavioural relationship between the stumpage prices and other variables (e.g., national income, aggregate demand for forest products, unemployment rate). The idea was to construct as simplistic models as possible, but still powerful enough to forecast the future values (see Harvey 1993). The best method for the purpose was linear regression by ordinary least squares, OLS (see, e.g., Koutsoyiannis 1981). In identifying a possible trend in a time series OLS is the most convenient and powerful method since it results in a straight line which correponds the underlying data (see, e.g., Koutsoyiannis 1981, Chatfield 1989).

With respect to the observations there were two issues which should be noted. First, for Silver birch veneer the initial stumpage prices were from 1975-1995 instead of 1973-1995 (see Finnish statistical...1998, p.158). The values of the years 1973 and 1974 were omitted because of the oil crisis occuring at that time - the applied method for modelling (see below) would have resulted in decreasing future values (i.e, a negative trend) if those values had been included in the analysis. In time series analysis it is well justified to omit so-called outliers at the beginning or at the end of the series if these observations can be explained by some exogeneous phenomenon (see, e.g., SPSS 1994). Second, time series of softwood logs were used in forecasting the future prices for Scots pine sawlogs. The time series of softwood logs was considerably longer than that of Scots pine sawlogs (see, e.g., Finnish Statistical...1998, p. 158). However, the future prices of softwood logs needed to be converted into the future prices of Scots pine sawlogs. This was achieved through the following procedure. The future prices of softwood logs obtained from the linear regression (Appendix 4) were converted into specific coefficients by dividing each forecasted value by the value obtained for the year 1995. Next, the value of Scots pine sawlogs in the felling season of 1994/1995 (FIM 238/m^3: Finnish Statistical...1998, p.158) was multiplied by these coefficients to attain the future prices for Scots pine sawlogs. Similar procedures have been applied earlier in Finland (see, e.g., Keipi & Laakkonen 1980).

Because of the difficulty in including all the important explanatory variables in the equation, time series regression frequently violates the assumption of uncorrelated errors. This usually leads to the goodness-to-fit and significance levels being unreliable (e.g., SPSS 1994). Not surprisingly also in this research linear regressions showed poor statistical behaviour (Appendix 4). Consequently, a sensitivity analysis regarding the method for forecasting future prices was called for. In each study the assessments were recalculated with a) the stumpage prices for felling season 1994/1995 (Finnish Statistical...1998, p. 158) and b) a triple trend (i.e, triplicating the annual increase of the linear equation).

An auxiliary analysis was conducted in order to compare the past cost development with the past development of benefits. Indices of wage and salary earnings (Statistical Yearbook of Finland 1997, Table 345) were chosen to represent past cost development. Average stumpage prices (softwood logs) in private forests (Finnish statistical...1998, p. 158) were adopted for depicting the past development of benefits. The primary idea was to examine whether there would be a tendency for costs or benefits to increase (annually) at a different pace. Technically the past development of both series was modelled by dividing each value (1950-1996) by the deflated numeraire corresponding to the value of the year 1949. The level of deflation was calculated according to the wholesale price index for domestic goods (Statistical Yearbook of Finland 1997, Table 373). The two series were then plotted into the same diagram (Figure 2.5). On the basis of visual examination, it seems that costs are prone to increase faster than benefits. Thus, it can be surmised that there were solid grounds for applying separate time series models for forecasting the future costs and benefits.

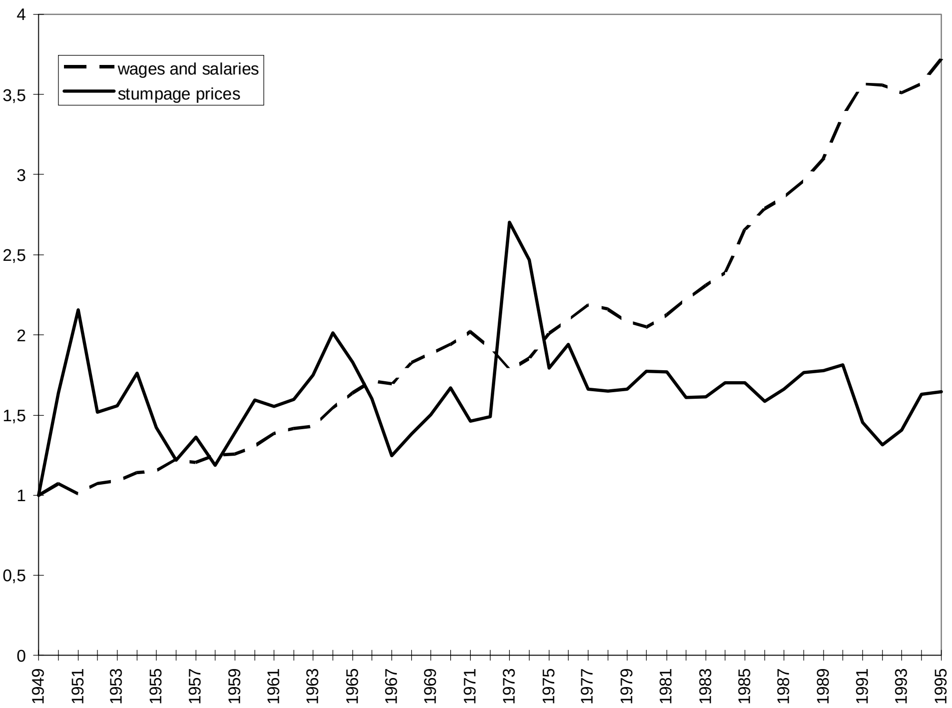

Figure 2.5. Time series for wages and salaries reflecting past development for costs, and stumpage prices reflecting past development for benefits; 1949-1996. The base year for both series was 1949 (whose value was set for numeraire). Both series deflated by the wholesale price index of domestic goods.

Differential costs and time series analysis

As regards costs, again the primary idea was to obtain wide-ranging time series on which to base the modelling. The longest available time series was derived from the average hourly earnings of workers in public sector between 1970-1995 (Statistical Yearbook of Finland 1997, Statistics Finland 1999). Then, this series was compared to the *overall* cost development of the seed orchard activity by plotting the observations into the same graph. They followed approximately the same pattern, and the average earnings per hour were chosen as the base data of the time series analysis. The observations were deflated by the wholesale price index of domestic goods (Statistical Yearbook of Finland 1997, Table 373) before adjusting them to time series analysis. The deflated differential costs before the year 1996 were taken as such into assessments, but the forecasted values (since the year 1996) of differential costs were calculated by a specific procedure. First, the initial forecasted values from the regression model (Appendix 4) were converted into annual increases (expressed in percentages). This was done by subtracting from each future value (according to the regression) the value obtained for the previous year. The differences were further divided by that value of the previous year. Finally, these annual increases were applied to the differential costs to attain future differential costs.

Linear regression model (parameters estimated by OLS; Koutsoyiannis 1981, Harvey 1993) for forecasting the future cost development was employed also here. Contradictory to the linear regressions of stumpage prices the regression model of costs showed satisfactory statistical behaviour (Appendix 4). Thus, there was no need for sensitivity analysis with regard to forecasting method. However, sensitivity to possible changes in trend costs was indirectly tested by another analysis which included 50% annual increase and 25% annual decrease of the costs.

3. Empirical studies

3.1 Society's viewpoint

3.1.1 Study 1: Profitability of present-generation seed orchards

3.1.1.1 Framework and restrictions

Scots pine

Due to the combined effect of background pollination and lower seed production capacity than anticipated, the orchard seed of northern clones (i.e. seed from seed orchards established for northern Finland) cannot be used in the initial target area. In practice, this has led to seed orchards for southern and central Finland and for northern Finland producing seed approximately to the same target area (e.g., Nikkanen et al. 1999). This fact was taken into account including all functioning present-generation seed orchards in the assessments regardless of their *original* target area. In other words, the profitability was determined for the *entity* of all present seed orchards.

There were two time horizons for the costs of present-generation Scots pine seed orchards: a) from 1965 to 2018 assuming that the average seed production time of a single seed orchard is 40 years with a 15-year time lag between establishment and seed production, and b) from 1965 to 2028 assuming that the average seed production time is 50 years (Ahtikoski 1995). Further, there were two alternatives within both time horizons for estimated annual seed supply, resulting also in two different sets of differential costs (Ahtikoski 1995). The first alternative (denoted as "40A" or "50A", depending on the seed production time) was based on the annual sales from Patama nursery of the FPS (Ahtikoski 1995): these sales were adjusted to reflect the annual cultivation hectares by using specific "conversion coefficients" (Ahtikoski 1995, p. 10). In another, hypothetical alternative ("40B" or "50B") it was assumed that *after* the year 1994 (between 1978 and 1993 the hectares were identical to the base alternative) the area annually cultivated with improved material would correspond to total cultivation area in southern and Central Finland, indicating app. 64 000 hectares (Ahtikoski 1995). This hypothetical alternative was taken into the assessment in order to emphasize the initial magnitude of the establishment: originally it was assumed that the established seed orchards would produce enough seed for the entire cultivation area in southern Finland (e.g., Metsäpuiden...1989, Venäläinen & Koponen 1997).

The annual financial values of differential costs were based on the combined values of the FPS and FFTB during 1971-1993 (Ahtikoski 1995), reflecting an annual average of FIM 7.23 millions (nominal, i.e. not deflated). The differential costs of seed orchards after the year 1994 were formed according to this figure. Besides the above-mentioned annual average there were other differential costs included in the assessments (see Appendix 5). Initially, the assessment was conducted by assuming that market prices coincided with shadow prices (Ahtikoski 1995), but also an alternative assessment with shadow pricing was conducted *post hoc*. The shadow prices were calculated according to the general procedure presented earlier (see Figure 2.4). The study specific cost classes and the division into input categories are presented in detail in Appendix 6. Finally, the inputs were shadow priced with special reference to prevailing market structures (Appendix 7). The shadow pricing principles were identical for present (this study) and next-generation seed orchards (Study 2) so that these generations could be compared with regard to possible welfare effects.

Pesonen & Hirvelä's harvest scheduling models (1992) and Vuokila & Väliaho's growth and yield models (1980) were applied in order to calculate the differential benefits reflecting genetic gains. The initial harvest scheduling models of Pesonen and Hirvelä (1992) were, however, altered by decreasing the removal of the first thinning by 20% and the removals of other thinnings by 15%

(Ahtikoski 1995). These changes were done, because the initial removals in Pesonen & Hirvelä's models were considered to be too optimistic in the long-run, i.e. within rotation period (Ahtikoski 1995) - this was found out in test simulations of MELA program. The initial models were tested against the MELA test simulation of the FPS. In general the removals of Pesonen and Hirvelä's harvest scheduling models were considerably higher than the corresponding values of the MELA simulation. Alternative genetic gains were applied according to progeny test results (see Appendix 8), and they were incorporated into *two* harvest scheduling models; one by Pesonen & Hirvelä and the other by Vuokila & Väliaho. It is noteworthy that the procedure changed only the outturns, not the harvesting times, and left also the proportions of sawlogs and pulpwood intact. The stumpage prices were, as mentioned earlier, set to equal shadow prices (see Appendix 3).

Southern Finland (temperature sum > 950 d.d.) was divided equally into two growth regions for Pesonen & Hirvelä's models, and the annual cultivation area (app. 24 000 or 64 000ha) was divided further into Myrtillus and Vaccinium type forests according to the proportions suggested in 1992 by Saarenmaa (Ahtikoski 1995, p. 10).

The height-over-age site classification applied in Vuokila & Väliaho's models was equalled to forest site types in southern Finland by assuming that height index H_{100}= 27 m (dominant height at age 100yr) would correspond to Myrtillus type forest, and height index H_{100}= 24 m would correspond to Vaccinium type. The annual total cultivation area was assumed to be divided into these two height classes (corresponding to forest site types) according to Saarenmaa (1992).

The shadow priced differential benefits and costs were finally calculated in present value by the following specific cost-benefit formula:

$$NPV = \sum_{t=22}^{108 \vee 118} B_t^{diff} * (D_p)^t - \left[\sum_{t=-29}^{-20} C_t^{es} * (D_p)^t + \sum_{t=-29}^{-1} C_t^{diff\,1} * (D_p)^t + \sum_{t=0}^{24 \vee 34} C_t^{diff\,2} * (D_p)^t \right] \quad [3.1]$$

where NPV= net present value, FIM (base year 1994)

B_t^{diff}= the sum of differential benefits (of growth regions) in year *t*, reflecting a genetic gain of 3%, 7% or 10%, FIM

C_t^{es} = past establishment costs of seed orchards, FIM

$C_t^{diff\ 1}$= past differential costs of seed orchards in year *t*, FIM

t = - 29 (reflecting actual year 1965)

"108" reflecting an average seed production of 40 years, and

"118" reflecting an average seed production of 50years

"24" reflecting an average seed production of 40 years, and

" 34" reflecting an average seed production of 50 years

$C_t^{diff\ 2}$= differential costs of seed orchards in year *t*, FIM

D_p = discount factor (see Table 2.1) with a 3%, 5% or 8% discount rate

Additionally, an applied cost-benefit formula for evaluating the net benefit per produced orchard seed kilogram was constructed. The discounted and prolonged costs and discounted benefits were transformed to correspond to the produced amounts of orchard seed (assuming that the seed is also sold) within the time horizon of 1978-2018. The prerequisite of this assessment was that future orchard seed demand between 1994 and 2018 would correspond to the average derived from 1978-1993. The formula was:

$$NB_{kg} = NPV \Big/ \sum_{t=-16}^{24} KG_t \qquad [3.2]$$

where NB_{kg}= net benefit for one kilogram of produced orchard seed with the assumption of 40-year seed production, FIM

NPV = formula [3.1] (with "108" and "24" assumptions)

KG_t = the produced (and sold) amount of orchard seed in year *t* (e.g. "-16" idicating the actual year of 1978)

To make a complete and useful economic analysis the analyst also has to provide some idea of what would happen to the chosen measures of project efficiency if the actual values of various inputs and/or outputs turn out to be different from the expected values. Using the list of parameters and estimates of the reasonable range of values for them, the sensitivity analysis is carried out (Gregersen & Contreras 1992). For Scots pine only the sensitivity to trend prices was tested. This was done by recalculating the assessments with stumpage prices of felling season 1994/1995 ("*no trend*") and with stumpage prices reflecting a triple trend compared to the original (see Appendix 4). Sensitivity to changes in cost trend was not tested due to the good statistical behaviour of the original forecasting model (see Appendix 4). The sensitivity to different harvest scheduling models was tested earlier.

Silver birch

There were no significant establishment or land procurement costs involved with Silver birch, because all seed orchards were in polythene tunnels covering only approximately a hectare (Finnish Statistical...1997). Basically, the assessments were conducted applying the same principles as for Scots pine, and the annual differential costs of Silver birch were derived from the combined values of the FPS and the FFTB between 1971-1993, reflecting an annual average of FIM 1.57 million (Ahtikoski 1995). These differential costs were further divided into inputs which were shadow-priced based on prevailing market structures (Appendix 7). The differential future costs (after the year 1994) were estimated according to the past annual average. The time period for the differential costs was between 1971 and 2002 (Ahtikoski 1995). There was only one alternative for annual orchard seed supply which reflected the past orchard seed sales from Haapastensyrjä Breeding Centre between 1973-1993. This average was converted into annual cultivation hectares resulting in a total of 1700 hectares (Ahtikoski 1995).

The differential benefits were calculated based on the growth and yield models of Oikarinen (1983). The removals of thinnings and final cut were increased according to percentage reflecting genetic gains. The genetic gains were estimated on the basis of progeny test results (see Appendix 9). There were two underlying harvest scheduling models with three intermediate thinnings, one for H_{50}= 26m, and the other for H_{50}= 24m. The rotation period for both models was 60 years (see Ahtikoski 1995; Appendix 4). The harvest scheduling models were extended into two growth regions (South and Central Finland) by a specific procedure (Ahtikoski 1995, p. 10).

The present values of shadow priced differential costs and benefits were calculated according to an applied cost-benefit formula:

$$NPV = \sum_{t=-1}^{68} B_t^{diff} * (D_p)^t - \left[\sum_{t=-23}^{-1} C_t^{diff\ 1} * (D_p)^t + \sum_{t=0}^{8} C_t^{diff\ 2} * (D_p)^t \right] \qquad [3.3]$$

where NPV= net present value, FIM (base year 1994)

B_t^{diff} = the sum of differential benefits (of growth regions) in year *t*, reflecting the genetic gains in pairs (see Appendix 9)

$C_t^{diff\ 1}$= past differential costs of seed orchards in year *t* (e.g. "-23" indicating an actual year of 1971), FIM

$C_t^{diff\ 2}$ = differential costs of seed orchards in year *t*, FIM

D_p = discount factor with a 3%, 5% or 8% discount rate

An auxiliary cost-benefit formula was applied. The purpose was to find out the *net* benefit per one kilogram of produced and sold orchard seed during the time period of 1973-2002. The costs and benefits (appropriately discounted and prolonged) were transformed to correspond to the sold amount of orchard seed. The formula was:

$$NB_{kg} = NPV \Big/ \sum_{t=-21}^{8} KG_t \qquad [3.4]$$

where NB_{kg}= net benefit for one kilogram of produced orchard seed

NPV = formula [3.3]

KG_t = the sold amount of orchard seed in year *t* (e.g. "- 21" indicating the actual year of 1973)

The assessments rested upon relatively restrictive assumptions. These needed to be examined in detail in order to evaluate how sensitive the NPVs are with respect to these assumptions. The robustness of the results as regards several variables was tested by sensitivity analyses (Table 3.1).

Table 3.1. Sensitivity analyses for Silver birch, study 1.

variable	*range*	*specification*
trend stumpage price	no trend, original trend, triple trend	*no trend* indicates stumpage prices of felling season 1994/1995, in *triple trend* the annual absolute increase is tripled
removal percentage	30% (denoted as "model B"), 50% ("model A")	one alternative adopts the removal percentage of 30% for both site classes, and the other adopts the removal percentage of 50% for site class H_{50}= 26m and 40% for site class H_{50}= 24m
rotation period*	5 (denoted as "early2"), 10 ("early1")	"5" indicates that rotation period is shortened by 5 years due to genetic gains (harvesting times intact), "10" indicates that rotation period is shortened by 10 years and each thinning is executed 5 years earlier

*Recent progeny test results (Hagqvist & Hahl 1998) indicate that average rotation period could be decreased even by 10 years.

3.1.1.2 Results

Scots pine

The results (assessed according to formula [3.1]) indicated that the more hectares could be cultivated with the orchard seed, the higher the net benefits would be (Figure 3.1: 40A vs. 40B). This result supports the well-known fact that present-generation seed orchards have not been utilized with the magnitude as anticipated at the time of their establishment (see, e.g., Nikkanen & Antola 1998). If orchard seed had been utilized in larger annual area, the more profitable the seed orchards would have been from the society's viewpoint (Figure 3.1: "40A" vs. "40B"). In this connection, only the results for the average length of 40 years of productive life are presented, since at present 50-year length of productive life of seed orchards is not tenabledue to intensive establishments of the next generation seed orchards. These new orchards start to compensate the present seed orchards from approximately the year 2010 (see, Männyn...1997).

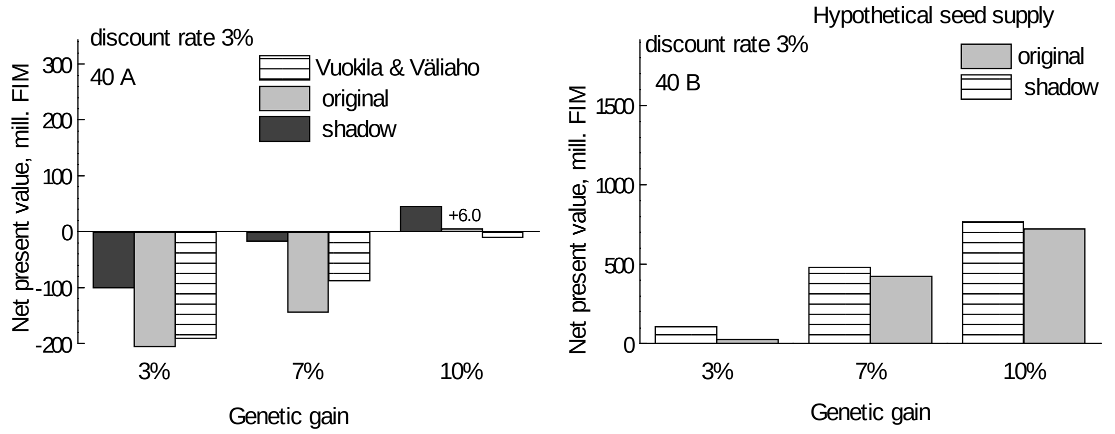

Figure 3.1. Net present values (NPVs) for Scots pine with original set of prices ("original"), shadow prices ("shadow") and according to Vuokila &Väliaho's models ("Vuokila & Väliaho"). "Hypothetical seed supply" ("40B") reflects the results with approximately 64 000 hectares of annual cultivation area. Discount rate 3 per cent in both graphs.

The exact genetic gain (the percentage increase in removal volume) where NPV would equal zero was estimated by linear interpolation (MatLab 1992, Lindfield & Penny 1995). For the shadow priced alternative this estimated genetic gain was 7.7% (discount rate 3%) indicating an over-than-average percentage with regard to latest progeny test results (see Appendix 8). For the hypothetical alternative this corresponding break-even genetic gain was only 1.99%. This further confirms the fact that the present-generation orchard seed should have been utilized more intensively, i.e., the large scale establishment and annual management of seed orchards have burdened the profitability considerably.

Net present values (NPVs) of the original alternative were sensitive to shadow pricing procedure (Figure 3.1) indicating that further knowledge on market structures of inputs used in seed orchards is of vital importance. Vuokila & Väliaho's harvest scheduling models resulted in somewhat similar net present values for each genetic gain as those by Pesonen & Hirvelä (Figure 3.1). There was no significant effect of different trend stumpage prices either, although the NPV turned into negative with 10% genetic gain when stumpage prices of felling season 1994/1995 (i.e no trend) were used instead of the original trend (Figure 3.2a). On the other hand, the use of trend prices is supported by recent studies (e.g. Toppinen 1998) which confirm that there has been a positive trend in stumpage prices during the last 50 years.

The *net benefit* associated with the produced and sold orchard seed kilogram (according to formula [3.2]) in original alternative was approximately FIM 1 000 when the genetic gain was 10% (Figure 3.2b). With other genetic gains the net benefit was negative. These are in accordance with the former overall results (see Figure 3.1), but what is interesting here is the magnitude of the net benefit per kilogram. Thus, it is important to be able to forecast the demand of the orchard seed.

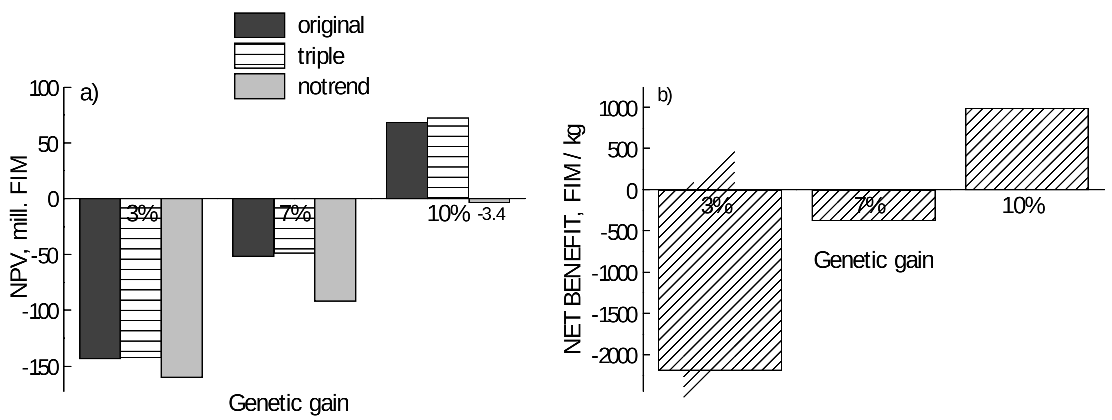

Figure 3.2. a) NPVs with alternative trend stumpage prices (original, triple trend, no trend). b) Net benefit per produced orchard seed kilogram, FIM /kg. Discount rate 3 per cent in both graphs.

Silver birch

The net present value (discount rate 3%) was negative even with genetic gains of 10% in South and 8% in Central Finland (Figure 3.3a). If the genetic gains turn out to be 15% in South and 12% in Central Finland, the present value of net benefits per one kilogram is over FIM 20 thousand, the discount rate being 3% (Figure 3.3b).

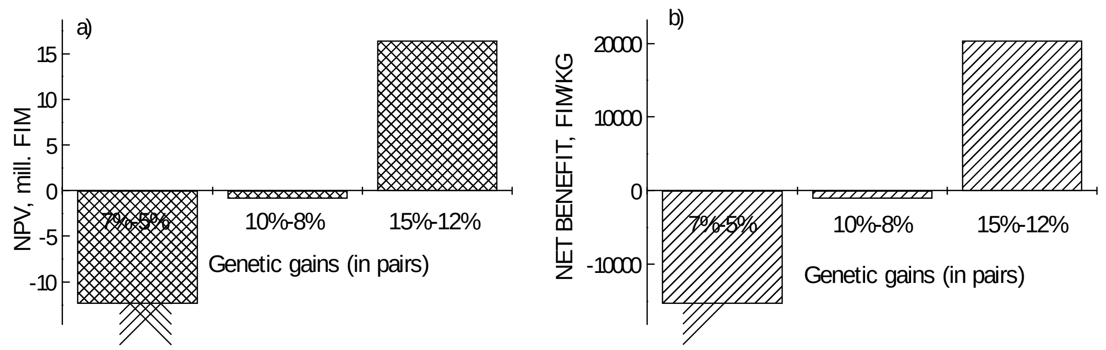

Figure 3.3. a) NPVs for Silver birch present-generation seed orchards. b) Net benefit per produced orchard seed kilogram, FIM /kg. Discount rate 3 per cent in both graphs.

The above mentioned is in accordance with the overall results (see Figure 3.3a), but what is significant here is the magnitude of the net benefit per kilogram of orchard seed. Thus, it is of paramount importance to forecast future demand accurately and in a way that that does not burden the profitability.

One reason for the considerable difference between the two species in net benefit is that Silver birch orchard seed is more "effective" with regard to the seed-to-plantable seedling ratio, i.e. one kilogram of seed "spreads" to larger area and thus more benefits can be attained. Another reason is that with the corresponding genetic gain (e.g. 7%) the harvest scheduling model of Silver birch leads to higher PVs of the benefits compared to Scots pine. In addition, the regional distribution and time period of costs were different. Thus, these two species cannot be compared *per se*, but the comparison can be made when evaluating the different production and cost structures. It can be argued from the results above (net benefits per produced kilogram) that in case of present-generation seed orchards Silver birch is more cost-effective than Scots pine.

The different removal percentages had only a minor effect on the NPV (Figure 3.4a), but the analysis was distinguishably sensitive to changes in harvest scheduling (Figure 3.4b). For example, when genetic gains only reflected earlier final cut (by ten years) and intermediate thinnings (by five

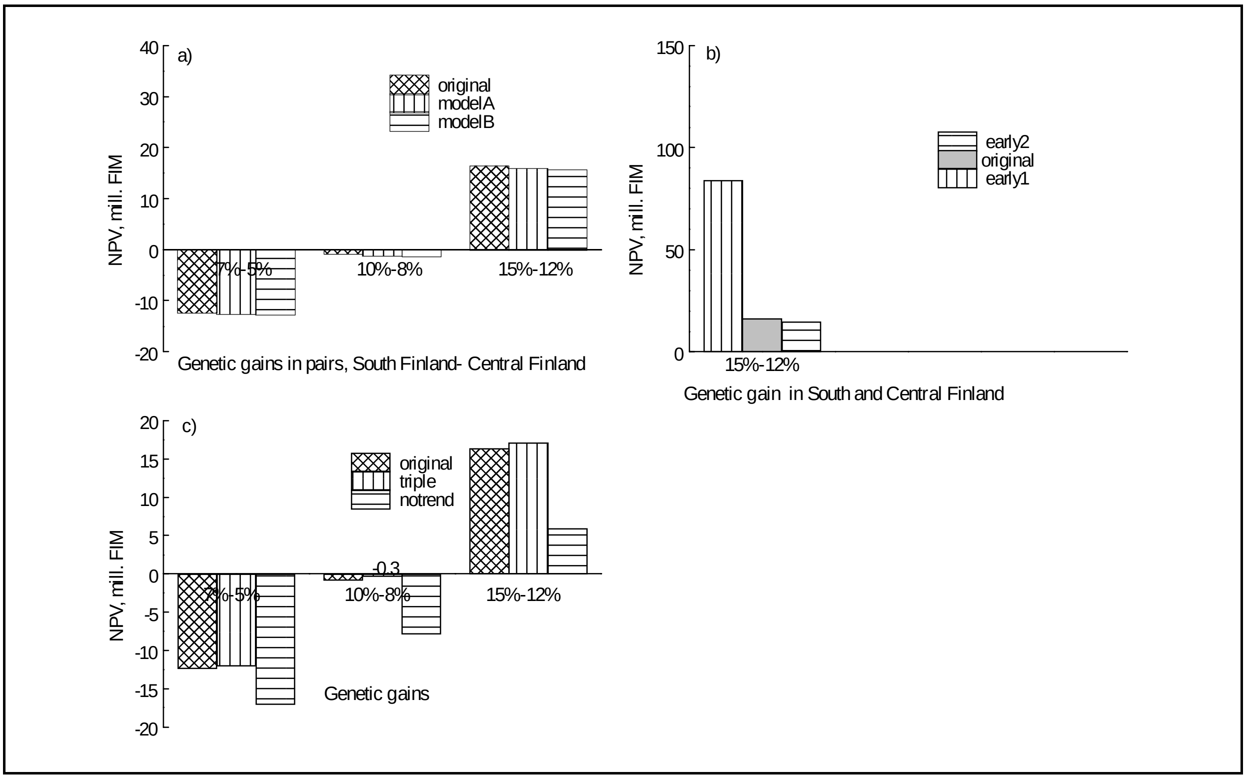

Figure 3.4. NPVs of Silver birch present-generation seed orchards with alternative removal percentages in harvests (a). "Model A" indicates 30% average removal percentage in each harvest, and "model B" indicates 50% respectively (a). In "early 1" thinnings areexecuted 5 years earlier and final cut 10 years earlier than in the original harvest scheduling model, and in "early 2" each thinning is executed 5 years earlier leaving final cut intact (b). NPVs with alternative stumpage prices are presented in c). Discount rate 3% in each graph (a-c).

years) - compared to the original harvest scheduling model of Oikarinen (1983) - the net present value ("early 1") was more than three times higher than in the model in which genetic gains were estimated by increasing cutting removals of the underlying harvest scheduling model of Oikarinen 1983 (Figure 3.4b). However, decreasing the rotation period by only 5 years (intact harvests; "early2") resulted in lower NPV than the harvest scheduling model with increased cutting removals (Figure 3.4b). The results support that long rotation periods are the most important single factor which burdens the profitability in private forestry (see, e.g., Keltikangas 1973).

3.1.2 Study 2: Profitability of the next-generation seed orchards, South and Central Finland

3.1.2.1 Framework & restrictions

Scots pine

The aim of this study was to evaluate *ex ante* the possible economic net returns of next-generation seed orchards from the society's point of view. Assessments were conducted by applying an empirical cost-benefit analysis (CBA). There were two specific assumptions made in the assessments. First, the possible deadweight loss due to public funding (see Boadway & Bruce 1984, Brent 1996) was ignored mainly because of the use of a partial equilibrium framework and a small project assumption. Secondly, no distributional weights were applied - it was assumed that Finland has not an objective to equalize income distribution *with the same scope* as less-developed countries have (see, e.g., Niskanen 1995). Moreover, the inequalities of income in Finland have at least declined over time (Fellman et al. 1996).

The establishment schedule was based on the report " Metsäpuiden siemenviljelysohjelma vuosille 1990-2025" (1989). The initial figures (see, Metsäpuiden siemenviljelysohjelma..1989, p. 45) were, however, slightly altered: establishment for each time period was postponed by 5 years due to delays in the original seed orchard establishment schedule (see, Männyn...1997). In addition, the annual average seed production per hectare (kg) was not taken into account as an endogenous variable. The primary interests were the establishment schedule of the seed orchards and the assumption that the produced orchard seed would meet the anticipated demand. It was conceived that 60% of the annual sowing area in South and Central Finland (temperature sum > 950 d.d) would be sown with orchard seed by the year 2019, reflecting a total of 10 460 hectares. This figure was based on the report "Metsänviljelyaineistotyöryhmän raportti" (1994). The annually planted area with the next-generation orchard seed starts to compensate linearly the present-generation orchard seed from the year 2010 achieving the level of past-ten-year average sales of Patama nursery, 21 305 hectares, by the year 2021 (see Appendix 10). Specific conversion coefficients were used in translating the produced amounts of seed (kg) into cultivation hectares. The seed-to-plantable seedling ratio was 1 kg to 90 000 seedlings, indicating that 1 kg of orchard seed suffices for 36 hectares (planting intensity 2500 seedling/hectare). In direct sowing 1kg of orchard seed was directed to 3 hectares in terrain.

Differential costs were obtained from the accounting records of the FPS and the FFTB between 1990-1995 (Internal accounting spreadsheets 1990-1995, Tietopankki 1996). These were partly based on recent experiences of managers, especially with regard to establishment costs (Lahtinen 1995, 1997). The annual differential costs were approximately FIM 5.4 million (further details in Appendix 11). The cost classes generating these differential costs were divided into subactivities and the inputs of each subactivity were shadow-priced according to the general procedure (see Figure 2.4). The proportions of inputs within each subactivity and the average tax rates were mainly based on internal book-keeping and recent experiences of local managers (proportions and tax rates are presented in detail in Appendix 12). The actual shadow prices were determined based on prevailing market structures for each input (see, Appendix 7). The future values of the differential costs were estimated on the basis of the formula presented in Appendix 4. Formally the shadow priced differential costs were calculated by the following:

$$C^{diff} = \sum_{t=-1}^{15} C_t^{es} * (D_p)^t + \sum_{t=0}^{40} \left(C_t^{m} + C_t^{p} + C_t^{ad}\right) * (D_p)^t \qquad [3.5]$$

, where C^{diff} = discounted *differential* costs of seed orchards in present value, FIM

C_t^{es}= establishment costs of the seed orchards in year *t*

C_t^{m}= management costs of the seed orchards (including administration, fertilization, roguing etc.) in year *n*

C_t^{p}= progeny testing costs in year *n*

C_t^{ad}= differential administration costs of the seed orchard activity compared to the administration costs of the stand seed collection in year *n*

D_p = discount factor with a 2%, 3%, 4%, 5% or 6% discount rate

The same arguments for chosen discount rates were used here as in Study 1.

The genetic gains were incorporated into MELA program by increasing annual growth level according to corresponding percentage (see Appendix 13 for details). The present value of the harvest scheduling model reflecting the increased annual growth level was subtracted by the present value of initial harvest scheduling model. The difference indicated differential benefit at present value. The initial biological data for simulation was located in four former local units of the FPS (see Ahtikoski 1997; a map on page 251, and Appendix 14). The harvest scheduling models incorporated with the genetic gains were simulated by MELA for two forest site types extending the models to four "growth regions" in South and Central Finland (Appendix 15). The division into forest site types, i.e. Myrtillus and Vaccinium (or corresponding) type forests was made by the proportions suggested by Saarenmaa (1992).

In each growth region the modified annual growth level (i.e., growth level with incorporated genetic gain) was on average assumed to be homogeneous. The division into growth regions was mostly based on the results of the 8th NFI (Salminen 1993). Initially, it was needed in order to be able to constitute the annual total hectares generating the benefits. Former forestry board districts were chosen as the" base units" for the simulation, because the main forest statistics are given in Finland accurately at forestry board level. The proportion (%) of each growth region of the annually sown or planted area was based on averages derived from the 1986-1995 figures of former forestry board districts (Statistical Yearbook...1987-1996) in the particular growth region (Appendix 16). The percentages reflecting genetic gains were based on progeny test results (see Appendix 8).

In this study the differential benefit accured from genetic gain could be expressed at stand level by the following:

$$B_{st}^{diff} = \sum_{t=38}^{99} JT_t * (D_p)^t - \sum_{n=38}^{102} NS_n * (D_p)^n \qquad [3.6]$$

, where B_{st}^{diff} = present value of differential benefits at stand level, FIM (base year 1996)

JT_t = outturn of a thinning or final cut (*valued at stumpage price*) in an improved stand reflecting a genetic gain of 8%, 12% or 15%, FIM

NS_n = outturn of a thinning or final cut in a normal stand (*valued at stumpage*)

D_p = discount factor with a 2%, 3%, 4%, 5% or 6% discount rate

Again, the discount rate range (2%-6%) was used according to the arguments augmented in study 1. The future stumpage prices were estimated based on trend equations presented in Appendix 4.

The net benefits at national level were estimated according to the following cost-benefit formula:

$$NPV = \sum_{t=2010}^{2035} \sum_{a=1}^{4} \sum_{k}^{K} B_{st}^{diff} - C^{diff} \qquad [3.7]$$

where NPV = net present value of next-generation seed orchards, FIM

t = year when improved material is cultivated

a = growth region

k, K = individual stands within a growth region

B_{st}^{diff} = formula [3.6]

C^{diff} = formula [3.5]

A supplementary analysis was conducted. In this procedure the net benefit per produced orchard seed (expressed in FIM/kg) was assessed. The discounted benefits and costs were transformed to correspond to the projected sales of orchard seed. Two discount rates, 3% and 5%, were applied in the assessment, and the formula was:

$$NB_{kg} = NB_{agg} \Big/ \sum_{t=12}^{37} KG_t \qquad [3.8]$$

where NB_{kg}= net benefit for produced orchard seed, FIM/kilogram

NB_{agg}= formula [3.7]

KG_t = the sold amount of orchard seed in year *t*

Separate sensitivity analyses were run to evaluate how sensitive the net benefits (i.e. results) were with respect to the underlying assumptions made of the study. The sensitivity to changes in a) shadow prices b) annual cultivation area c) site quality d) division of growth regions e) stem quality f) annual costs and g) trend for stumpage prices was tested (Table 3.2). Additionally, two supplementary analyses were executed. First, the effect of alternative harvest scheduling models on the NPV was evaluated. Second, the orchard seed hectares to be established were analysed by conducting a break-even analysis (see Appendix 17).

Initially in each analysis, a)-g), five different values of the NPV on the basis of five different discount rates (2, 3, 4, 5 and 6%) were calculated. Then the intermediate points between the integers of discount rates were estimated by spline-function interpolation (see, e.g. Lindfield & Penny 1995). Spline-function interpolation was chosen mainly due to two reasons: a) nonlinear relation between the NPV and discount rates and b) the graphs obtained by spline-function interpolation were illustrative and easy to interpret. The initial discrete values of the NPV were converted into continuous curves by MicroCal Origin (1994) software. The interpolations (i.e., point estimates for IRR) were executed with MatLab software (MatLab 1992). Finally, the results of the sensitivity analyses were presented with MicroCal Origin (1994) by plotting the NPVs as continuous functions of discount rate.

Table 3.2. Sensitivity analyses conducted in Study 2, Scots pine.

Sensitivity analysis	range	specification
shadow prices of differential costs	30% decrease, market prices	
annual cultivation area	30% decrease, 30% increase	
site quality	Vaccinium, Myrtillus type	This was tested by assuming that all improved forests would be cultivated on either Vaccinium or Myrtillus type sites on each growth region
division of growth regions	"worst", "best"	This was tested by assuming that all the improved material would be cultivated in the growth region resulting in the lowest NPVs (denoted as " worst"), or alternatively in the growth region resulting in the highest NPVs ("best").
stem quality	0%, + 8%	The proportion of sawlogs in the final cut was increased by 8% (see Venäläinen et al. 1996a,b). No improvement in quality at present generation (compared to natural stands) was assumed.
annual costs *	25% decrease, 50% increase	
trend for stumpage prices	no trend, triple trend	

* Note: to some extent this analysis and the analysis for shadow prices were overlapping

Silver birch

The same public funding and distributional weight assumptions were adopted also for Silver birch. The actual assessments for Silver birch were based mainly on the report " Männyn, kuusen ja rauduskoivun siemenviljelysten perustamissuunnitelmat" (1997). The total annual area was directed so that 50% was cultivated in South Finland and 50% in Central Finland. A specific compensation schedule between present and next-generation seed orchards was adopted (Appendix 18). The total annual cultivation area was divided into South and Central Finland. In the former

70% of the annual seed was planted in site class H_{50}= 26m and 30% in site class H_{50}= 24m, whereas in Central Finland the corresponding figures were 40% and 60%, respectively. The last crop from the third-generation seed orchards will be collected by the year 2021 in South Finland and by the year 2027 in Central Finland. The difference in time schedule is due to the different compositions of present-generation seed orchards established for South and Central Finland (e.g. normal seed orchards vs. so-called two-clones-quality seed orchards). The underlying idea was that the total production in the next generation would not exceed the present level of orchard seed production, i.e., 1 700 hectares.

For Silver birch the annual differential costs were FIM 2.1 million (see Appendix 12). Besides the total differential costs it was assumed that a new polythene tunnel would be built in 2005, costing approximately FIM 1.5 million. The shadow-pricing was done as suggested by the general procedure (see Figure 2.4), and the proportions of inputs within each subactivity were mainly based on internal book-keeping (e.g., Internal Accounting...1971-1989) and recent experiences of managers (proportions of the inputs are presented in Appendix 19). The actual shadow prices were determined according to prevailing market structures for each input (see Appendix 7).

The future differential costs were estimated based on trend equation presented in Appendix 4. Technically, the differential costs of Silver birch next-generation seed orchards can be presented by the specific formula:

$$C^{diff} = C^{B} * (D_p)^{10} + \sum_{t=9}^{31} \left(C_t^{p} + C_t^{ma} + C_t^{ad}\right) * (D_p)^{t} \qquad [3.9]$$

,where

C^{diff}= differential costs of Silver birch seed orchards, FIM (base year 1996)

C^{B}= building costs of a new polythene tunnel in year 2005, FIM

C_t^{p}= progeny testing costs in year *t*, FIM

C_t^{ma}= annual management costs in year *t*, FIM

C_t^{ad}= administration costs in year *t*, FIM

D_p = discount factor with a 2%, 3%, 4%, 5% or 6% discount rate

All terms on the right-hand side of the equation [3.9] were first appropriately shadow-priced on the basis of the principles explained above.

The future benefits were evaluated by assuming that stands would grow as Oikarinen's growth and yield models suggest (Oikarinen 1983, pp. 49, 59). The genetic gains were incorporated into two harvest scheduling models by increasing the outturns according to the corresponding genetic gain.These models were the same as in Study 1 (see, Ahtikoski 1995). The latest Finnish progeny test results on present seed orchards indicate that the genetic gain in volume growth could be as high as 29% in South and 26% in Central Finland (Hagqvist & Hahl 1998). However, in this connection lower values for genetic gains were adopted, since it was *a priori* assumed that the latest progeny test results (Hagqvist & Hahl 1998) cannot be applied to reflect an average of *all* improved stands even in the next-generation. In other words, caution was exercised in this respect.

At stand level the differential benefits within the given time period (see above) can be calculated with the following formula:

$$B_{st}^{diff} = \sum_{t=29}^{92} B_t^g * (D_p)^t - \sum_{t=29}^{92} B_t^0 * (D_p)^t \qquad [3.10]$$

,where B_{st}^{diff}= differential benefit, FIM (base year 1996)

B_t^g= economic value of thinning or final cut in an improved stand (valued at stumpage) in year *t* reflecting genetic gains, FIM

B_t^0= economic value of thinning or final cut in a normal stand (valued at stumpage) in year *t*, FIM

p= discount percent (2, 3, 4, 5 or 6%)

The future stumpage prices were estimated according to trend equations presented in Appendix 4.

Finally, the net benefits (from the society's viewpoint) were assessed by the following specific cost-benefit formula:

$$NPV = \left[\sum_{t=2004}^{2021} \sum_{s}^{S} B_{st}^{diff} + \sum_{t=2010}^{2027} \sum_{k}^{K} B_{st}^{diff} \right] - C^{diff} \qquad [3.11]$$

,where NPV = Net present value, FIM
B_{st}^{diff} = formula [3.10]
s, S = individual stands in South Finland
k, K = individual stands in Central Finland
C^{diff}= formula [3.9]

The discounted costs and benefits were transformed to correspond the anticipated amount of sold orchard seed in order to find out the net benefit of produced seed within the given time period. The average net benefit per produced (and sold) kilogram of Silver birch orchard seed was simply applied by the following formula:

$$NB_{kg} = NB_{agg} \Big/ \sum_{t=8}^{31} KG_t \qquad [3.12]$$

where NB_{kg}= net benefit per sold orchard seed kilogram between the years 2004 and 2027, FIM (base year 1996)
NB_{agg}= formula [3.11]
KG_t= the sold amount of orchard seed in year *t*

Several different sensitivity analyses were conducted for Silver birch. The same discount rates as for Scots pine were used for Silver birch. Intermediate points between the integers of discount rates were interpolated by spline function (see, Lindfield & Penny 1995). The same underlying premises of interpolation method were applied for Scots pine and Silver birch. The sensitivity analyses are presented in Table 3.3.

Table 3.3. Sensitivity analyses conducted for Silver birch, Study 2.

sensitivity analysis	range	specification
annual costs	25% decrease, 50% increase	
site quality	H_{50}= 24m, H_{50}= 26m	This was analyzed by assuming that all the improved material in South and Central Finland would be cultivated on site class H_{50}= 24m , or alternatively on site class H_{50}= 26m.
annual cultivation area*	30% decrease, 30% increase	
trend stumpage prices	no trend, triple trend	

* Additionally, a break-even analysis was applied in order to evaluate how much the annual cultivation area could decrease so that benefits would still break-even with costs. In the analysis only direct production costs (incl. seed collection and restorage costs) were altered accordingly, leaving e.g. administration costs unchanged. By taking indirect costs such as administration costs into account would have involved speculativiness due to nonlinear relation between administration and seed production.

For Silver birch there was no need to examine the effect of alternative establishment magnitudes, since the establishment costs of Silver birch seed orchards do not play a crucial role with regard to total costs.

3.1.2.2 Results

Scots pine

The net present values (NPVs) for next-generation seed orchards were positive even with 6% discount rate when the genetic gain was 12% or 15% (Figure 3.5). In general, considerably higher discount rates resulted in positive NPV compared to present-generation seed orchards. In this respect the next-generation seed orchards are more desirable from the society's viewpoint.

The *net benefit* per produced kilogram of orchard seed (see formula [3.8]) was over FIM 3 000 when the genetic gain was 8%, and over FIM 5 000 when the genetic gain was 12% (discount rate was 3 per cent). Further, the "social cost" of produced orchard seed (i.e., the present value of differential costs divided by the amount of produced orchard seed) was FIM 950/kg, when discount rate was 3% (FIM 640/kg with 5 per cent discount rate).

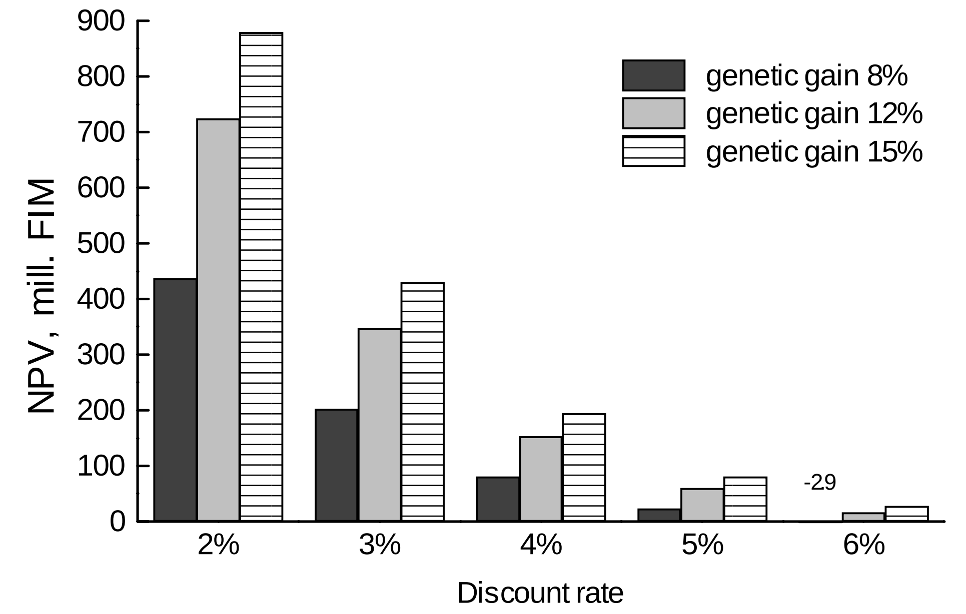

Figure 3.5. Net present values of Scots pine next-generation seed orchards with alternative discount rates.

Sensitivity analyses /Scots pine

The results were insignificantly sensitive to changes in input prices within the range of 30% decrease in shadow prices and market prices, i.e., financial values (Figure 3.6a). For example, the difference in net benefit was only approximately FIM 15 mill. when the shadow prices of the costs (input prices) were decreased by 30%, the discount rate being 4% and the genetic gain 15% (Figure 3.6a). The spread of the IRR was app. 0.1%. The results with other genetic gains (8% and 12%) were similar, but they are not shown here due to paucity. The result of the sensitivity analysis indicates that a reliable estimate of the profitability could as well have been evaluated with market prices without making an essential error.

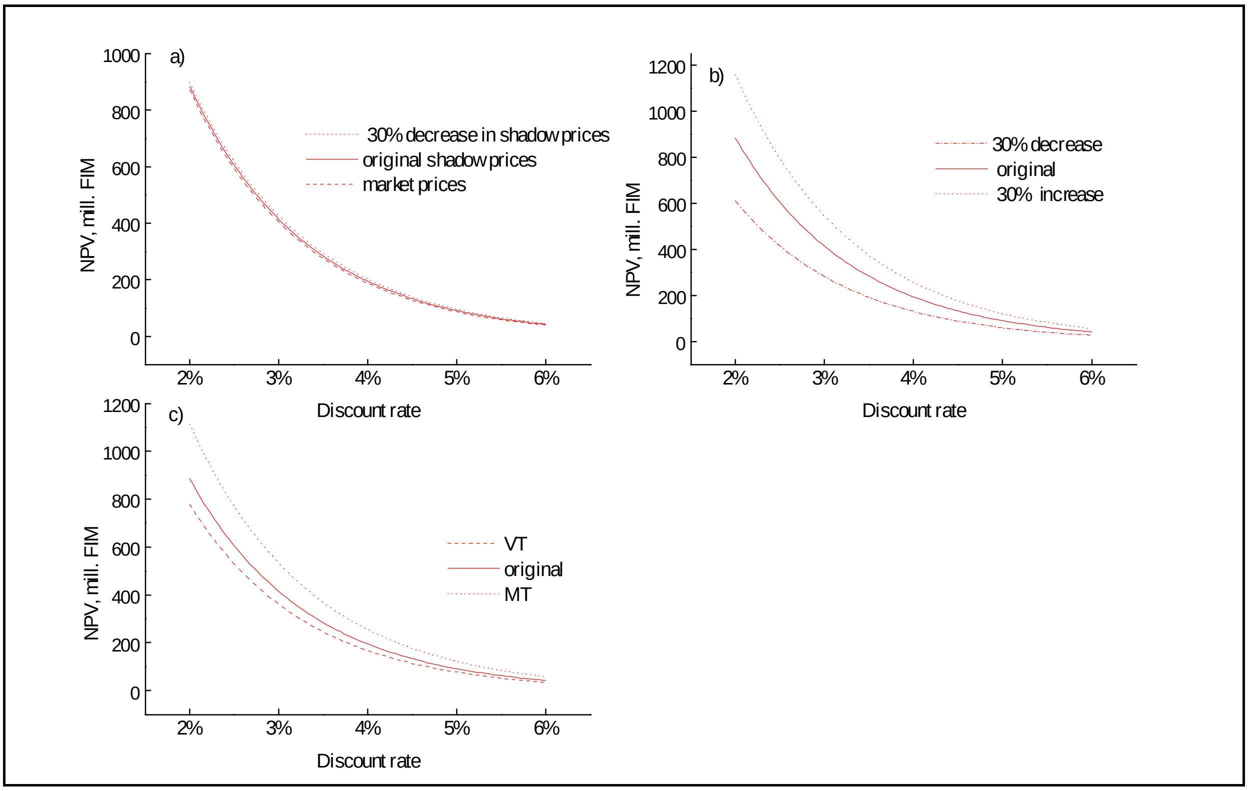

Figure 3.6. NPVs of Scots pine next-generation seed orchards with alternative sets of differential costs (a), annual cultivation areas (b) and site qualities (c). For instance, "market prices" indicate that financial, i.e. market values for differential costs are used (a) , "30% decrease" reflects a 30% decrease in annual cultivation areas (b) and "VT" assumes that all the improved material would be cultivated on Vaccinium type (or corresponding) forests (c). In each graph (a-c) genetic gain is 15% and discount rate varies from 2% to 6%.

The analysis was most sensitive to changes in annual cultivation areas (Figure 3.6b). The difference in net benefit was app. FIM 130 mill. (genetic gain 15%) between the original annual cultivation area and the option where the annually cultivated hectares were increased by 30%, the discount rate being 3 per cent (Figure 3.6b). The result is notable since the initial present value of differential costs was only FIM 62 mill. (3% discount rate). The spread of the IRR was, however, only 0.4%. The difference in net benefit emphasizes further the importance of the annual cultivation area for the profitability of the seed orchard activity.

The analysis was also very sensitive to changes in site quality: the difference in net benefits between these two options (MT, VT) was approximately FIM 40 mill. (Figure 3.6c) when the discount rate was 5 per cent. The result is considerable since the total costs of the seed orchard activity were only some FIM 42 mill. (5 per cent discount rate).

The net benefits were sensitive to changes in growth region-division: the difference in net benefits between the two options was over FIM 480 mill., when the discount rate was 2 per cent, and the difference was approximately FIM 22 mill. when the rate was 5 per cent, the genetic gain being 12% (Figure 3.7a). It should be noted that the total costs of the seed orchard activity were FIM 78 mill. (2 per cent discount rate), and FIM 42 mill. (5 per cent discount rate).

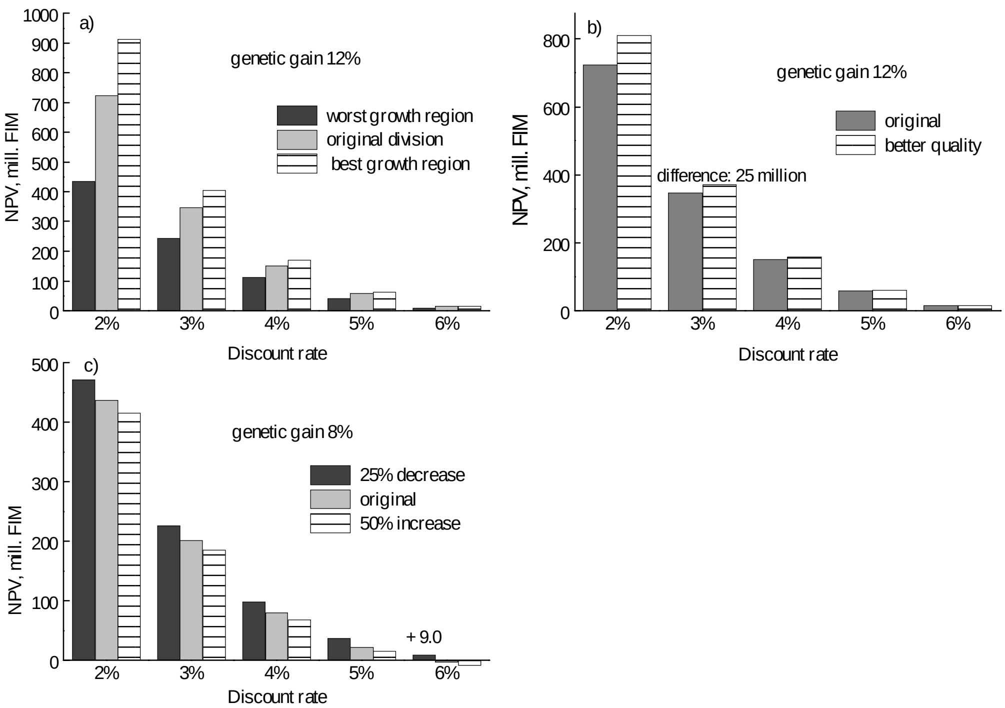

Figure 3.7. NPVs of Scots pine next-generation seed orchards with alternative divisions of growth regions (a), stem qualities (b) and annual differential costs (c). For instance, "worst growth region" assumes that all the Scots pine orchard seed is annually cultivated in areas which correpond to the lowest NPVs of the growth regions (a), "better quality" indicates that the proportion of sawlogs in the final cut is increased by 8% (b) and "50% increase" reflects an annual increase of 50% in differential costs (c). Genetic gains in graphs (a-c) are 12%, 12% and 8%, respectively. Discount rate varies from 2% to 6%.

The sensitivity analysis as regards potentially higher stem quality resulted in a net benefit difference of approximately FIM 26 mill. , genetic gain being 12% and discount rate 3 per cent (Figure 3.7b). This is a relatively high value compared to the original total costs which were some FIM 62 mill. (3 per cent discount rate). The analysis indicates that the subsidy granted for research focusing on quality traits is well justified in the near future.

The analysis was moderately sensitive to changes in costs, although 25% decrease in annual differential costs resulted in that NPV was positive even with 6 per cent discount rate (Figure 3.7c). The lowest possible genetic gain was used in this connection, since the lower the genetic gain was, the higher were the relative costs (due to diminishing benefit-cost ratios).

The sensitivity analysis concerning the harvest scheduling models indicated that the NPVs assessed with the original harvest scheduling model MELA were distinctively higher than with the two alternative models (Figure 3.8). In addition, the benefit-cost ratios were considerably higher with original MELA harvest scheduling model than with the alternative harvest scheduling models

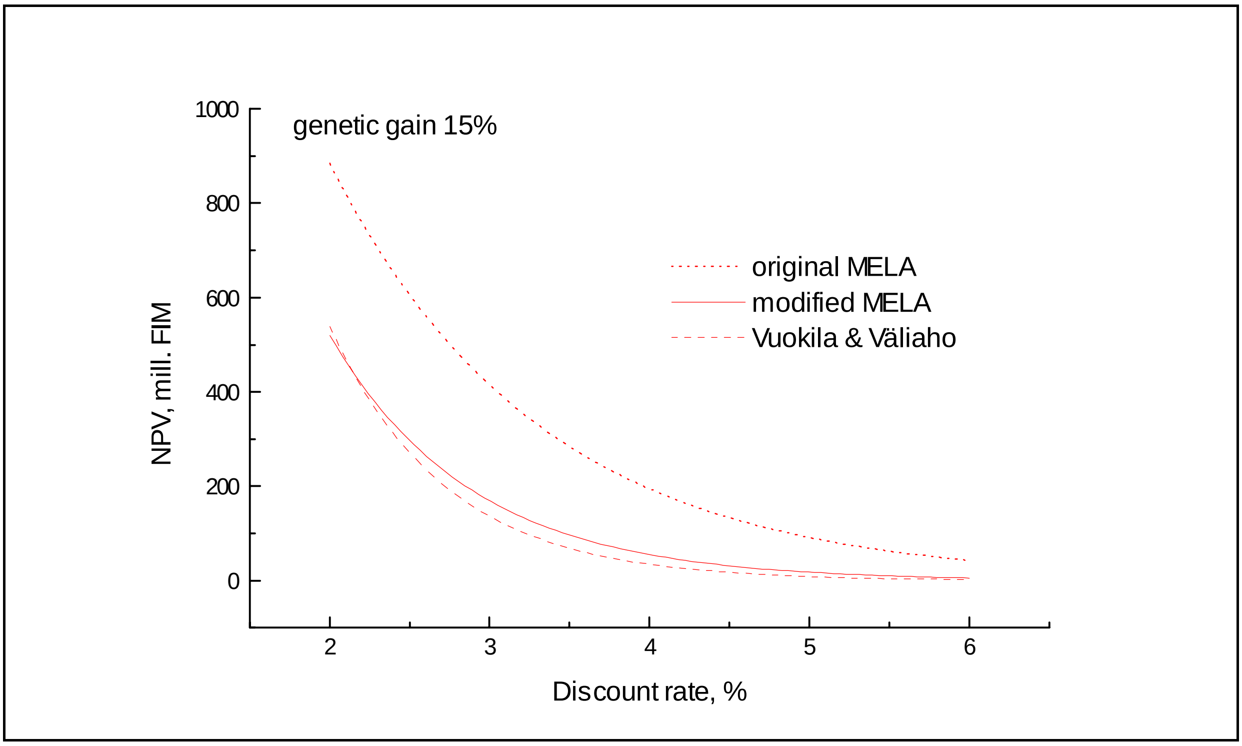

Figure 3.8. The effect of different harvest scheduling models for Scots pine on the NPV.

(modified MELA and Vuokila & Väliaho). For example, the benefit-cost ratio for the original MELA harvest scheduling model was app. 7.9 (discount rate 3%) whereas the corresponding figures for modified MELA and Vuokila & Väliaho's model were 3.8 and 3.4, respectively. Moreover, with 6 per cent discount rate the benefit-cost ratios for modified MELA and Vuokila & Väliaho's model were below unity indicating that costs were greater than benefits (for the original MELA model the value was app. 1.7). Thus, the results essentially depended on the chosen harvest scheduling model.

It was noticeable that the *modified* MELA harvest scheduling model (with 15% genetic gain) resulted in similar NPVs as Vuokila & Väliaho's model with the same genetic gain. This is presumably due to similar calculating procedure of the genetic gains within the two models (i.e. changing only outturns of the thinnings and final cut). As to the applied harvest scheduling models of this study, the original MELA harvest scheduling model can be viewed as the upper-boundary whereas the other models indicate the lower-boundary for a given genetic gain percentage.

If the annual average seed production (kg/hectare) is 10kg instead of the assumed 7-8 kg (not constant due to initial problem setting), then 405 hectares instead of the original 500 hectares of next-generation seed orchards need to be established to secure the seed supply for annual cultivation area of approximately 32 000 hectares in South and Central Finland. The break-even analysis (see Appendix 17) showed that considerably high increases in annual total costs (in order to attain and maintain the annual average seed crop of 10kg) between 2010 and 2035 are permitted and still the new NPV equal the original NPVs (Figure 3.9).

For example, the annual total costs (discount rate 3%) must increase some 36% in order for new NPVs to equal original NPVs, the genetic gain being 12% (Figure 3.9). Thus, it can be said that the subsidy granted for activities contributing to higher annual average seed crop is well justified. The greater seed crops surely warrant the extra cost involved.

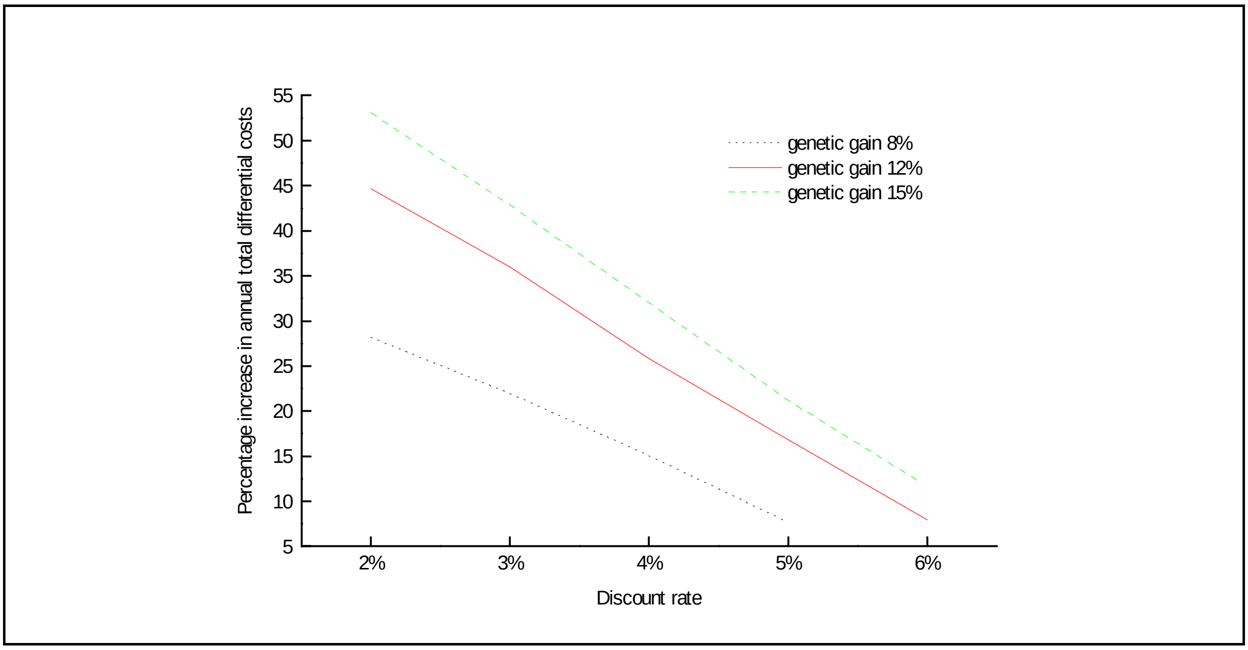

Figure 3.9. Break-even curves for each genetic gain of Scots pine. Each point in the curve indicates the percentage increase in annual differential costs so that the original NPV and the NPV for alternative assessment with annual seed crop of 10kg/hectare would be equal.

The results did not alter considerably when different trend stumpage prices were applied. For example, when stumpage prices of felling season 1994/1995 ("no trend") were used instead of original trend stumpage prices (see Appendix 4), the NPV (genetic gain 8%) was still positive with 5 per cent discount rate (cf. Figure 3.5). On the other hand, with triple trend the assessment resulted positive NPV when discounting with 6 per cent (cf. Figure 3.5).

Silver birch

The NPVs turned into negative with 4 per cent discount rate, when the genetic gain was 10% in South and 8% in Central Finland (Figure 3.10). With 6 per cent discount rate the NPVs were negative regardless of the genetic gains (Figure 3.10).

The *net benefit* per produced orchard seed (see formula [3.12]) between the years 2004 and 2026 was FIM 33 939 /kg, when the discount rate was 3 per cent and the genetic gains 15% in South and 12% in Central Finland. The figure is significantly higher than the corresponding figure in study 1 (cf. Figure 3.3).

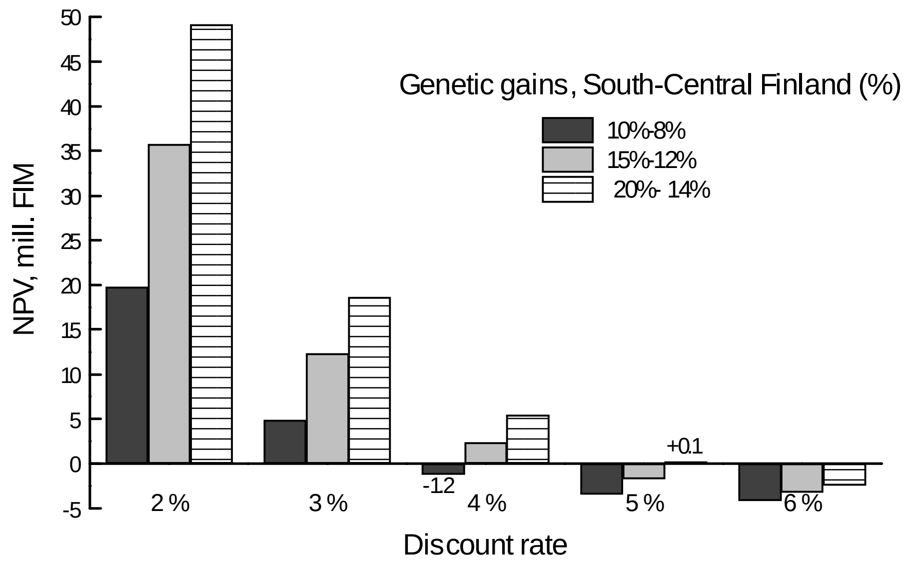

Figure 3.10. NPVs for Silver birch next-generation seed orchards.

Sensitivity analysis / Silver birch

The analysis was moderately sensitive to changes in costs: when the annual costs were decreased by 25% the NPV was FIM 13.8 mill. and when the costs were increased by 50% the net benefit was FIM 8.7 mill. (discount rate 3%), the genetic gain being 15% in South and 12% in Central Finland (Figure 3.11a). The initial differential costs were FIM 9.9 mill. (discount rate 3%). However, the NPV with 15% and 12% genetic gains turned into negative with 4 per cent discount rate when the annual differential costs were increased by 50% (Figure 3.11a). The spread of the IRR was 0.8% which can be deemed as insignificant.

The analysis was also moderately sensitive to changes in site quality and annual cultivation area (Figures 3.11b, c). If the future does not unfold as projected, annual cultivation areas may change. A break-even analysis indicated that annual cultivation area can decrease considerably, and still the benefits are able to break-even with costs (Figure 3.11d). For example, the annual cultivation area could decrease by half, and still the present value of differential benefits would break-even to present value of differential costs, the discount rate being 3 per cent and genetic gains 15% and 12% (Figure 3.11d). In this respect the next-generation Silver birch seed orchards are robust - small changes in annual cultivation area do not burden the profitability considerably.

Sensitivity to changes in trend stumpage prices was also moderate with Silver birch, although the NPV turned into negative with 4 per cent discount rate, the genetic gains being15%-12% (cf. Figure 3.10).

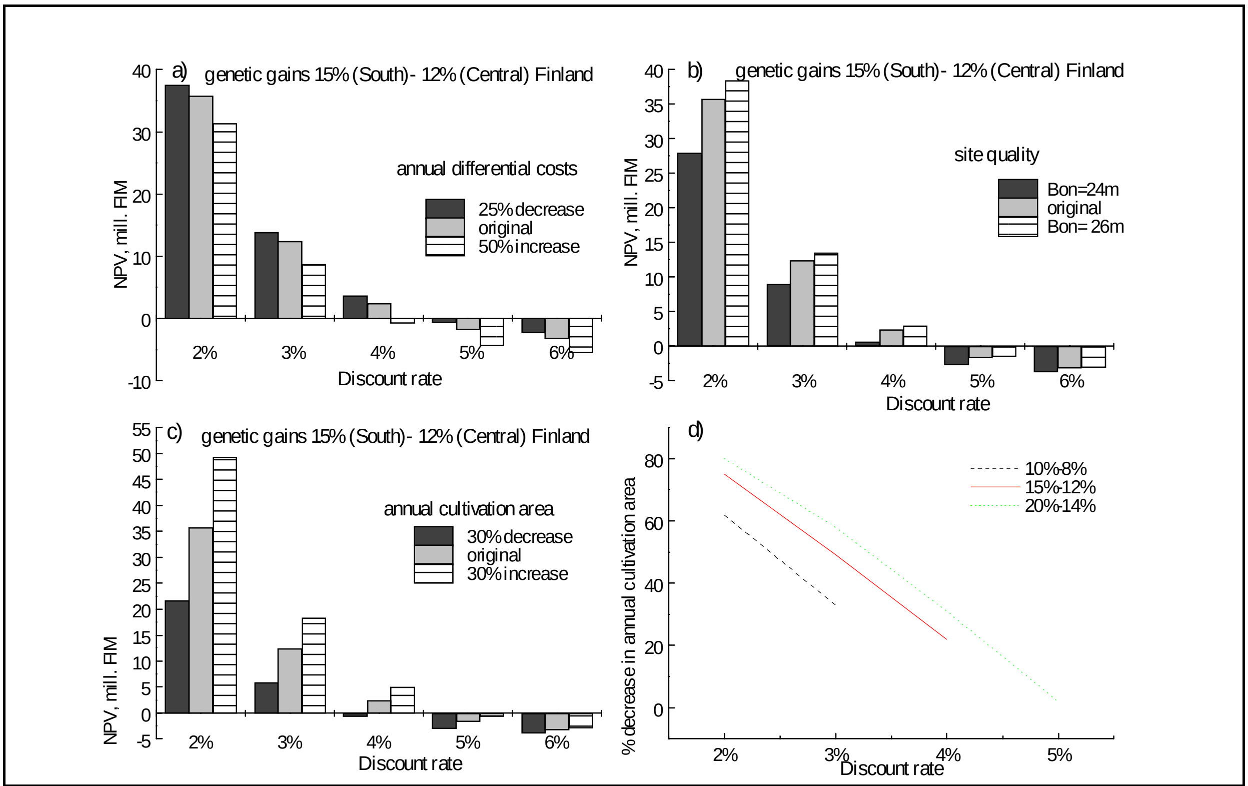

Figure 3.11. NPVs for Silver birch next-generation seed orchards with alternative annual differential costs (a), site qualities (b) and annual cultivation areas (c). For instance, "Bon=24m" indicates that all the improved material is cultivated on site class H_{50}= 24m. In each graph (a-c) the genetic gains (15% for South and 12% for Central Finland) and the discount rates (2% to 6%) are the same. Break-even curves (d) indicate the percentage decrease in annual cultivation for *zero* NPV (i.e. discounted differential benefits equal to discounted differential costs).

3.1.3 Study 3: Profitability of Scots pine next-generation seed orchards of northern clones

3.1.3.1 Framework & restrictions

Due to the divergent climatic conditions prevailing in southern and northern Finland, also the breeding goals for southern and northern Finland differ to some extent. This was one of the main reasons for introducing separate seed orchard programs for southern and northern Finland in the latest national report (Männyn...1997). In this study, Scots pine next-generation seed orchards of northern clones were evaluated emphasizing the distinctive features of northern Finland. The assessments (conducted in a cost-benefit framework) were based on the recent report "Männyn, kuusen ja koivun siemenviljelysten perustamissuunnitelmat" (1997). The next-generation seed orchards of northern clones were assumed to be established according to the original report (with minor alterations concerning the years 2011-2020), reflecting a total of 250 hectares to be established during 1999-2020 (Männyn...1997). The time from establishment to seed production was estimated to be 25 years (Männyn...1997), which is considered to be moderately cautious. The hectares to be regenerated with orchard seed were based on past-ten-year average (1988-1997) of four (former) northernmost forestry board districts (see, e.g., Statistical yearbook...1995, p. 34), consisting of a total of 18 729 hectares (of which 7 245 was sown). The sowing area was changed by dividing it into a half based on the original report (Männyn...1997). The annual area to be cultivated with the orchard seed in northern Finland increased by "leaps" (Figure 3.12) due to the specific assumptions made in the assessments (see Appendix 20).

At this juncture, it should be noted that the area of the four (former) northernmost forestry board districts does not correspond exactly to the area referred to the original report (Männyn...1997). Rather, it had to be in accordance with study 2. In study 2 the next-generation Scots pine seed orchards were assumed to produce seed for South and Central Finland in the area covered by forestry board districts 1-15. In this study the target area was covered by forestry board districts 16-19. There may, of course, be some overlaps (i.e. seed produced by seed orchards established for South and Central Finland might be used in northern Finland and vice versa) between these areas, but they are considered to be insignificant regards to overall results.

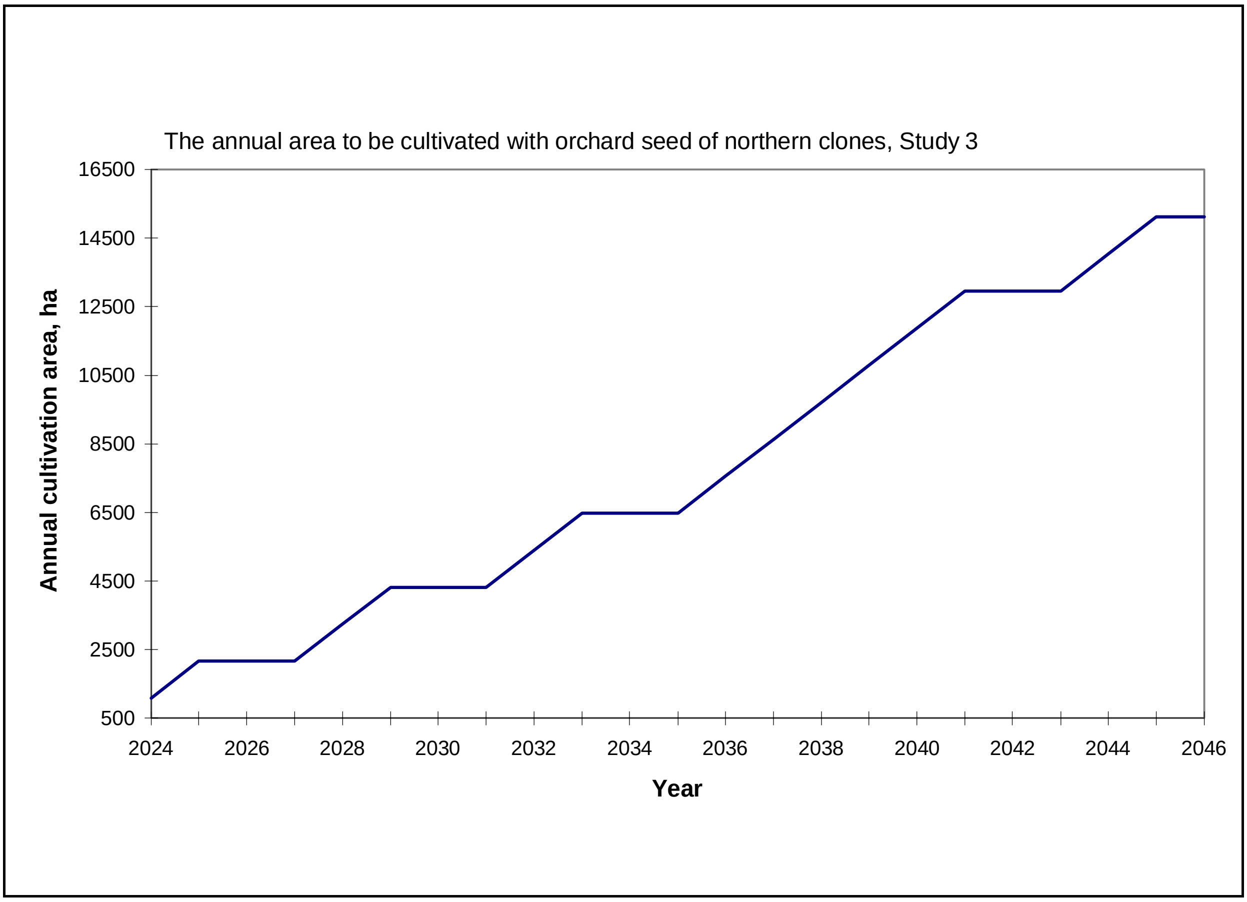

Figure 3.12. Development of the annual cultivation area (according to the establishment schedule) between 2024-2046, study 3.

The time period for differential costs ranged from 1997 to 2046; after which the seed production will decrease (due to the estimated average production age of 20 years) since the remaining seed orchards cannot compensate the gap of the production without the annual average seed production exceeding a 7kg/hectare. The financial value of annual differential costs was FIM 3.42 million (Table 3.4), which was based on the averages for 1990-1995 (Internal Accounting...1990-1995) and on recent experiences of local managers (Lahtinen 1996, 1997). Progeny testing (Table 3.4) included, for instance, special measures such as freeze testing and selective harvesting of the seed orchards (Pulkkinen 1995). Freeze-testing is an essential stage between present and next generation. Through testing the most tolerant clones can be separated and exploited in the establishment of next-generation seed orchards. Besides those annual progeny testing costs, there were additional costs related to the identification of the best surviving clones and freeze-testing equipment. These costs (regarded also as differential costs) occurred between 1996 and 1999, and their estimated combined value was FIM 2.1 million (Ahtikoski 1996a)

Table 3.4. Key activities, input categories and annual financial values for Study 3. Percentages indicate the proportions of the inputs within an activity, and the percentages in parenthesis are the average tax rates on the inputs. The bold figure in each input category reflects the ratio between the economic value and market price of the input (the ratio corresponds to the coefficient in formula [2.2]).

Key activity [financial value, Finnish Marks; FIM]	social security payments	semiskilled labour **0.65**	skilled labour **0.8**	contractors' fees **0.8**	intermediate goods **0.7**	"miscel-laneous" **0.7**
Annual management of seed orchards [1.12 million]	10%	44% (27%)	0%	31% (22%)	3% (22%)	12% (22%)
Progeny testing (incl. special measures) [1.2 million]	13%	45% (27%)	10% (33%)	15% (22%)	7% (22%)	10% (22%)
Administration [1.1 million]	16%	15% (27%)	46% (33%)	0%	8% (22%)	15% (22%)

The shadow pricing procedure of this study did not follow the general procedure (see Figure 2.4) due to the specific structure of original book-keeping records. In this study, the cost classes (also denoted as key activities) did not consist of subactivities, but were analysed as such by dividing them directly into input categories (Table 3.4). This resulted in a slightly different input categories compared to Study 2. The procurement costs of the land and establishment costs were assumed to be identical to those of study 2, but their timing was different. Here it was presumed that procurement of the land occurs five years before establishment. Site preparation, grafting, construction of the roads and soil and climate measurements will take four years until the graftings are planted in the orchard (Männyn...1997).

The inputs of each key activity were shadow priced applying the same principles as in studies 1 and 2 (see Appendix 7). Prior to shadow pricing transfer payments (taxes and social security payments) were removed from the financial values. The future values of the costs were forecasted by trend presented in Appendix 4. Finally, the shadow-priced differential costs were assessed on the basis of the following:

$$C^{diff} = \sum_{t=-3}^{22} C_t^{es} * (D_p)^t + \sum_{t=1}^{48} \left(C_t^{p} + C_t^{m}\right) * (D_p)^t + \sum_{t=26}^{48} C_t^{ad} * (D_p)^t \qquad [3.13]$$

, where C^{diff} = discounted *differential* costs of seed orchard activity, FIM (base year 1998)

C_t^{es}= establishment costs (incl. site preparation, grafting, constr. of the roads, measurements, planting) of the seed orchards in year *t*, FIM

C_t^{m}= management costs of the seed orchards (including supervision, fertilization, roguing etc.) in year *t*, FIM

C_t^{p}= progeny testing costs (incl. special measurements) in year *t*, FIM

C_t^{ad}= differential administration costs of the seed orchard activity compared to the administration costs of the stand seed collection, in year *t*, FIM

D_p = discount factor with a 2%, 3%, 4%, 5% or 6% discount rate

The same arguments for chosen discount percentages were used here as for study 1 and 2.

According to the initial biological data (Appendix 21) and genetic gains (reflecting recent progeny test results) the harvest scheduling models were simulated for Myrtillus and Vaccinium type pine forests. The proportions of Myrtillus and Vaccinium type in planting and sowing followed the proportions presented by Saarenmaa (1992). The genetic gains were fed into the growth functions of MELA by increasing the annual growth level (see Appendix 13 for details). Then the simulated harvest scheduling models of Taivalkoski region (Appendix 22) were extended to former forestry board districts 16-19 forming a homogenous growth region of northern Finland. The assumption was that *on average* pine forests grow as the Taivalkoski models (for Myrtillus and Vaccinium type separately) suggest, although there are regional differences in growth conditions and even in silvicultural practices in northern Finland.

The genetic gains were adopted from the progeny test results for southern Finland (Venäläinen et al. 1994) assuming that these figures are applicable also for northern Finland. This had to be done due to a lack of progeny test results on field conditions in northern Finland. The genetic gains were 3%, 7% or 10%. These figures indicated the gains from phenotypic selection under field conditions, and can be considered to be conservative, since they represent present-generation results. However, the main quality concerning the pine breeding for northern Finland is the hardiness of the reforestation material - in other words to qurantee that orchard seed is at least as tolerant as local stand seed to freezing stress. Thus, genetic gain, for instance, in volume growth is of secondary interest.

The differential benefits due to genetic gains at stand level can be expressed by the following:

$$B_{st}^{diff} = \sum_{t=57}^{121} JT_t * (D_p)^t - \sum_{n=62}^{126} NS_n * (D_p)^n \qquad [3.14]$$

, where B^{diff}= present value of differential benefits at stand level, when genetic gain is 3%, 7% or 10%, FIM (base year 1998)

JT_t= outturn of a thinning or final cut (*valued at stumpage price*) in an improved stand in year t [e.g t=57 : (1999 (first establishment) +25 (time lag) + 31 (time for first thinning)) - 1998], FIM

NS_n= outturn of a thinning or final cut in a normal stand (without genetic gain) in year t, FIM

D_p= discount factor with a 2%, 3%, 4%, 5% or 6% discount rate

The discount percent range (2%-6%) was also in this case used according to the arguments of study 1. The future stumpage prices were estimated by the trend equations presented in Appendix 4.

To be able to assess the possible net benefits at national level, the following cost-benefit formula was adopted:

$$NPV = \sum_{t=2024}^{2046} \sum_{k}^{K} B_{st}^{diff} - C^{diff} \qquad [3.15]$$

, where NPV = net present value for the next-generation seed orchards of northern clones, FIM

k, K = individual stands (incl. MT and VT forest site types) in the target area, i.e. northern Finland

B_{st}^{diff}= formula [3.14]

C^{diff}= formula [3.13]

The sensitivities to changes in *a priori* chosen main variables were tested. These variables were assumed to most affect the results (Table 3.5). The same five discount rates as in Study 2 were applied here. The intermediate points between the integers of discount rates were estimated by spline-function interpolation (Lindfield & Penny 1995).

Table 3.5. Sensitivity analyses conducted in Study 3.

sensitivity analysis	range	specification
average seed crop*	"4kg to 7kg" (denoted as alternative C), "7kg" (alternative B)	Two alternatives: in the first alternative the annual average seed crop was fixed to 7 kg/hectare, and in the second alternative it was assumed that the annual average seed crop in each seed orchard would increase by 1 kg per year from 4kg to 7kg
harvest scheduling model **	-	This was examined by constructing an alternative harvest scheduling model according to Vuokila & Väliaho's growth and yield models (1980).
site quality	Vaccinium, Myrtillus type	This was tested by assuming that all the planted and sown seed is cultivated either on Myrtillus or Vaccinium type forests.
annual costs	25% decrease, 50% increase	
annual cultivation area	30% decrease, 30% increase	
shadow prices of inputs	30% decrease, market prices	
trend stumpage prices	no trend, triple trend	

* It was assumed that when the past-ten-year cultivation average (15 107 hectares) is exceeded by the production of the next-generation seed orchards then no more seed orchards will be established. The first alternative resulted in that the last establishment will occur in 2012 indicating that only 160 hectares will be established instead of the original 250 hectares. The second alternative resulted in that the last establishment will occur in 2014 indicating that 180 hectares to be established.

** Height index H_{100}= 21 m in Vuokila & Väliaho's models (1980) was assumed to correspond to Myrtillus type, and height index H_{100}= 18m to Empetrum-Vaccinium type forests in northern Finland (see Vuokila & Väliaho 1980, p. 26). For height index H_{100}= 21 m there were 3 intermediate thinnings and the removal percentage was 25% (Vuokila & Väliaho 1980, p. 236), and for height index H_{100}= 18m there were 2 intermediate thinnings and the removal percentage being 30% (Vuokila & Väliaho 1980: p. 259). For Vuokila & Väliaho's growth and yield models the percentages reflecting the genetic gains (3, 7 or 10%) were incorporated by increasing only the outturns, keeping harvesting times unchanged.

3.1.3.2 Results

The NPV turned into negative when the discount rate was 3 per cent, the genetic gain being 3% or 7% (Figure 3.13a). With 5 per cent discount rate the NPV was negative regardless of the genetic gain applied (Figure 3.13a).The spread of the IRR with regard to genetic gains was 0.89 percentage units; this spread appears to be moderate.

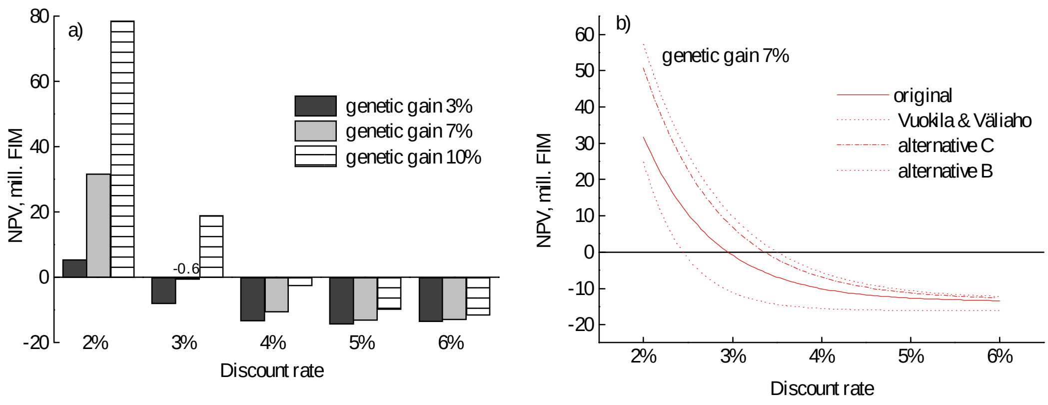

Figure 3.13. NPVs for Scots pine next-generation seed orchards of northern clones (a). The effect of average annual seed crop ("alternative B": 7kg and "alternative C": 4-5-6-7kg) and an alternative harvest scheduling model (Vuokila & Väliaho) on the NPV is presented in graph b.

Sensitivity analyses

The effect of an average seed crop (kg/hectare/year) on the NPV was significant. For example, with 3 per cent discount rate the NPV for alternative B (average seed production 7kg) was about FIM 10 million, whereas for the original assessment it was negative FIM 0.6 million, the genetic gain being 7% (Figure 3.13b). The difference, some FIM 11 million, is considerable with regard to the initial PV of differential costs which was FIM 27 million (discount rate 3%). The NPVs for alternative C ("4kg to 7kg") lie between these two "extremes". With reference to the results of the sensitivity analysis, it can be argued that there is a great incentive to invest in activities (such as careful planning in land procurement and intensified annual management) which contribute to higher seed crops.

The NPV was very sensitive to harvest scheduling models as was to be expected; it was FIM -11 million for genetic gain 7% (discount rate 3 per cent) with Vuokila & Väliaho's models whereas the corresponding original value was FIM - 0.6million (Figure 3.13b).

The effect of site quality on the NPV was significant with respect to the spread of IRR. The spread was 1.08% between "EVT" and "MT" with 15% genetic gain. (Figure 3.14a).

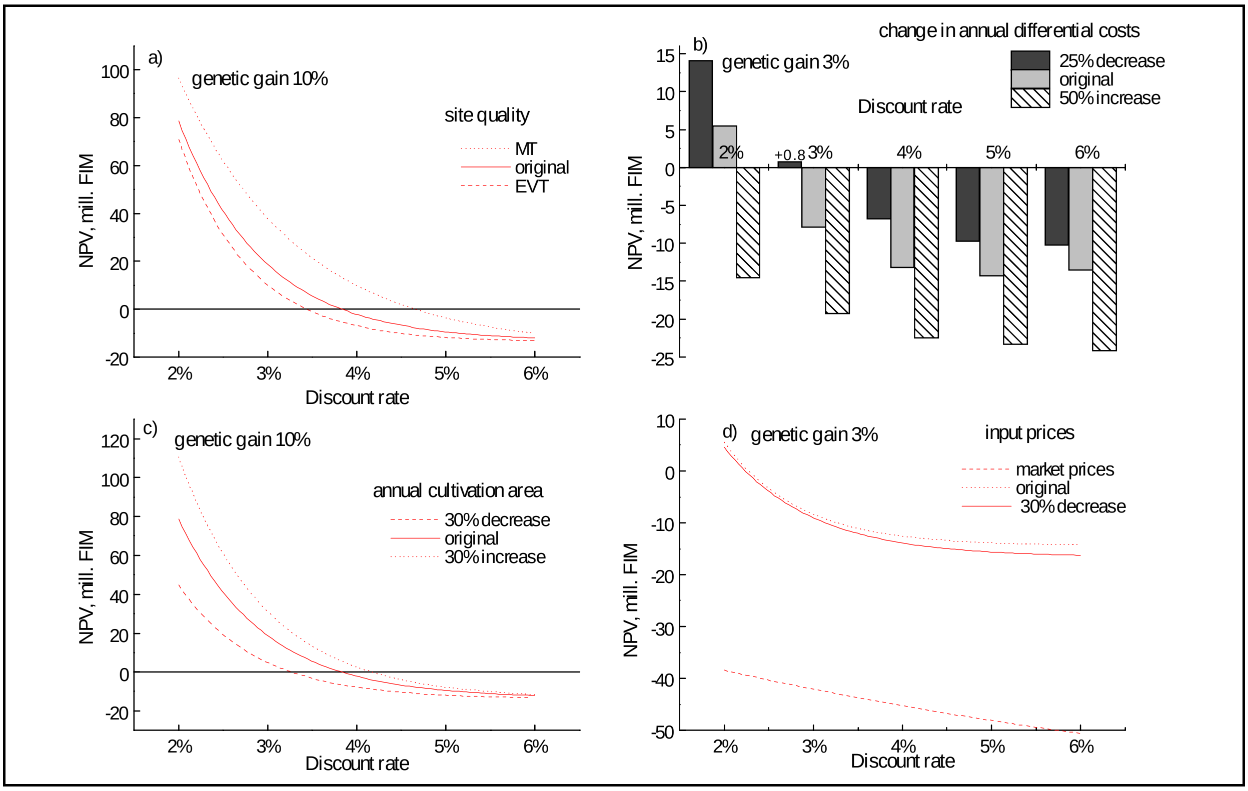

Figure 3.14. NPVs for Scots pine next-generation seed orchards of northern clones with alternative site qualities (a), annual differential costs (b), annual cultivation areas (c) and input prices (d). For instance, "MT" indicates that all the improved material is cultivated on Myrtillus (or correponding) type forests (a) and "30% decrease" in input prices assumes that shadow priced differential costs are decreased by 30% (d). In each graph (a-d) discount rate varies from 2% to 6%.

The NPVs were very sensitive to changes in annual differential costs; with 3 per cent discount rate the NPV in an assessment with 25% decrease resulted in a positive NPV, whereas with original differential costs the NPV was negative (Figure 3.14b). The lowest genetic gain was chosen *a priori*, because with low genetic gains the costs are expected to form a bigger portion of the benefits than with high genetic gains. Thus, the effect of the changes in cost is relatively higher. The result supports views which state that the original set of *differential* prices might be at too high a level (see, also Table 3.4) . The results were only moderately sensitive to changes in annual cultivation area (Figure 3.14c). One reason for this insensitivness is that in this study the benefit-costs ratios were considerably lower than in Study 2. The NPVs were most sensitive to changes in input pricing. For example, when market prices of the inputs were applied, the NPV was about FIM - 39 million with 2 per cent discount rate, whereas the NPV for the assessment with 30% decrease in shadow prices was FIM + 4.5million, the genetic gain being 3% (Figure 3.14d). (Note that the curve for market prices is linear although it should be loglinear as the other curves - this depiction bias originates from so-called magnitude problem associated with the software). From the result it can be concluded that utmost care must be afforded in analysing the underlying market structures of the inputs used for seed orchards. The NPVs of this study were much more sensitive to shadow pricing procedure than those of study 2. One possible reason for the divergence is the different division of input categories. Another is the fact that seed orchards of northern clones require more labour (relative to other inputs) than those for South and Central Finland.

The sensitivity to changes in trend stumpage prices was tested at 3% genetic gain level. All the alternatives ("no trend", "original trend": see Appendix 4, "triple trend") resulted in negative NPVs with discount rate of 3%.

3.2. Seed producers’ viewpoint

3.2.1 Study 4: Market environment and production costs of orchard seed

3.2.1.1 Framework & restrictions

Scots pine first-generation seed orchards

The purpose of this study was to examine whether there are economies to scale to be exploited for orchard seed producers. The market structures were examined by forming mathematically the long-run average cost (LAC) curves and revealing minimum efficient scales (MES). By comparing the output at MES *relative* to the size of the total market, estimates about the prevailing market structure can be made. In this connection the market demand curve was chosen to approximate the size of the total orchard seed market. The procedure ignores potential seed stocks. This should be emphasized, given the long-term conditions of excess orchard seed supply in Finland (see, e.g., Männyn...1997)

Two separate LAC curves were calculated; one reflecting direct production costs between 1993-1997, whereas in the other the past establishment costs were also taken into account (see Appendix 23). The direct production costs included annual collecting costs, transporting costs, seed extraction costs, management costs of the seed orchards and administration costs between 1993-1997. The cost data were collected from annual seed orchard records, updated by the FPS, and there were totally over 750 cost observations (5 years * 5 cost categories * 30-36 seed orchards each year) to be modelled. The costs were deflated by the wholesale price index (Statistical Yearbook of Finland 1997) for 1997. As regards seed orchards, the time period of five years might be considered as long run, since all relevant inputs can be adjusted to changes. Moreover, currently there is no means to affect these sunk establishment costs. The chosen 5-year period could be long enough for a firm to force down *all* factors of production when deciding to produce zero output. There are no quasi-fixed factors (see, Varian 1987, p. 315) present either.

An *estimation* of the market demand curve was based on the orchard seed sales of Patama nursery. The procedure was based on several limitations (see Appendix 24 for further detail) due to the specific features of the Finnish orchard seed markets.

The long-run average cost (LAC) function was estimated by polynomial regression since the theory (e.g., Lipsey 1987, Begg et al.1994) implies that LAC function is of second order. Prior to modelling the costs were plotted in order to illustrate whether there was such a pattern. Moreover, polynomial regression method was the most satisfactory with regard to R^2 (0.94-0.96) and residual behaviour (MicroCal Origin 1994). However, residuals were only checked by visual examination, because the primary purpose of the method was to *approximate*, not to model the underlying cost observations. In addition, it was assumed that further developed models would not increase the accuracy essentially due to the conventional approach applied here (i.e. costs were presented as a function of quantity) and incomplete original data set.

Silver birch present-generation seed orchards

For Silver birch the data underlying the LAC function was based on annual collecting costs, transporting costs, seed extraction costs, management costs of the seed orchards and administration costs between the 1992-1996. In total, there were over 125 cost observations (5 years * 5 cost categories * 5-8 seed orchards each year). The 1997 observations were excluded, because in that year the cost calculation procedure was changed resulting in an incomparatable cost classes with other years (e.g. production costs included different types of indivisible reservations for salaries which did not reflect actual production). The costs were deflated by the wholesale price index (Statistical yearbook of Finland 1997) for the year 1996.

An estimation for the market demand curve of Silver birch orchard seed was based on the sales from Haapastensyrjä Breeding Centre. Also here specific limitations were called for (see Appendix 24 for further details). A linear estimation (OLS method) for the demand curve was applied. As was the case with Scots pine, the prevailing prices for Silver birch orchard seed are also under the price rationing.

The LAC function was estimated by polynomial regression (MicroCal Origin 1994). The method was found to be the most satisfactory with regard to R^2 and residual behaviour. The price elasticity was evaluated for the average price (weighted by the quantity demanded) of the most demanded vitality class.

Scots pine next-generation seed orchards

This analysis was a pure case study calculation where a hypothetical next-generation Scots pine seed orchard was established. The business economical profitability was evaluated *ex ante*. The objective of the analysis was to examine the limits under which the established seed orchard is business economically profitable, and further to analyse whether these limits are attainable, given e.g. the biological constraints. Presently, this kind of assessment is called for because the establishments of Scots pine next-phase seed orchards are at hand (e.g., Männyn...1997). According to preliminary calculations a minimum area which is a "functional entity" is 20 hectares (Antola et al. 1996, Männyn...1997). This assumption was adopted here without further challenging the assumption *per se*. The establishment costs were based on recent experiences of local managers. These costs for *20 hectare* next-phase seed orchard are estimated to be approximately FIM 1.2 million (in 1998 money value). This figure partly represents already-realized establishment costs (Lahtinen 1997).

The business economical profitability *per established seed orchard hectare* was assessed by the following formula:

$$NPV_{ha} = \sum_{t=15}^{35} SR_t * (D_p)^t - \sum_{t=0}^{35} C_t * (D_p)^t \qquad [3.16]$$

where NPV_{ha} = net present value, FIM/hectare
SR= total sales revenue in year *t*, FIM
C= production costs in year t , including, e.g. management, collection (Obs.: the variable further consisted of average annual seed crop; kg/hectare, collected cones required for 1kg of orchard seed; litres), FIM
D_p= discount factor with a 4% to 10% discount rate

Scots pine sawlogs stumpage price development in southern Finland during 1982-1994 (see Appendix 4: Study 1) was applied to forecast the future prices of orchard seed. This development was seen adequate for the purpose, mainly due to a lack of adequant and uniform time-series of orchard seed sales (i.e. more than 5 years). The adopted forecasting method (linear regression) resulted in a 0.5 per cent annual increase in prices (not constant due to linearity). The future costs were forecasted by the formula given in Appendix 4.

The main variables and their presumed base levels are presented in Table 3.6.The figures reflected the cost and price levels of 1996 and 1997, respectively.

Table 3.6. Main variables and their base levels in Study 4, next-generation Scots pine seed orchards.

Main variable	*Base level*
annual management costs	FIM 1 000 /hectare
the amount of collected cones required for 1 kg of seed	150 litres
collecting costs	FIM 8 /litre
production age	20 years
average annual seed crop	10 kg/ hectare
Selling price for vitality class ">95%"	FIM 2 400 /kg
Selling price for vitality class "91-95%"	FIM 2 200 /kg

Each of the afore-mentioned base levels was applied from the national report (Antola et al. 1996, Männyn...1997). The base levels reflected experts' general ideas which can be considered to be "most up-to-date". However, the base level for an average annual seed crop, 10 kg/hectare, is rather high with regard to an average seed crop of the present-generation seed orchards, the average being approximately 4 kg (pers. comm. Lahtinen 1998). On the other hand, these new seed orchards are established on better soils. There is also more careful planning and management involved in the next generation. Furthermore, the 4 kg average includes also the past seed crops from seed orchards which at present are disregarded, i.e. left unmanaged.

In order to model the effect of different variables on NPV, various mathematical formulas were tested. The formulas can be seen as mathematical simplifications for surveying the impacts of different variables on business economical profitability. By the mathematical model the significance of each variable could be examined in further detail, but it should be noted that these mathematical formulas did not reflect stochastic processes as is often the case in statistical inference (see, e.g., Maddala 1977, Koutsoyiannis 1981, Chatfield 1989, Marshall et al. 1995). The formulas should not be interpreted as such. Rather, the idea was to capture the essential interrelations between regressors and simulated net present values and to present these in mathematical form. The formulas should be viewed as purely mathematical constructions for estimating the relative importance of each variable in the process. However, the process is not unknown, instead it is based on formal calculation procedures (cf. Maddala 1977). These parameter estimations are simplifications in order to aid practical decision-making. The adopted approach (i.e. modelling non-stochasticity) is presented in Appendix 25. The simulations were conducted under specific limitations (see Appendix 26).

Sensitivity analyses

Sensitivity analyses were conducted to evaluate the effect of changes in four *a priori* chosen main variables. Prior to showing the results three issues should be taken up. Firstly, the average annual seed crop (kg/hectare) was assumed to be fixed to a certain level (base level 10 kg/hectare) for the whole production time. Secondly, all the cost variables and price variables reflected particular cost and price development.

3.2.1.2 Results

Scots pine present-generation seed orchards

The resulting long-run average cost, LAC function was :

$$f_{LAC} = 0.00047\, x^2 - 2.12744\, x + c \qquad [3.17]$$

where f_{LAC} = long-run average cost function

x= quantity (kg/year)

c= constant, which was 377102 for LAC_1 (no establishment and past annual costs), and 5455.1 for LAC_2 (establishment and past annual costs incl.)

By differentiating formula [3.17] (with constant for LAC_1) and setting the derivate to zero, a minimum efficient scale (MES) was obtained. The output level where MES was achieved was 2263.2 kg/year. By comparing the MES value to the market demand it could be concluded that the prevailing market structure of Scots pine orchard seed production lies between oligopolistic competition and natural monopoly (Begg et al. 1994): a single firm (here Forest and Park Service) can produce almost the entire industry output (Figure 3.15).Thus, it can be argued that natural barriers to entry do exist, since the output (at MES) is very large relative to total demand (cf. Lipsey 1987).

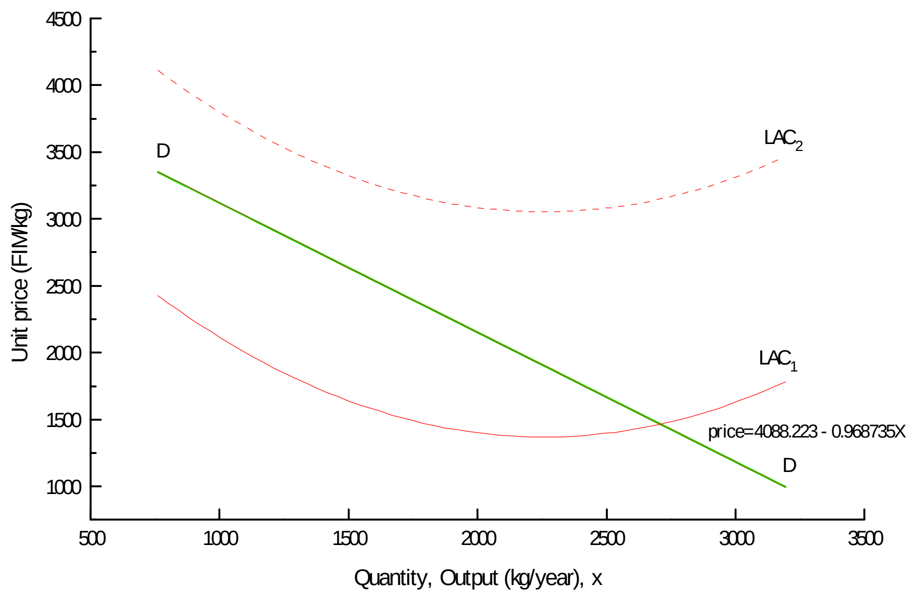

Figure 3.15. Long-run average cost curves (LACs) of Scots pine present-generation orchard seed production and *market* demand curve (DD). In LAC_2 the past establishment and annual management costs are included.

One commonly used method to examine the type of industry in which the firm operates is to calculate how much higher average (unit) costs are when the output is one-third of that of MES (e.g., Scherer 1980, Begg et al. 1994). The average unit cost increase was here 78% indicating that in Scots pine orchard seed production large fixed costs burden the profitability considerably at low output levels. Usually large fixed costs are common in heavy manufacturing industries (Begg et al. 1994).

Long-run marginal cost (LMC) and revenue (MR) functions were formed in order to examine the profit maximization condition (see Appendix 27). The profit maximization condition was met at output level x= 627.8 kg. In a perfect competition (i.e. price equals marginal cost) this output would result in 1 655.5 FIM/kg unit price which is clearly below the LAC curve at that point (see Figure 3.17). However, when adopting the assumption of imperfect competition (i.e. price does *not* equal to marginal cost) this output level (627.8 kg) results in a unit price of 2 871.9 FIM/kg according to the demand function. This exceeds the LAC curve at that output level, the exact unit price according to LAC (establishment and past annual management costs omitted; see LAC_1 in Figure 3.17) function being 2 567.1 FIM/kg. Thus, this result further confirms that the prevailing market structure of Scots pine orchard seed markets does not reflect competition.

The price elasticity of vitality class ">95%" (see Appendix 24) was -2.88 (around the average price 2 193FIM/kg), and the price elasticity of vitality class "90-95%" was -10.5 (around the average price 1998 FIM/kg). In addition, price elasticities of demand were also evaluated for the lower parts of the demand curves (generally price elasticity becomes less elastic along a linear demand curve: see, e.g. Parkin 1997), particularly at the points which indicated the lowest prices during 1993-1997. The elasticities were -1.3 and -5.5 for vitality class ">95%" and "90-95%", respectively.

The results indicate that the demand for Scots pine orchard seed is very elastic - this is, however, not a surprise, given the fact that stand seed is almost an identical substitute for orchard seed. When applying the results to structure decision-making it should be pointed out that in a case of elastic demand an increase in price will reduce demand to the extent that revenue will fall (e.g., Varian 1987).

Silver birch present-generation seed orchards

The best fitting LAC function for Silver birch orchard seed production was:

$$f_{LAC} = 0.16079\,x^2 - 55.69711\,x + 6109.82759 \qquad [3.18]$$

where f_{LAC}= long run average cost function

x= output (kg/year)

By differentiating formula [3.18] and setting the derivate to zero, a MES was obtained. The output where MES was achieved was 173.2 kg/year. When comparing this output level relative to estimated market demand (a linear approximation, R^2= 0.72, residuals checked visually) it emerged that the prevailing market structure is imperfect (Figure 3.16). Moreover, the market demand exceeds clearly the LAC curve indicating that the activity is very profitable in the long run.

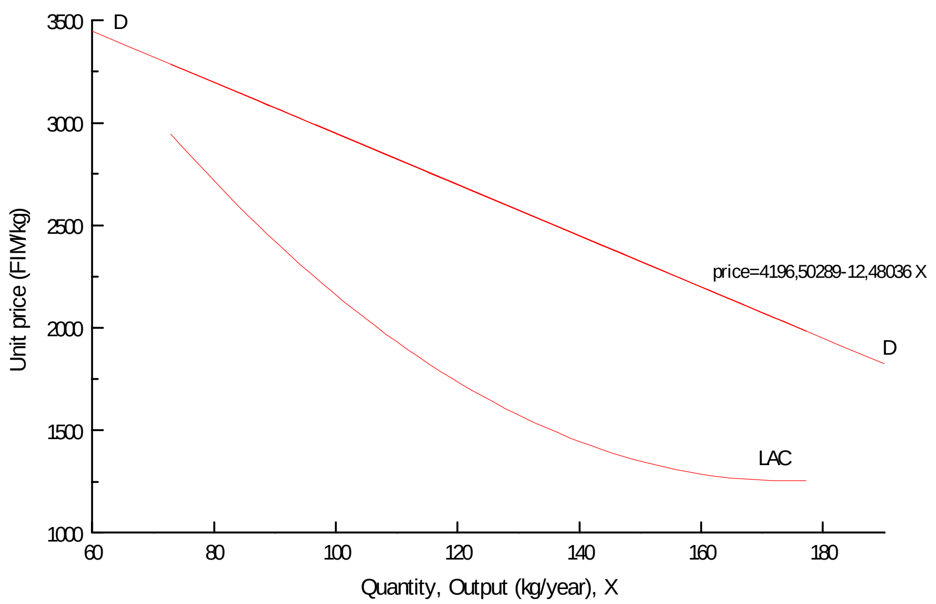

Figure 3.16. Long-run average cost curve (LAC) of Silver birch present orchard seed production and market demand curve (DD).

The cost increase was more than 100% when output was one-third of that of MES. This indicates that the fixed cost factor is dominant in Silver birch orchard seed production. Perhaps this is due to the fact that Silver birch seed orchards in polythene tunnels require intensive management (e.g., fertilization, artificial lightning, culling) *regardless* of production level.

The same principles as which were used for Scots pine, were adopted in determining the profit maximization condition for Silver birch (see Appendix 27). Because of the underlying 2nd degree polynomial, two (positive) profit maximization points were found. The points were x (output) = 36.7 or x= 107.9 kg/year. In the latter point the market price exceeded the long-run average costs (FIM 2850 vs. FIM 1970). The magnitude was such that perfect price discrimination can well take place.

The price elasticity of average price (3 121 FIM/kg), was -2.9. In addition, price elasticity around the lowest price (2 700FIM/kg) was still -1.8. This indicates that the demand for Silver birch orchard seed is elastic.

Scots pine next-generation seed orchards

When the establishment costs are taken into account, the net present value is negative whenever the collection cost is above FIM 7 per litre (Figure 3.17a). The analysis was conducted by keeping the other main variables (e.g. annual management, purchase prices) at their base levels (see Table 3.6). Collection costs and average crop were presented in integers so that decimals were omitted. By omitting the decimal values the calculation capacity of the software (MicroCal Origin 1994) was not violated. This led to the borders of the grid being vertical - in real-world the borders are, of course, not so sharp. When the establishment costs are disregarded (subsidized by e.g. the government) the

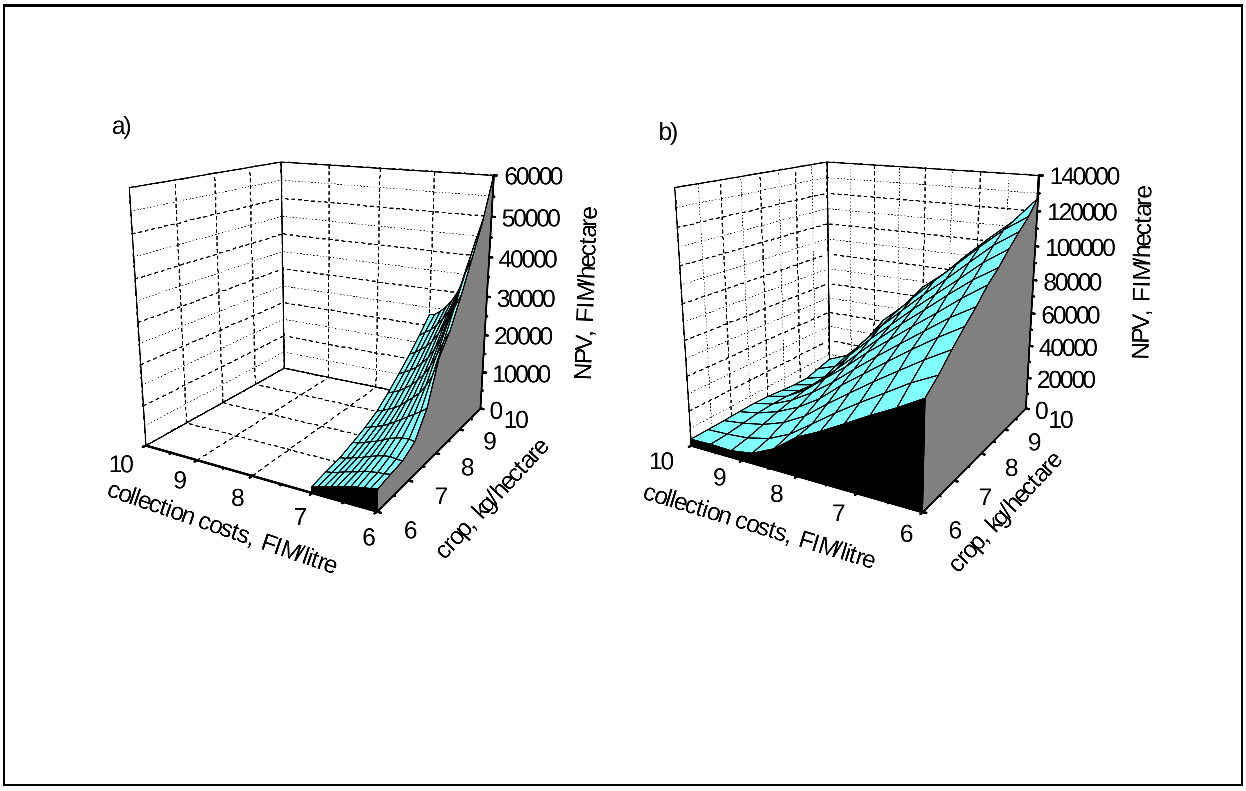

Figure 3.17. Net present value for *a hectare* of next-generation Scots pine seed orchard as a function of collection costs and average annual seed crop without (a) and with (b) a government subsidy. Only positive NPVs are illustrated. Discount rate 4%.

net present value (FIM per hectare) is positive even with FIM 10 per litre collection cost, regardless of the seed crop (within the range of 6-10 kg/hectare), at 4% discount rate (Figure 3.17b). It should be noted that future costs are in this connection converted to reflect the cost levels of 1996, e.g., FIM 7 or FIM 10 per litre. This is done to relate the results to present decision-making.

The effect of establishment costs, the amount of cones required for 1 kg of orchard seed and average crop on the NPV are presented in Figure 3.18. When establishment costs are taken into account, the net present value is positive only when approximately 130 litres of cones are needed for 1 kg of seed (corresponding app. 17 pro mille), the average crop being 7kg and discount rate 4% (Figure 3.18a). Nevertheless, when establishment costs were omitted, even with 170 litres of cones needed for 1kg (corresponding app. 13 pro mille), the NPV was positive with the lowest average

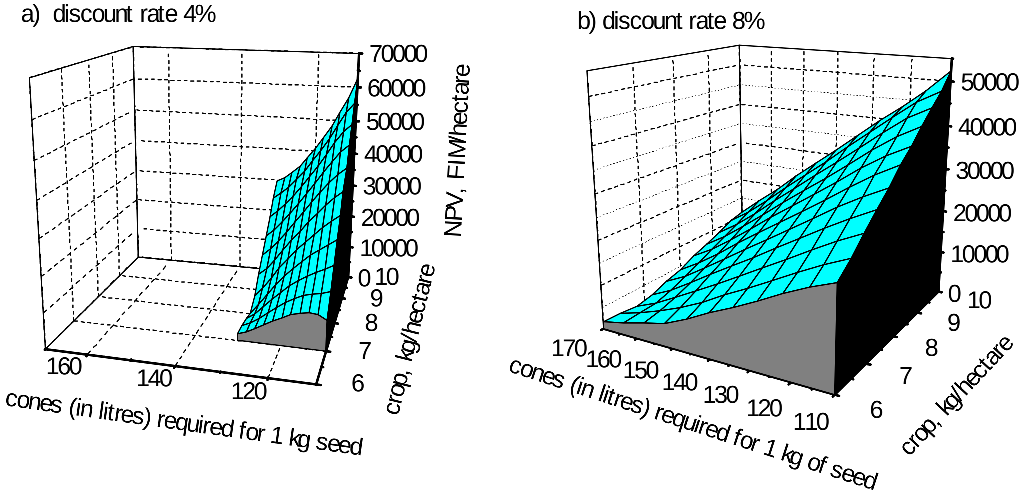

Figure 3.18. Net present value for *a hectare* of next-generation Scots pine seed orchard as a function of cones required for 1kg seed and average annual seed crop with government subsidizing the establishment (b), and without government subsidy (a). Only positive NPVs are illustrated (Note the different discount rates).

crop, 6kg/hectare, and *with 8%* discount rate (Figure 3.18b). Presently, the former figure, 130 litres, seems to be too high a value (see, Antola et al. 1996). The establishment costs appear to be the most dominant single factor affecting the business economical profitability of a seed orchard.

The best fitted formula for the purpose was nonlinear by nature (i.e., it cannot be transformed to linearity by, e.g., taking logarithms on both sides of the equation: see Greene 1997). Formally, it was:

$$NPV = \alpha_1 * ccones + \alpha_2 * \log_{10}(crop) + \alpha_3 * colcost + \alpha_4 * \ln(rate) + \alpha_5 * price + \alpha_6 * managcost + \epsilon \quad [3.19]$$

where NPV= net present value per hectare, FIM

ccones= collected cones required for 1kg of orchard seed, litre

crop= average annual seed crop per hectare, kg

colcost= collection costs, FIM per litre

rate= discount rate, 4% to 10%

price= sales price of the orchard seed, FIM per kg

managcost= annual management cost, FIM per hectare

ϵ = error term (see Appendix 25)

Formula [3.19] includes the establishment costs. Further, the underlying assumptions are as follows: a) time to seed production is 15 years, b) a seed orchard produces for 20 years ; i.e. the production time is 20 years (during that time the average crop is fixed) and c) no constant (fixed) variable is incorporated into the model. This last assumption was based on the *a priori* idea that if all values of the independent variables in formula [3.19] are set to close to zero, the NPV should be "insolvable" - had we incorporated a constant this would have resulted in an inconsistent interpretation with no relation to reality whatsoever. The parameters of formula [3.19] and the asymptotic correlation matrix of the parameter estimates are shown in Appendix 28. The main variables and their relative effects on the NPV in formula [3.19] are expressed in Table 3.7. Formula [3.19] can be interpreted by various ways, but here the following procedure was adopted. For each variable so-called base level was determined. *A priori* these base levels can be seen as the most relevant values, given the present knowledge on the next-generation seed orchards (see, e.g., Antola et al. 1996, Nikkanen et al. 1999), and the specific study context applied here (see Chapter 1.4). For each variable some alternative values are also depicted. The base levels and these alternative values together form a relevant scope with respect to present knowledge on the next generation. The calculated relative importances of the variables can be compared to each other *as such* - this will aid decision-making considerably.

Table 3.7. Main variables, simulation ranges (with intervals), *a priori* chosen base levels and simulation points of formula [3.19]. Percentage changes in the NPV corresponding a 1% change in the base level, point 1 and point 2 are shown while keeping the other variables at their base levels. With respect to present knowledge the points 1 and 2 are less likely to occur than the base levels, but they can also be considered to be relevant values. The absolute values of the NPVs for the base level, point 1 and point 2 are presented in parenthesis.

variable	Simulation range simulation intervals	*base level* (NPV,FIM/hectare) point 1 (NPV,FIM/hectare) point 2 (NPV,FIM/hectare)	percentage change in the NPV corresponding a **1%** change in the base level point 1 point 2, *ceteris paribus*
ccones	from 135 to 180 litres with 15 litre intervals	*150 litres* (1268) 135 litres (13 404) 165 litres (-10 869)	96 % 9.2% 12.3%
crop	from 6 to 11kg with 1 kg intervals	*10 kg* (1268) 9 kg (- 4 692) 11 kg (6 659)	44 % 12% 8.6%
colcost	from 6 to FIM 10 with FIM 1 intervals	*FIM 8* (1 268) FIM 7 (16 854) FIM 9 (-12 319)	98 % 6.5% 10.0%

rate	from 3 to 10 per cent with 0.5% intervals	*4 per cent* (1 268) 5 per cent (-12 072) 3 per cent (18 465)	97% 5.0% 3.2%
price	from FIM 1 900 to FIM 2700 /kg with FIM 100 intervals	*FIM 2400* (1 268) FIM 2 200 (-16 715) FIM 2 500 (10 259)	170% 11.8% 22.0%
managcost	from FIM 800 to FIM 1200 /hectare with FIM 100 intervals	*FIM 1000* (1 268) FIM 900 (2 852) FIM 1100 (- 316)	12 % 4.8% 55 %

The results distinctively emphasize the dominant role of pricing on the profitability (Table 3.7). For instance, if the selling price of orchard seed is changed from the base level by a 1%, this results in a 170% change in the NPV, the other variables being at their base levels (Table 3.7). However, also the changes in so-called biological variables (such as *ccones* and *crop*) lead to significant changes in the NPV (Table 3.7). This implies that in the next-generation there are still factors which affect the profitability considerably, and which cannot be fully controlled even by intensified seed orchard management. In other words, there are some risky elements involved - to reduce the risks new methods to improve, for instance, the predictability of annual seed crop are called for. On the other hand, "correct" pricing compensates the risks of biological variables. This, however, requires that the seed producer could also estimate the market demand for orchard seed - orchard seed prices cannot be increased arbitrarily.

The R square of formula [3.19] was 0.92, and residuals (n=630) were examined only visually, since the plots showed satisfactory model behaviour with regard to normality (stem-and-leaf plot) and homoscedasticity. In this connection, however, it should be pointed out that the model was initially based on simulated values, not stochastic observations (see Appendix 25). Residuals showed no misbehaviour when plotted against discount rate. There was also no trend to be seen in the model prediction regarding the NPV either. Additionally, in the scatterplot matrix no pattern between standardized residuals and predicted values was observed. Finally, in normal probability plot of standardized residuals the points fell more or less on the normal line (no significant deviations from the straight line).

Sensitivity analyses

The profitability was most sensitive to collection costs of cones, establishment costs and to annual management costs prior to seed production (Figures 3.19a, b). If collecting costs would decrease from FIM 8 to FIM 6 this would result in higher PV of sales revenues compared to those of costs even with 6 per cent discount rate (Figure 3.19a). If establishment costs and annual management costs prior to seed production (years 1 to 15 from the establishment) are omitted (e.g., subsidized by government), the seed orchard would be business economically profitable even with 10% discount rate (Figure 3.19b).

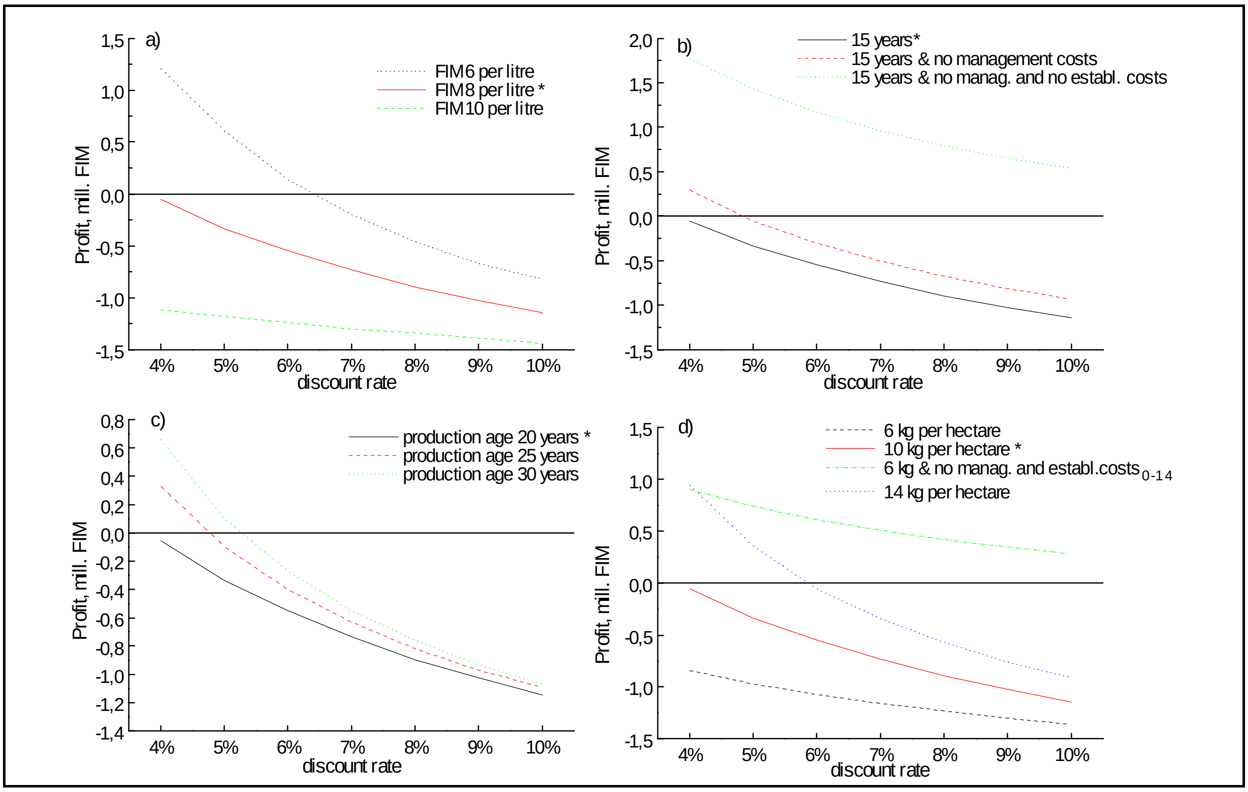

Figure 3.19. Profit (mill. FIM *per 20 hectares*) with alternative cone collection costs (a), establishment and management costs (b), production age (c) and combined effect of average annual seed crop and establishment and management costs (d). Solid lines (and asterisks) present base values (see Table 3.6).

Production time (i.e. time period under which seed orchard produces seed) had only a minor effect on the profitability (Figure 3.19c). However, the effect of an average annual seed crop (kg/hectare) on profitability was significant (Figure 3.19d). Moreover, from the graph it emerges that an "external subsidy" is of vital importance: without the subsidy the *average annual* seed crop must be very high (e.g. 14 kg/hectare) so that profits be attainable (Figure 3.19d). Currently, this seed crop level is almost impossible to achieve (see, e.g., Antola et al. 1996). On the other hand, if establishment costs and annual management costs prior to seed production are funded externally (e.g. by the government), as low as 6 kg/hectare annual seed crop is sufficient to quarantee profits even with 10% discount rate (Figure 3.19d).

The effect of time to seed production (sometimes denoted as production lag) on profitability was examined by changing it from 15 years to 10 years. The idea was to estimate how much the annual management costs could be increased during the *first ten* years so that the alternative (i.e. shortened time to seed production) would be as profitable as the original alternative. With 5 per cent discount rate the increase in annual management costs within the first 10 years was some FIM 1300, indicating a 130 per cent increase. This result suggests that more intensive management over the first years after the establishment is well justified if it leads to shortened production lag.

3.3 Private forest owner's viewpoint

3.3.1 Study 5: Financial profitability of using Scots pine orchard seed in direct sowing

3.3.1.1 Purpose and framework

Purpose

The initial purpose of the study was to estimate possible differences in NPVs between pine stands sown with stand seed and with orchard seed. Genetic gains were assumed to generate faster growth rate resulting in an increase in the NPV of the outturns. This increase was examined at forest holding level and from a private forest owner's point of view (Ahtikoski 1997). Assessments were conducted with special reference to initial sowing costs of both seed options (stand and orchard seed). The profitability was determined according to formula [2.13].

Framework

The simulations were executed for four former local units of the FPS due to practical reasons: the software for tree growth and harvest scheduling modelling and detailed growth data were available and operable (with reasonably small modifications) at the FPS (see, Ahtikoski 1997, p. 241). Due to the initial growth data (young stands of the FPS), some caution must be taken when applying the results to private forests . On the other hand, in a preliminary comparison between growth characte-ristics of young stands of the FPS and those of owned by private people no evidence of significant divergences emerged (Ahtikoski 1997).

The basic assumption at this juncture was that the same amount of orchard seed (expressed in g/hectare) was used in direct sowing. This leads to cost difference due to different unit prices of stand and orchard seed. The cost data were primarily based on the calculations of Hänninen (1995) whcih indicate that orchard seed is more expensive than stand seed. In Finland, however, the prevailing prices of Scots pine stand and orchard seed vary considerably and there is no exact figure to be used for a particular region. In light of this prospect it is convenient to illustrate the NPVs as functions of consecutive sowing cost differences.

The benefits were simulated by incorporating genetic gains into the growth functions of MELA program (see Appendix 13). The genetic gains reflected the latest progeny test results concerning first-generation Scots pine seed orchards (Venäläinen et al. 1994) in southern parts of the country. The percentages were 3%, 7% or 10%.

Because the applied method (increasing annual growth level in MELA) affected the general structure of the stand , and thus resulted in various NPVs, a supplementary analysis was conducted. In the analyses genetic gains were studied against the corresponding changes in the NPV (%). These were plotted in the same diagram. Furthermore, the harvest scheduling models including genetic gains were tested against the models without genetic gains to look for potential biases in the simulation. This was done by forming diameter distribution for normal and improved stand, and comparing them during the growth and at the end of rotation.

To attain deeper knowledge with regard to main factors (discount rate, genetic gain, stumpage prices and initial sowing costs) the effect of these on the *simulated* net benefits was examined. This was done by testing different mathematical formulas applying the same principles as in Study 4 (see Appendix 25 for modelling procedure). The formulas were constructed according to harvest scheduling models of Jyväskylä region.

A priori there were two main factors affecting the financial profitability of using orchard seed in direct sowing. First, the results depended on the genetic gain applied. However, no sensitivity analysis concerning the genetic gains was conducted, since the results *as such* included different genetic gains. Second, so-called market related factors were tested by sensitivity analysis. The sensitivity to changes in trend stumpage prices ("no trend", "triple trend") and initial sowing costs were analysed. In addition, the NPVs were recalculated based on Vuokila & Väliaho's growth and yield models to study the effect of different harvest scheduling models on the results.

3.3.1.2 Results

The net present values for improved stands were similar in all regions (Figure 3.20). One reason for the similarity was that these different growth regions were located in southern Finland where the growth conditions with regard to climate and soil nutrition are more or less similar (Kuusipalo 1996), or at least the growth potential of Vaccinium type pine forests is of similar magnitude. Even with eight per cent discount rate the net present value was positive in all regions, the genetic gain being the lowest, i.e. 3% (Figure 3.20).

For a 3% genetic gain the corresponding increases in the NPV varied between 5.9% and 7.9% (Figure 3.21), the former value indicating the result for Hämeenlinna, and the latter for Karstula model (discount rate 3 per cent). As a rule of thumb, the increase in the monetary value (presented by the NPV) was more than twice as much as the initial genetic gain (expressed in percentage) when discounting with 3 per cent.

With low genetic gains (from 3% to app. 8%) the proportionate increase in NPV was higher for Hämeenlinna model than for Karstula model (discount rate 5 per cent). Nevertheless, with high

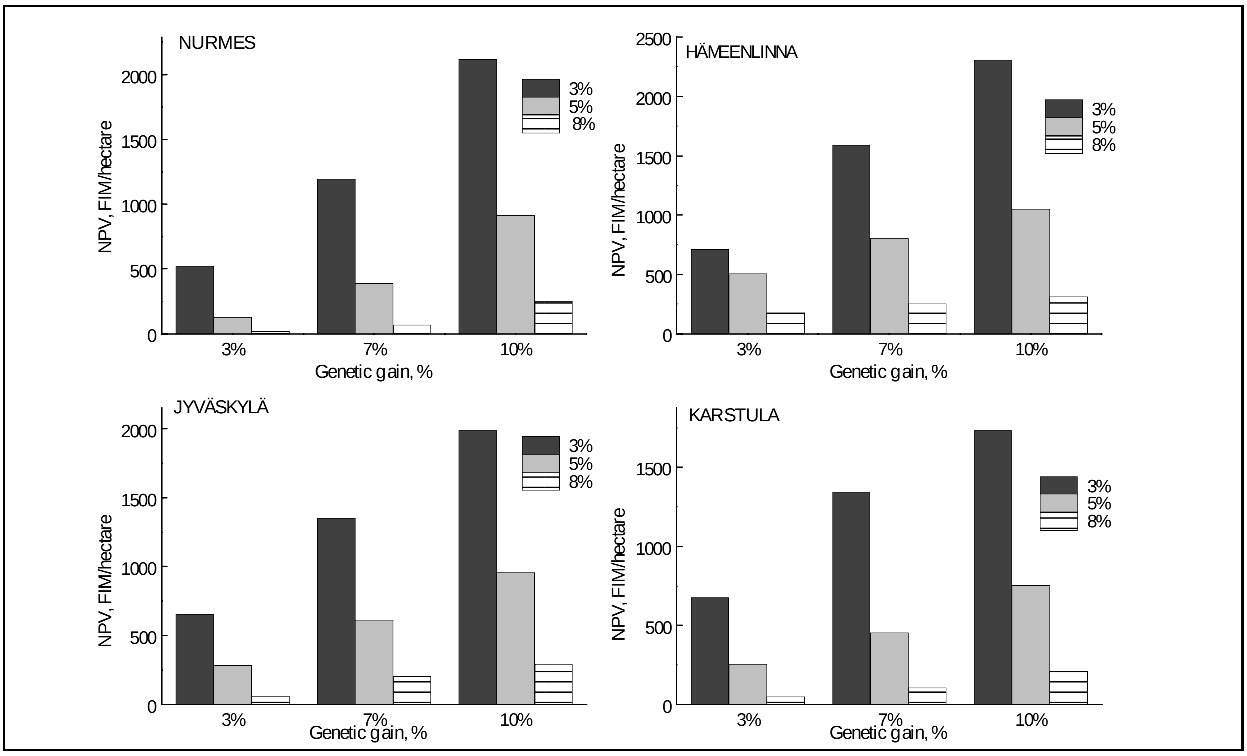

Figure 3.20. NPV (FIM/hectare) with alternative discount rates in Nurmes, Hämeenlinna, Jyväskylä and Karstula region (the FPS).

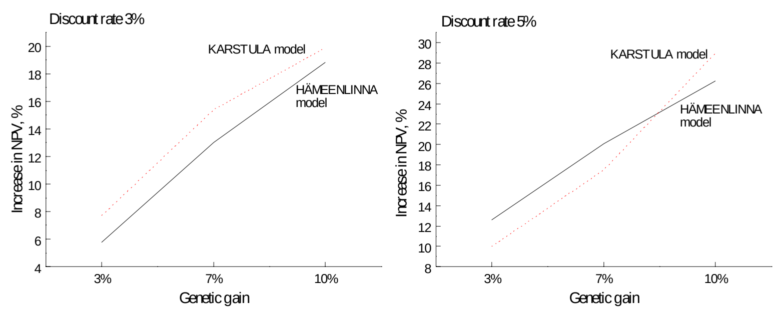

Figure 3.21. The relative increase (%) in NPV corresponding the initial genetic gain expressed in percentages. The lower line indicates the results of Hämeenlinna model for Vaccinium type, and the upper line for Karstula model for Vaccinium type (a). When discounting with 5 per cent the lines intercept (b). The models for Jyväskylä and Nurmes lie between these two "extremes"

genetic gains Karstula model resulted in greater proportionate increases in NPV. These "controversial" results are due to the fact that genetic gains were incorporated into the growth models of MELA exogeneously, resulting in a nonlinear behaviour with respect to harvest scheduling.

The mathematical formulas were tested for Jyväskylä region, but because of the similarity of the NPVs in different regions (see Figure 3.20) the formulas can be applied also to other regions with caution. The best fitted formula for estimating the effects of the main variables in Jyväskylä region was :

$$NB = \alpha * \ln(rate) + \alpha_1 * \sqrt{gengain} + \alpha_2 * relprice + \alpha_3 * costdiff + \epsilon \qquad [3.20]$$

where NB= net benefit, FIM/ hectare

rate = discount percent, 3% to 8%, with half a per cent interval

gengain = from 1% to 10%

relprice= relative trend stumpage price level (+/-30% compared to the original trend price level, with 5% intervals)

costdiff= initial sowing cost difference, FIM/hectare with FIM 50 intervals between FIM 50 and FIM 550

ϵ = error term

Parameter estimates and technical details of formula [3.20] are presented in Appendix 29. The relative impacts of the variables on the net benefit are here demonstrated by the following. First, so-called default value for each variable was chosen. These default values were based on several studies on the present generation (e.g. Venäläinen et al. 1994, Hänninen 1995, Venäläinen & Koponen 1997), and they can be considered to be a relevant basis with respect to current decision making environment. In addition, the 4 per cent discount rate was chosen here as the default value. This is in accordance with the base level of discount rate in formula [3.19]: the 4 per cent discount rate was the highest discount rate resulting in a *positive* net present value or net benefit for *both* the seed producer and private forest owner, respectively. The main variables, default values and relative importances of variables in formula [3.20] are shown in Table 3.8.

Table 3.8. Main variables and their default values of formula [3.20]. Percentage changes in the Net Benefit (NB) corresponding a 1% change in the default value are presented while keeping the other default values intact. For the sake of comparison another value for each variable (and the corresponding percentage change in the NB) is also presented. These alternative values are shown below the default values, and they were selected on the basis of prevaling conditions.

variable	default value	percentage change in the NB corresponding a **1%** change in the default or alternative value, *ceteris paribus*
rate	*4 per cent* 3 per cent	4.4% 1.9 %
geggain	*3 %* (in volume growth) 5 %	1.9% 0.7%
relprice	*1.0* 1.05	4.5% 1.9%
costdiff	*FIM 250 / hectare* FIM 350 / hectare	1.2% 1.0%

The results indicate that relative price and discount rate are the most dominant factors affecting the Net Benefit , at least in the neighbourhood of default values (Table 3.8). Overally, it seems that the effects of the variables on the Net Benefit in formula [3.20] were considerably smaller than those of formula [3.19] on the Net Present value. However, these effects in different formulas ([3.19] and [3.20]) should be compared with extra caution, because a) the formulas are in the first place estimated for different agents (seed producer vs. private forest owner), and b) the primary idea was to "rank" the relative importances of the variables in each formula so that the ranking could aid decision-making.

Also in this connection it should be pointed out that the error term (ϵ) only represents the misspecification of the mathematical formula as regards *simulated* net benefit values (see Appendix 25). Therefore, the formula should be considered as a decision-making tool rather than a statistical model in a traditional sense. This should be kept in mind when interpreting the results. In general, the model behaviour was satisfactory (see Appendix 29).

Sensitivity analyses

The difference investment method was applied by subtracting the initial sowing cost difference from the net present values (of the outturns), resulting in net benefits. For example, if the initial sowing cost difference was approximately FIM 600/hectare in Jyväskylä region, then the genetic gain had to be 7% in order for *net* benefit equaling zero, at 5% discount rate (Figure 3.22). A break-even occurred when the initial sowing cost difference was FIM 700/hectare in Hämeenlinna region, the genetic gain and the discount rate being 3% (Figure 3.22).

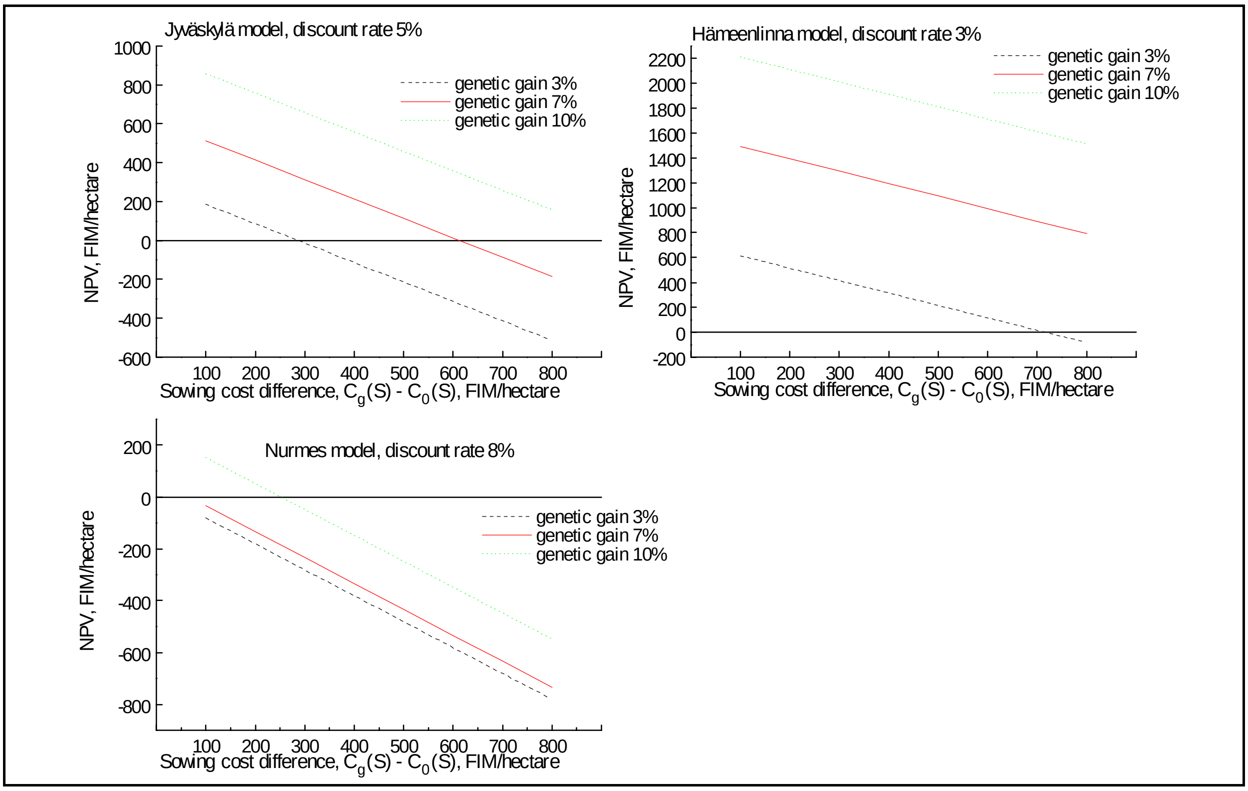

Figure 3.22. Net present value (FIM/hectare) against initial sowing cost difference in Jyväskylä (a), Hämeenlinna (b) and Nurmes (c) region. Different genetic gains and discount rates applied.

Vuokila & Väliaho's growth and yield models resulted in considerably lower present values than those of MELA modelling (Figure 3.23a). The main reason for that was the difference in calculation method. In Vuokila & Väliaho's models the genetic gains were estimated by increasing the outturns and keeping harvesting times unchanged, whereas in the MELA simulation the genetic gains were fed into the growth process themselves which resulted in changes in both the outturns and harvesting times. It can be argued that the MELA method simulates nature more realistically. Moreover, in Finland it is probable that thinnings are executed as early as possible, given the growth conditions and law. Differences in the NPVs originate also from the different initial data sets used for Vuokila & Väliaho's and MELA models. As a conclusion, the results according to former model could be seen as "a lower boundary" for a given genetic gain, whereas the results reflecting the MELA simulation can be viewed as "an upper boundary".

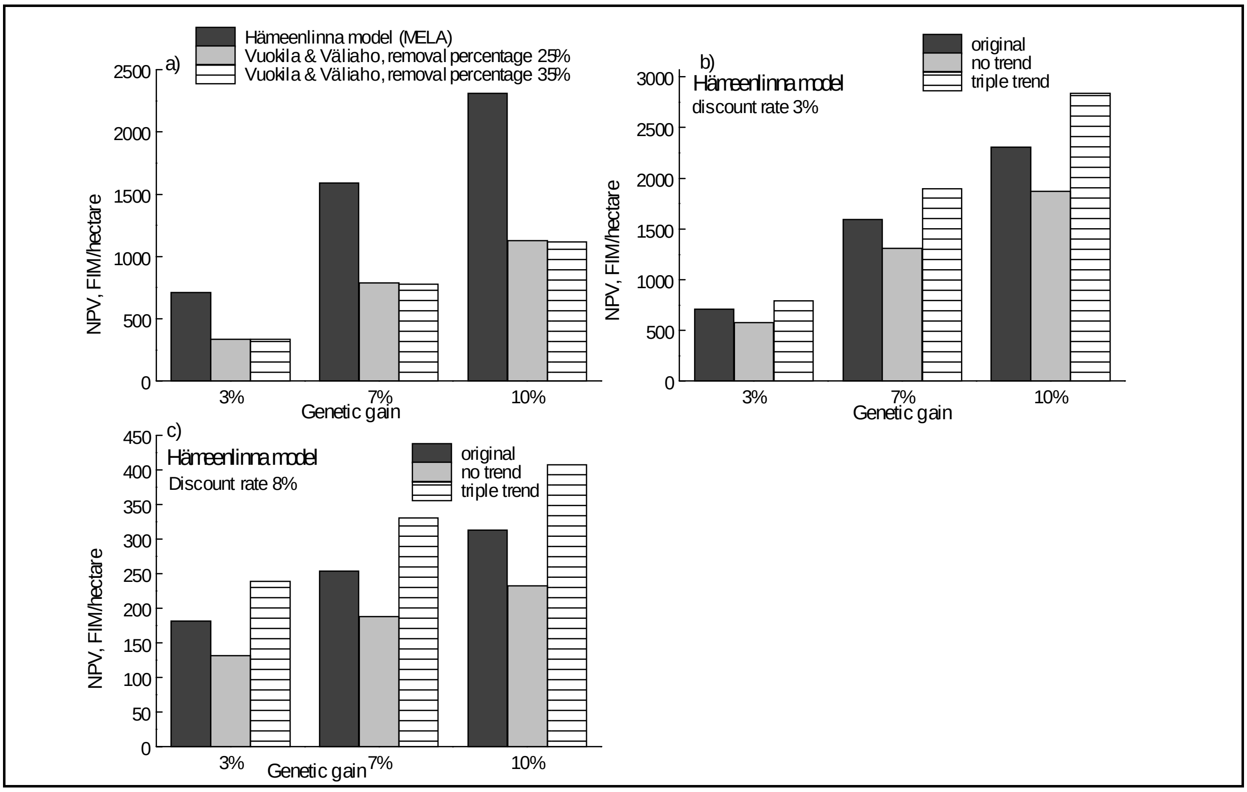

Figure 3.23. Net present value evaluated by original MELA simulation ("Hämeenlinna model ") and by Vuokila & Väliaho's harvest scheduling models applying two different removal percentages (a). Discount rate 3%. Sensitivity to changes in trend stumpage prices with 3 per cent discount rate (b) and 8 per cent discount rate (c) for Hämeenlinna model.

The results were only moderately sensitive to changes in trend stumpage prices (Figure 3.23b and c).

4. Conclusions

This research reports on the profitability of the present and next-generation Scots pine and Silver birch seed orchards in Finland. The specific goal of this work was to determine the conditions under which seed orchards are economically attractive for three *a priori* chosen agents. The conditions were divided into biological and market related conditions. Then, these conditions were examined with special reference to prevailing conditions and decision-making process. Further insights were provided in analyzing the extent at which the decision makers (either at public or private level) can control the variables creating the economically desirable conditions. Contradicting traditional views in the forest economics literature the concept of risk is here interpreted by the following. If the relevant variables with respect to profitability can (to some extent) be altered through the decision-making process, then the investment is characterized by low-risk elements. If, on the other hand, these variables cannot be affected by the decision maker, then the investment is categorized as a high-risk investment. The main topic was surveyed in five independent empirical studies by using methods consistent to current theory of economics.

Prior to making conclusions, one particular issue should be emphasized to avoid misinterpretations. The time period used in the assessments was very long. This gave rise to various forms of uncertainty, but most of them could be ignored due to the differential approach applied here. For example, it can be expected that both improved and unimproved stands are under the *same* uncertainties as regards, e.g,. fire occurrence, conservation, general roundwood market shocks and time series analysis. On the other hand, the long time horizon is a phenomenon *per se* consisting of uncertainties which cannot be captured without making restrictive assumptions about the future. The essential question is whether these restrictive assumptions are reasonable - this can be tested *post hoc* by sensitivity analyses as was the case here.

This thesis has produced new information on the economical aspects of the Finnish tree breeding. Especially, the results provide new insights into a) detailed shadow pricing procedure of the annual costs of the seed orchard activity, b) applicable methods for converting the genetic gains into monetary values, c) mathematical tools for evaluating relative importancies and interrelations of the main variables and d) estimation of relevant risk elements associated with tree breeding. Especially, the intuition behind the shadow pricing procedure is that it gives new knowledge on the *true* (net) impacts of the tree breeding on social welfare. In addition, the research breaks new ground in providing a shortcut method for assessing genetic gains. Namely, to estimate the increase (%) in the NPV associated with a particular genetic gain at stand level.

The main results (Study 2) proved promising: with Scots pine next-generation seed orchards the Net Present Values (NPVs) were positive even with 6% discount rate for a 12% and 15% genetic gain. The results allowed considerable changes in variables (e.g. input prices, site quality, costs and harvest scheduling) which can be considered to be controlled by public decisions. However, the results were very sensitive to changes in annual average seed crop which is partly affected by biological processes beyond the control of public decisions. This implies that there will be some risk elements involved with the next generation. On the other hand, the magnitudes of net benefits per produced orchard seed kilogram hint to a possibility that risks can be reduced considerably by directing *relatively* more subsidy (compared to present generation) into activities which improve the biological conditions of the seed orchards. Further, the next-generation seed orchards will be established in better soils than those of the present generation, let alone the fact that the risk of background pollination is considerably lower with the next generation (Nikkanen & Antola 1998). Both these issues contribute profitability significantly.

In general, investing in the next-generation Scots pine seed orchards seems to be charaterized by low-risk elements. The results (Study 2) also indicated that activities contributing Scots pine's stem quality warrant the extra costs involved. Surprisingly, the assessments resulted in similar outcomes irrespective of whether market or shadow prices of inputs were applied. This is mainly explained by the resulting high benefit-cost ratios.

For Silver birch next-generation seed orchards (Study 2), positive NPVs were attainable only with 4 per cent discount rate. The attainable discount rates were generally lower than those of Scots pine, which can be partly explained by the fact that future annual cultivation areas were forecasted according to different time periods for Scots pine and Silver birch. The applied method can be said to be "unfavourable" to Silver birch since its time-series included years in the 70s lowering the derived annual average. On the other hand, the net benefits per produced orchard seed kilogram were distinctively high values implying that there is a potential to improve the economic outcome considerably. This can be done by directing relatively more subsidy into those activities which are the most efficient from the society's viewpoint. For instance, to develop methods which enable better correspondence between the seed production and orchard seed's market demand so that overproduction problems (characteristic of present generation) can be avoided. The results were in general sensitive to changes in annual cultivation area and costs, as expected (benefit-cost ratios were smaller than for Scots pine). These variables, however, can be considered to be the variables which can be affected by public decision, at least to some extent. Thus, also with Silver birch next-generation seed orchards low-risk elements are prevalent.

For next-generation Scots pine seed orchards of northern clones (Study 3), only a 3 per cent or less resulted in positive NPVs. The significant difference in profitability between the seed orchards for South and Central Finland (Study 2) and for northern Finland (Study 3) originates from several distinctive facts. First of all, it should be pointed out that the breeding goals for southern and central Finland and for northern Finland are separate (see, e.g., Nikkanen & Antola 1998). It can be argued that the breeding goals for southern and central Finland (growth yield and quality) evidently lead to economically more desirable outcomes than the corresponding for northern Finland (survival). Part of the difference can be explained by the different structures of original book-keeping records which led to applying separate cost classes and division of subactivities (see Appendix 12 vs. Table 3.4). Second, *relatively* much higher differential costs (e.g., maintenance of the freeze testing capacity) are tied up with seed orchards of northern clones than those for South and Central Finland. Thirdly, smaller values for average seed crops were applied for northern Finland bearing in mind that a profitability and seed crop are directly correlated. Finally, different absolute genetic gains were applied - it can well be argued that higher absolute genetic gains are attainable in southern Finland where growth potential generally is higher than in northern Finland (see, Kuusipalo 1996). In other words, the better the initial soil and climatic conditions, the higher gains from tree breeding can be obtained. Contradicting the results of Study 2 the NPVs of Study 3 were very sensitive to changes in input pricing. One possible reason for that is the different division of input categories, the other being the fact that seed orchards of northern clones require more labour input relatively to other inputs. Thus, changing the prices of labour input would directly affect the NPV considerably. As expected, the results were sensitive to changes in annual cultivation area, differential costs, average seed crop and harvest scheduling modelling, which all except the average seed crop can be considered to be variables affected by public decisions. In this respect, investing into the Scots pine next-generation seed orchards of northern clones can also be characterized by low-risk elements.

Generally, the results (Studies 2 and 3) indicated that the minimum values for the main variables required for a positive NPV are obtainable with reference to the present knowledge on biological and economical conditions. In addition, the most relevant variables with respect to profitability can be controlled by public decisions suggesting that low-risk elements are dominant with the next-generation seed orchards. However, it can be argued that seed orchards to be established for the northern Finland are significantly more dependent on public funding than those established for southern Finland.

The results of Study 1 showed that present-generation Scots pine seed orchards are profitable (i.e. NPV > 0) from the society's viewpoint only when the genetic gain in volume growth is over 7 percent, the discount rate being 3 per cent. The former seems to be a higher value than suggested by the latest progeny test results (Venäläinen et al. 1994). It should, however, be reminded that the assessment included *all* Scots pine present-generation seed orchards. This has effected the profitability: for example, the net benefits per produced orchard seed kilogram were significantly lower than the corresponding of the next generation indicating fewer alternatives for decision makers to redirect the annual subsidy into more efficient breeding activities.

With Silver birch present-generation seed orchards the highest genetic gains, 15% in South and 12% in Central Finland, resulted in positive net present value when discounting with 3% (Study 1). These genetic gains (15% and 12%) seem to be attainable, given the latest progeny test results on the present generation (Hagqvist & Hahl 1998). In addition, the high values of net benefits per produced orchard seed kilogram indicated that the subsidy could be *re*directed between the breeding activities so that the overall profitability would be improved to some extent. The key issue in the near future is to adjust seed production to correspond to market demand more accurately than in the past - this can be best achieved by placing relatively more inputs to develop solid methods for estimating market demand.

The discount rate (3%) resulting in a positive NPV was relatively low with both species, although such a rate could be “justified” in long-term public investments (e.g., Musgrave & Musgrave 1989) and especially in long-term environmental projects (Weitzman 1998). In general, the results of both species were robust with regard to site quality and stumpage prices. In this respect the present seed orchards can be considered to be low-risk investments.

Principally, the main cause for the poor profitability (i.e. low discount rates for positive NPVs) of present seed orchards is that they could not have been utilized with the magnitude which was originally planned. However, the reasons for this defect are distinctive for the tree species in question. With Scots pine the background pollination and poor soil conditions of seed orchards have led to *unbalanced* seed production with respect to orchard seed demand. The background pollination has narrowed the original utilization areas (confirmed by the Finnish Forest Research Institute; see Nikkanen et al. 1999) of orchard seed, particularly in northern Finland, while in some parts of southern and Central Finland there has been an excess supply of orchard seed due to overlapping seed orchards. This background pollination can be considered to be a high risk element since there have been only limited methods (for both decision makers and breeders) to reduce the level of pollen contamination in the present seed orchards. Viewed in this fashion, the present-generation Scots pine seed orchards involve more risks than those of the next generation.

With Silver birch, on the other hand, the chronic overproduction of seed during the recent years has burdened the profitability considerably. The overproduction results from two separate facts, as was mentioned earlier. First, production techniques have developed faster than anticipated leading to higher production capacity (within the same polythene tunnel area) than was originally schemed. Second, drastic fluctuations (during the early 90s) in annual cultivation area have reduced the profitability. However, unlike Scots pine, both these effects can be controlled through decisions. Thus, from the society's viewpoint lower risks are associated with the present-generation Silver birch seed orchards than those of Scots pine.

The analysis on market environment for Scots pine and Silver birch present-generation orchard seed (Study 4) implied that there are still economies of scale to be exploited with both species. One main reason for the existence of economies of scale withScots pine orchard seed production is the impact of uncollected cones in seed orchards - the seed orchards have not been utilized in accordance with the initial magnitude of the establishments. The surprising outcome of the analysis of the next-generation Scots pine seed orchards (Study 4) was the essential importance of the government subsidy -without the subsidy the NPV for a single seed orchard is clearly negative even with low discount rates. In addition, the simulation results indicated that the price of the orchard seed was the most important variable for the financial profitability (Table 3.7). This implies that via right pricing decisions some of the risks associated with biological variables can be compensated. At present generation the total absence of the subsidy would most likely lead to higher prices for orchard seed, and it seems that there would not be enough demand with those higher prices, especially in case of Scots pine (see Figure 3.15). For Silver birch, however, the absence of the subsidy would not affect the profitability so drastically, since there might be enough demand for higher orchard seed prices (see Figure 3.16). Finally, the results clearly indicate the need to invest in methods which contribute to seed crop - even large extra costs involved in developing are warranted by higher seed crops.

With Scots pine the discrepancy between the discount rate resulting in a positive NPV for society (Study 2) and for a seed producer (Study 4) can be explained twofold. First, different set of prices were applied: social, i.e., shadow prices were used in examining the issue from the society's viewpoint, whereas market prices were adopted for seed producers. These different prices can partly explicate the discrepancy found. Primarily, the discrepancy originates from the fact that there is a 15-year time lag between the establishment and seed production in a Scots pine seed orchard. This is the main cause which burdens the financial profitability.

For a private forest owner sowing with Scots pine orchard seed was profitable even with as high as 8 per cent discount rate (Study 5). According to the results (see Figure 3.20) the difference (between the outturns of an improved stand and those of a normal stand) at present value is well above the prevailing extra costs involved with orchard seed in direct sowing. In addition, an interesting outcome was that the decision variables of the simulation (discount rate, genetic gain, relative stumpage price and sowing cost difference) had similar impacts on the financial profitability within the relevant scope of prevailing biological and economical conditions (Table 3.8). This can be interpreted by saying that decisions are dominated by private forest owner's *own* preferences. Furthermore, in practice private forest owners are willing to pay more for the orchard seed than for stand seed (Venäläinen & Koponen 1997). Thus, it seems that small increases in orchard seed prices (e.g. due to a possible decrease in annual subsidy) would not limit the demand considerably.

With both species the significant difference in profitability between the present (Study 1) and next generation (Study 2) can be explained by the effect of more efficient planning and establishment, and by the underlying, better than assumed correspondence between anticipated orchard seed demand and the magnitude of the establishment of the next-generation seed orchards. In the next-generation there will be no large-scale excess seed supply to burden the profitability. Of course, the higher genetic gains applied in the next generation affected the results, but they cannot explain all of the difference. Additionally, it should be emphasized that the *actual* results of tree breeding cannot be utilized until the next generation. Then, *at the first time* the individual trees are selected into breeding population according to progeny test results.

From the overall results (Study 1 and 2), it can be concluded that there might even be some welfare improvements attainable in the next-generation seed orchards for both species in the sense that higher discount rates, compared to the present generation can be applied. In other words, the resources (in a form of inputs directed into breeding activities) tied up in the next-generation seed orchards are more efficiently allocated from the society's point of view than the resources used in the present generation. Hypothetically, if we assume that the present and next-generation seed orchards were mutually exclusive projects society would gain by reallocating resources from the present to the next-generation seed orchards. Furthermore, the absolute value of discount rate applicable in the next generation appears to be a high value as regards rawmaterial supply in primary production.

Finally, the multilevel analysis resulted in a positive impact of tree breeding on each agent. In other words, the results suggest that via the present government subsidy, which itself is economically justified, the orchard seed production is made business economically profitable. Further, for a private forest owner the produced orchard seed also seems to be a profitable alternative to be used in direct forest sowing. The above-mentioned applies even more with the next generation, when lower risks are associated with the investment decisions, and higher genetic gains can be expected (see, e.g., Venäläinen et al. 1996b).

SELOSTE (Finnish Summary)

Tutkimuksen tausta ja tavoitteet
Määrätietoinen metsänjalostustoiminta alkoi Suomessa männyn (*Pinus sylvestris L.*) pluspuiden valinnalla. Varttamalla pluspuiden oksia perusrunkoihin perustettiin ensimmäiset avomaan siemenviljelykset 1950-luvun keskivaiheilla. Toiminta laajeni 1960- ja 70-luvuilla laajamittaisella männyn siemenviljelysten perustamisohjelmalla. Jalostustyön puolen vuosisadan mittaisesta historiasta huolimatta Suomessa ei kuitenkaan ole tarkasteltu metsänjalostuksen taloudellisia perusteita muutamaa tapaustutkimusta lukuun ottamatta. Tämä työ pyrkii osaltaan korjaamaan ko. epäkohtaa. Ensisijaisesti työssä tarkastellaan männyn ja rauduskoivun (*Betula pendula Roth*) seuraavan polven siemenviljelysten taloudellista kannattavuutta. Metsänjalostustoiminnan kannattavuutta tarkastellaan kolmen agentin (valtio, siemenentuottaja ja metsäomistaja) näkökulmasta. Lisäksi, kannattavuudelle kriittisiä muuttujanarvoja verrataan vallitseviin biologisiin ja taloudellisiin olosuhteisiin, jotta päätöksenteossa voitaisiin ottaa huomioon myös kannattavuuksiin liittyvät riskit.

Tutkimusmenetelmät
Valtion talouden tason tarkasteluissa (Osatutkimukset 1, 2 ja 3) laskelmat suoritetaan kustannushyötyanalyysilla (KHA) kiinnittäen erityistä huomiota a) varjohinnoitteluun ja b) erotuslaskentamenetelmään Varjohinnoittelemalla metsänjalostuksen *erotus*hyödyt ja -kustannukset (verrattuna metsikkökeruusiemen-vaihtoehtoon) voidaan laskelmissa evaluoida niiden todelliset vaikutukset yhteiskunnalle, mitä resurssien tehokas allokaatio edellyttääkin. Kannattavuuskriteerinä on Nettonykyarvo (NNA)- menetelmä, ja laskelmat suoritetaan vaihtoehtoisilla laskentakorkokannoilla (2-6%). Finanssista analyysia sovelletaan yksityisen metsänomistajan (Osatutkimus 5) ja siemenentuottajan (Osatutkimus 4) näkökulmasta tehtävissä laskelmissa. Lisäksi, ns. MES- ja LAC-analyyseja hyödynnetään määritettäessä nykyisten siemenviljelysten siementuotannon kannattavuutta. Siemenviljelyssiemenen markkinakysyntä formuloidaan yhtälömuotoon molemmilla puulajeilla. Myös metsänomistajalle ja siemenentuottajalle investointikriteerinä pidetään Nettonykyarvoa, joka lasketaan vaihtoehtoisilla korkokannoilla. Herkkyysanalyyseissa lasketaan myös sisäisiä korkokantoja. Sekä yksityiselle metsänomistajalle että siemenentuottajalle muodostetaan matemaattiset kannattavuusfunktiot mallintamalla päämuuttujien lasketut arvot ja arvojen interrelaatiot. Menettely tarjoaa helppokäyttöisen ja suhteellisen luotettavan apuvälineen päätöksenteon tueksi.

Tulokset
Tulosten mukaan seuraavan sukupolven männyn ja rauduskoivun siemenviljelykset (Osatutkimus 2) ovat taloudellisesti perusteltuja investointeja yhteiskunnan kannalta, ainakin kun käytetään laskentakorkokantaa valintakriteerinä (NNA on positiivinen männyllä 6%:lla, ja rauduskoivulla 4%:lla). Toisaalta myös seuraavaan sukupolveen liittyy riskejä. Tulokset ovat varsin herkkiä keskimääräiselle hehtaarikohtaiselle siementuotolle (mänty). Lähitulevaisuudessa onkin syytä panostaa menetelmiin, jotka takaavat riittävän suuren siementuoton, ja jotka eivät kuitenkaan heikennä oleellisesti saavutettavissa olevaa jalostushyötyä. Lisäksi, analyysien *erotus*hyödyt pohjautuvat *ex ante*-laskelmiin odotettavissa olevista jalostushyödyistä, sillä toistaiseksi ei ole käytettävissä jälkeläiskoetuloksia, jotka kattaisivat koko kiertoajan. Edellämainittua riskiä on kartoitettu vaihtoehtoisilla jalostushyödyn arvioilla ja kasvumalleilla (mänty: MELA, Vuokila & Väliaho).
Erot laskentakorkokannoissa puulajien välillä johtuvat pääasiallisesti siitä, että tulevaisuuden vuotuiset metsänviljelypinta-alat pohjautuivat puulajeittain eripituisiin aikasarjoihin. Rauduskoivulla

valitun aikasarjan voidaan katsoa olevan "epäsuotuisa" sisältäen 1970-luvun alkupuolen lukuarvoja, jotka laskivat selvästi vuosikeskiarvoa. Toisaalta, rauduskoivun siemenviljelyssiemenelle laskettu korkea kilokohtainen NNA implikoi mahdollisuudesta kohdentaa valtion tukea tehokkaammin. Vuotuisen tuen käyttöä voidaan tehostaa (yhteiskunnan näkökulmasta) esimerkiksi kehittämällä entistä tarkempia menetelmiä siemenen kysynnän ennustamiseksi. Tähän tarjoaa mahdollisuuden myös viime vuosien aikasarjamallinnuksen menetelmällinen kehittyminen. Tutkimustulosten mukaan Pohjois-Suomea varten perustettavien männyn siemenviljelysten kannattavuus (Osatutkimus 3) on selkeästi huonompi kuin Etelä-Suomen vastaavien. Kannattavuusero johtuu monista seikoista, joista muutamia on perusteltua nostaa tässä yhteydessä esille. Ensinnäkin, kloonien valinta uusiin männyn ns. valiosiemenviljelyksiin perustuu Etelä- ja Keski-Suomessa kasvuun ja laatuun kun taas Pohjois-Suomessa panostetaan viljelyvarmuutta. Voidaankin sanoa, että edellämainitut eteläisen Suomen jalostustavoitteet (kasvu ja laatu) edesauttavat kannattavuutta enemmän kuin viljelyvarmuus, jonka rahamääräinen arviointi on jo itsessään vaikeaa. Toiseksi, Pohjois-Suomen valiosiemenviljelyksille käytettiin pienempiä jalostushyödyn arvioita kuin Etelä- ja Keski-Suomen vastaaville.
Männyn siemenviljelyssiemenentuottajalle valtion subventio on siementä tuottamattomassa vaiheessa ehdoton edellytys liiketaloudelliselle kannattavuudelle (Osatutkimus 4). Ilman valtion tukea kannattavuus on negatiivinen jo varsin pienillä laskentakorkokannoilla. Toisaalta, nykyisillä männyn siemenviljelyksillä on vielä skaalaetuja hyödyntämättä, sillä viime vuosina on jätetty keräämättä osa siemenviljelyksien käpysadoista. Alueellinen epätasapaino siemenviljelyssiemenen tuotannossa johtuu puolestaan taustapölytysongelmasta - siementä ei aina voida käyttää alkuperäisillä kohdealueillaan. Rauduskoivun nykyinen siemenviljelystuotanto on liiketaloudellisesti kannattavaa (Osatutkimus 4). Pääasiassa hyvä kannattavuus on seurausta siitä, että viljelyksen siementä tuottamaton ajanjakso on oleellisesti pienempi kuin männyllä, ja toisaalta muovihuoneviljelyksiä voidaan kontrolloida huomattavasti tarkemmin kuin avomaan vastaavia.
Yksityisen metsänomistajan on varsin perusteltua käyttää männyn kylvössä siemenviljelyssiementä (Osatutkimus 5), kunhan *hehtaarikohtainen* kylvökustannusero siemenviljelyssiemenen ja metsikkösiemenen välillä ei keskimäärin nouse yli 300-800mk:n. Vaihteluvälin alarajalla (300mk) voidaan käyttää jopa 8%:n laskentakorkokantaa jalostushyödyn ollessa 10%.
Kokonaisuudessaan tulokset implikoivat nykyisenkaltaisen valtion subvention olevan yhteiskunnan kannalta varsin perusteltua. Lisäksi, yhteiskunnalle on odotettavissa *Pareto*-parannuksia siirryttäessä nykyisistä siemenviljelyksistä (Osatutkimus 1) seuraavaan sukupolveen (Osatutkimus 2).Tuki on nykymuodossaan mahdollistanut myös siemenviljelyssiemenentuottajalle liiketaloudellisesti kannattavan toiminnan. Kun edellämainittuihin lisätään se, että yksityiselle metsänomistajalle näyttäisi olevan perusteltua käyttää siemenviljelyssiementä kylvössä (mänty), niin voidaan todeta, että kaikille kolmelle agentille on kannattavaa toimia metsänjalostuksen parissa. On syytä kuitenkin painottaa, että osatutkimusten tulokset pohjautuivat arvioihin mahdollisesta jalostushyödystä - vasta *realisoituneiden* ja *kvantifioitujen* jalostushyötyjen avulla voidaan luotettavasti *ex post* selvittää suomalaisen metsänjalostuksen kannattavuus. Tätä ennen on päätöksenteossa tyydyttävä approksimaatioihin, *ex ante*-laskelmiin ja moniulotteisiin herkkyysanalyyseihin - kuten tämä tutkimus.

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LIST OF APPENDICES

Genetic gains and tree breeding

Genetic improvement of forest tree species is traditionally based on selection of superior individuals and their crosses in seed orchards. The principle is that the breeding value of selected individuals will be better than the average value of individuals in the population as a whole (e.g. Falconer & McKay 1996). Genetic testing is necessary for any successful tree improvement program. It lays the foundation for genetic decisions involving management of seed orchards and provides the material and information that will be the basis for advanced-generation tree improvement efforts (Zobel & Talbert 1984). In most breeding programs, genetic data are used to rank parents for their breeding values and help choose candidates for selection (White & Hodge 1989). An important task in any breeding program is to identify the specific group of traits showing both high heritability and good correlation with the future economic value of trees (Haapanen et al. 1993, 1997).

All the genetic variation in wild stands is a result of recombination and natural selection in heterogeneous environments in space and time. Different populations may exchange genes that will increase genetic variation in the populations through gene flow. Due to differences in response to environmental factors i.e.genotype-environment interaction, genotypes differ in viability and fertility. They therefore contribute different numbers of offspring to the next generation (have different fitness values). This leads to selection on individuals and changes of gene frequencies. If the number of offspring contributed to the next generation is determined by human interest, selection is artificial (Wricke & Weber 1986). Such selection may be very different from natural selection, the latter favouring fitness, the former favouring yield (e.g. Wang 1996). In a breeding population of forest trees the variability in natural stands is packed by crossing and selection into individual trees in the form of improved genotypes (Zobel & Talbert 1984). The primary objective of an applied tree improvement program is to change the frequency of desired alleles that influence important tree traits in such a way that the improved plants are superior in performance to unimproved material. New genetic combinations are created by bringing together genotypes found in different natural stands. The genotypes are found through progeny testing, which allows estimation of breeding values and selection of parental trees based on the performance of their progeny. Of the combinations, the most useful genotypes are selected for use in future breeding work and practical forest cultivation (Wricke & Weber 1986). Progeny testing is generally the most expensive and risky phase of a tree breeding program. It is often also the most critical phase, largely determining the progress and profitability of breeding (Mikola 1993b). In practice progeny test trials are established in order to find out the breeding values of different plus trees (e.g. Venäläinen et al. 1994, Namkoong et al. 1988) and to calculate the overall genetic gains with regard to, e.g. monetary value (Fins & Moore 1984, Williams & deSteiguer 1990, Thomson et al. 1987, Venäläinen et al. 1996a) or growth potential (e.g. Hagqvist & Hahl 1998).

Usually breeders are confronted with the question of how much gain per generation can be sacrificed in the interest of saving time. By selecting some time before rotation age, often called early selection, one is able to shorten the breeding generation only at the expense of gain per generation, since performance of genotypes at young ages is imperfectly related to that at "maturity" (Lambeth 1980). With the common Finnish tree species the time lag between selection and rotation age is without exception very large. Correlated gain in the mature trait after selection on the juvenile trait, also called generalized predicted gain (Williams & deSteiguer 1990), is given by:

$$G = ih_j \, h_m {}^{r}G_{j,\,m} \sigma_{pm} \qquad [1]$$

where G= gain

i= selection intensity

h_j= square root of heritability at selection age j

h_m= square root of heritability at rotation age m

${}^{r}G_{j,m}$= additive genetic correlation between traits j, m

σ_{pm}= phenotypic standard deviation for trait m

Differential costs

The differential costs, C^{diff} of formula [2.1] can be derived from the following:

First setting:

$$f_g(C^{so}, C^{co}, C^{ex}, C^{cu}, C^{ma}) = \sum_{l_1}^{L} C_l^{so} * (D_p)^l + \sum_{n_1}^{N} C_n^{co} * (D_p)^n$$
$$+ \sum_{m_1}^{M} C_m^{ex} * (D_p)^m + \sum_{k_1}^{K} C_k^{cu} * (D_p)^k + \sum_{z_1}^{Z} C_z^{ma} * (D_p)^z \qquad [1]$$

where $f_g(C^{so}, C^{co}, C^{ex}, C^{cu}, C^{ma})$= cost function for seed orchards

C^{so}= annual establishment costs, management costs and progeny testing costs of the seed orchards

C^{co} = annual collection costs of the cones in seed orchards

C^{ex} = annual extraction costs of the seed orchard cones

C^{cu}= annual cultivation costs of improved stands

C^{ma} = annual management costs of improved stands (including e.g thinning costs of saplings, harvesting costs)

D_p= discount factor (see Table [2.1])

, and:

$$f_0(C^{co}, C^{ex}, C^{cu}, C^{ma}) = \sum_{n_1}^{N} C_n^{co} * (D_p)^n + \sum_{m_1}^{M} C_m^{ex} * (D_p)^m$$
$$+ \sum_{k_1}^{K} C_k^{cu} * (D_p)^k + \sum_{r_1}^{R} C_r^{ma} * (D_p)^r \qquad [2]$$

where $f_0(C^{co}, C^{ex}, C^{cu}, C^{ma})$= cost function for (normal) stand seed acquisition

C^{co} = annual collection costs of the cones in normal stands

C^{ex} = annual extraction costs of the normal stand cones

C^{cu}= annual cultivation costs of normal stands
C^{ma} = annual management costs of normal stands
(including e.g thinning costs of saplings, harvesting costs)
D_p= discount factor (see above)

Then *a priori* assuming that r > z (see e.g. Ahtikoski 1997). This indicates that possible higher e.g. harvesting costs of improved stands are (implicitly) offset by the lower discount factor due to the abovementioned unequality. In addition, it should be stressed out that the future costs are forecasted by the linear trend equation which further favours the applied procedure, given that the trend is increasing (as is the case in Finland: unit costs have rather increased than declined during recent years). It should be emphasized that explicit cost functions cannot be formulated due to inaccurancies related to the initial cost data at forestry board level. Cultivation costs are assumed to be identical for both alternative with the caveat that possible divergencies in direct sowing costs (Scots pine) are *at the aggregate level* only marginal. To some extent this is supported by the fact that at the forestry board level the areas sowed with either orchard or stand seed cannot even be identified leading eventually to situations where the unit costs of sowing cannot be separated either.

From the abovementioned reasoning it follows that the four terms on the right-hand sides of the equations [1] and [2] can be considered to be identical, leading to that $f_g(\cdot) > f_0(\cdot)$ by the amount which eventually stands for the term differential cost:

$$C^{diff} = \sum_{l_1}^{L} C_l^{so} * (D_p)^l \qquad [3]$$

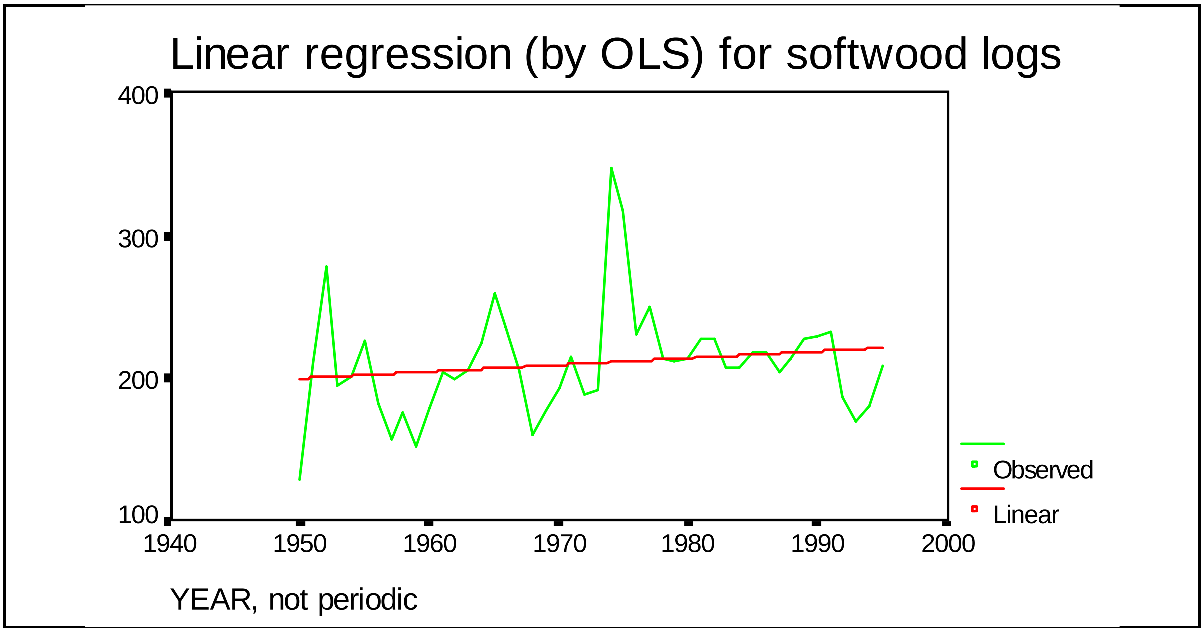
Stumpage prices as shadow prices

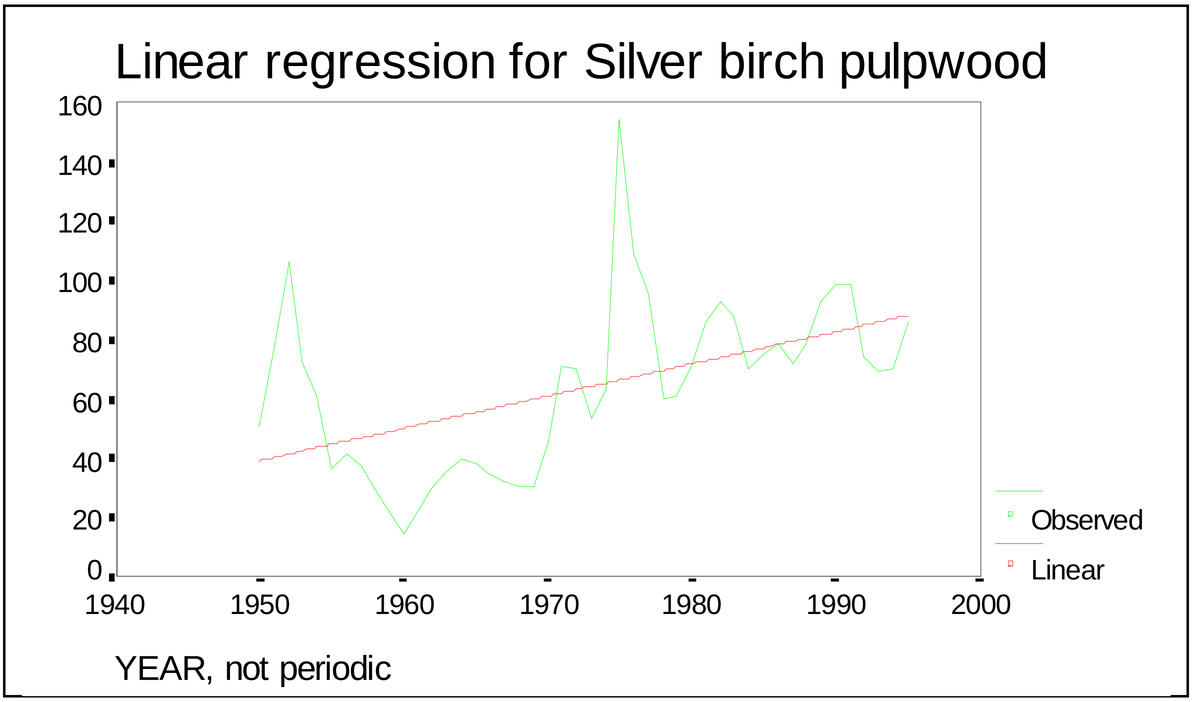
In the assessments made from the society's point of view shadow prices coincided with the stumpage (market) prices, although the roundwood market may not be competitive in Finland (Kuuluvainen & Mikkola 1993). On the other hand a recent study (Toppinen 1998) reported that there is no clear-cut evidence against the competitive market model, indicating that stumpage prices can be used as approximations for the equilibrium prices of the competitive market. However, most empirical modelling of the Finnish roundwood market is based theoretically on the perfect competition (Toppinen 1995), so it is impossible to say how sensitive the results are with respect to the assumption of perfect competition, let alone to that at present there are only a few significant buyers (indicating oligopolistic market structure), and that the forest industry has gained supernormal profits during the past few years (indicating that the industry might have been able to pay somewhat more for the wood) and that e.g. the fluctuations in the sawnwood export markets are efficiently carried into the Finnish sawlog market (Toppinen 1997).

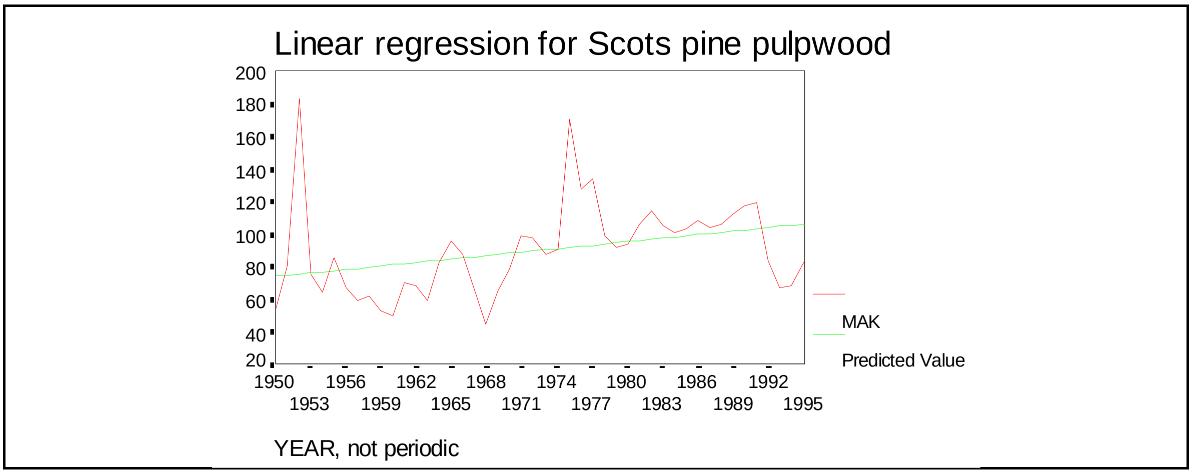
As from the abovementioned can be concluded there are arguments for and against the use of stumpage prices as social prices (i.e. shadow prices) as such, but in this dissertation the pros exceeded the cons. Primary, the use of stumpage prices as appropriate social prices is coherent with the initial problem setting of the thesis (bearing in mind that in the first place the analysis was limited to stumpage - tree breeding was assessed isolated from e.g. the wood processing industry).

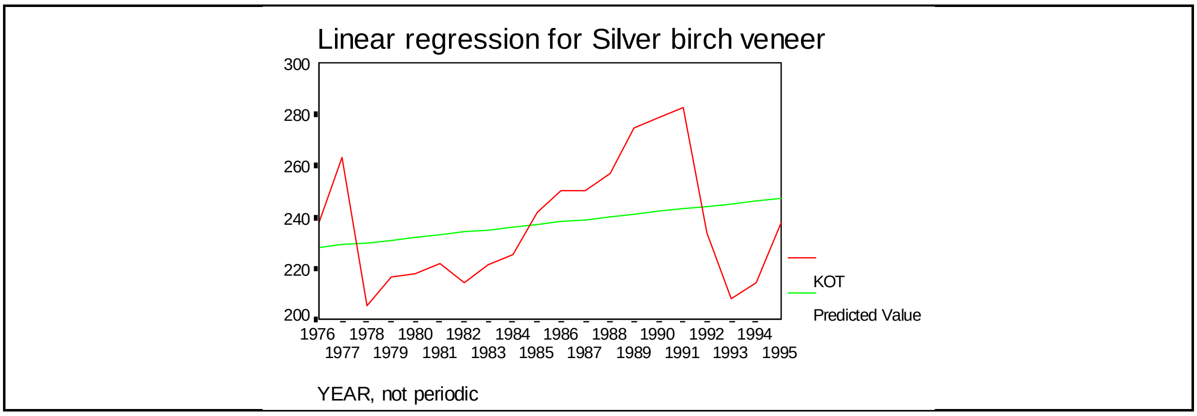
Time series, linear regression equations for forecasting future stumpage prices and costs.

FIGURES. Graphs on the linear regressions and sequence plots.






Linear regression for Scots pine pulpwood
200
180
160
140
120
100
80
60
40
20
1950 1956 1962 1968 1974 1980 1986 1992
1953 1959 1965 1971 1977 1983 1989 1995
YEAR, not periodic
MAK
Predicted Value


Linear regression for Silver birch veneer
300
280
260
240
220
200
1976 1978 1980 1982 1984 1986 1988 1990 1992 1994
1977 1979 1981 1983 1985 1987 1989 1991 1993 1995
YEAR, not periodic
KOT
Predicted Value

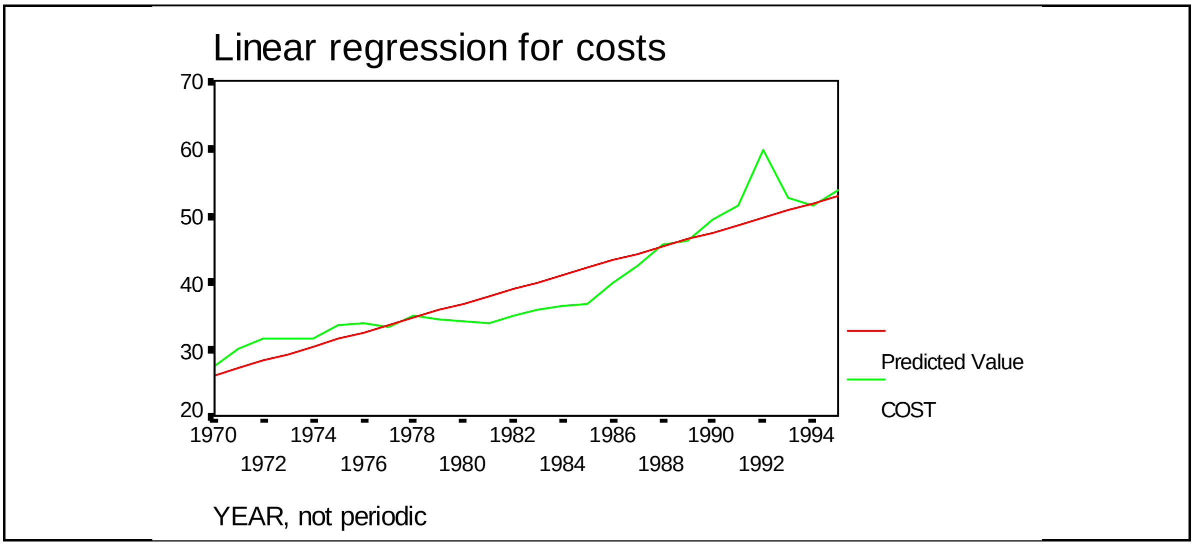

Linear regression for costs
70
60
50
40
30
20
1970 1974 1978 1982 1986 1990 1994
1972 1976 1980 1984 1988 1992
YEAR, not periodic
Predicted Value
COST

TABLE. Linear regressions (OLS) for forecasting. In each study, after the year 1995 annual stumpage prices and differential costs were forecasted by these linear regressions. Standard errors are presented in parenthesis below the coeffcients. R^2s are presented in bold. $COST_t$= cost (dependent) at year *t*, $STUMP_t$= stumpage price (dependent) at year *t* according to the equation, $YEAR_t$ = actual year (independent). (Note: the application of softwood logs for forecasting the future values of Scots pine sawlogs, and the method for forecasting future differential costs are discussed in more detail in Chapter 2.4).

Time series	*Time horizon for observations*	*Linear regression (by OLS) equation*
costs	1970-1995	$COST_t$ = 1.068198*$YEAR_t$ - 2078.133 (0.089) (176.609) **0.86**
Softwood logs	1950-1995	$STUMP_t$= 0.475093* $YEAR_t$ - 726.284512 (0.426) (840.363) **0.03**
Scots pine pulpwood	1950-1995	$STUMP_t$= 0.711788* $YEAR_t$ - 1313.66 (0.303) (598.46) **0.11**
Silver birch veneer	1975-1995	$STUMP_t$= 1.010268* $YEAR_t$ - 1768.2214 (0.9244) (1835.46) **0.06**
Silver birch pulp-wood	1950-1995	$STUMP_t$= 1.085198* $YEAR_t$ - 2076.66056 (0.2758) (543.99) **0.26**

Due to poor statistical behaviour of the linear regressions auxiliary regressions were modelled. These regressions included dummies, and can be considered to be far more sophisticated (henceforth denoted as sophisticated model) than those presented in the table above. However, in this Appendix only one auxiliary model is presented (due to paucity) with relevant diagnostics. Observations for this sophisticated model of Scots pine pulpwood were, distinct from initial linear regressions, from 1950 to 1998.

Variable	*Coefficient*	*Std.Error*	*t-value*	*t-prob.*
Constant	61.260	4.7136	12.996	0.0000
dum52	117.58	15.842	7.422	0.0000
dum68	-37.001	15.455	-2.394	0.0211
dum 75	82.342	15.432	5.336	0.0000
dum92-93	-37.384	9.6955	-3.856	0.0004
Trend	1.1485	0.16870	6.808	0.0000

R`y = 0.742885   F(5, 43) = 24.848 [0.0000]   å=15.2528   DW=0.852 RSS=10003.90191

AR 1 - 2F (2, 41) = 9.9254 [0.0000] **

ARCH 1 F (1, 41) = 5.3518 [0.0258] *

Then, model validation was tested for both the original linear regression and sophisticated model. It was expressed by *relative bias*, and it was calculated according to the following formula (see e.g. Hynynen 1995):

$$RB = \sum_{i=1950}^{1995} \left[(y_i - \hat{y}_i) / \hat{y}_i \right] \Big/ n \qquad [1]$$

, where RB= relative bias

y_i = observed value of *i*:th observation (Scots pine pulpwood stumpage price)

$\hat{y}_i$ = predicted value of *i*:th observation

n = number of observations (here n=46)

For the original Scots pine pulpwood model the relative bias (between 1950-1995) was 0.013, and 0.021 for the sophisticated model (incl. dummies). These figures indicate that both models underestimate the stumpage prices within that time horizon. In addition, the relative bias between these two models was tested, resulting in that the sophisticated model underestimated the stumpage prices by 5.9% when compared to the model predictions of the original linear model. In each case the relative bias can be considered to be moderate.

Table. Procurement costs of the land for present Scots pine seed orchards. Due to inaccurate original contracts of sale the figures are based on only 10 purchase prices between 1971-1974 assuming that the rest of the purchase prices would have adhered to these realized prices. The average purchase price was FIM 2 646 per hectare (in 1972 money value). This figure was applied in order to attain annual total costs of procurement between 1965-1974. (Note: here is presented only app. 2 500 hectares instead of total of 3 000 seed orchard hectares).

Year	Total cost of procurement, FIM
1965	432 092
1966	322 018
1967	586 883
1968	903 874
1969	311 434
1970	879 266
1971	982 460
1972	786 920
1973	662 823
1974	735 853

Table. The proportions of input categories in each key or sub activity, Scots pine Study 1.

Key or sub activity	labour	intermediate non-trated goods	contrac-tors' fees	rents (real estate)	land	"miscel-laneous"	total
Procure-ment (sub)	10%				90%		100%
Establish-ment (key)	26%	6%	60%			8%	100%
Progeny testing (key)	80%	5%				15%	100%
Annual manage-ment (key)	40%	5%	50%			5%	100%
Cone col-lection (sub)	30%	5%	60%			5%	100%
Admini-stration (key)	68%	4%		8%	5%	15%	100%

Shadow prices of the inputs, Studies 1, 2 and 3

Labour

In Finland, trade unions have a considerable role in wage determination. Further, the unionization rate in agriculture and forestry is high, approximately 80% (Santamäki-Vuori & Parviainen 1996) which suggests that the so-called insider and outsider factors (see, e.g., Solow 1987) could have a relevant effect on the wage determination in Finland. This is supported by a recent study from Kauhanen (1998). Thus, corrections of market wages are called for.

The labour force was divided into two groups: "semiskilled" labour and "specialized" labour. The shadow prices for these two groups differed according to the assumption that semiskilled persons could be drawn from the involuntary unemployment and specalized persons could work elsewhere. The shadow wage rate of semiskilled labour was estimated to be 0.65 times the market wage rate, i.e. approximately the same as the unemployment benefit in Finland. As a starting point for the shadow wage rate of specialized labour the value of 0.8 was applied. Both coefficients (0.65 and 0.8) entail a connotation that the effect of trade unions on wage determination is taken into account. The higher value for specialized labour merely indicates better opportunities to find another job (i.e.higher opportunity costs involved). After shadow pricing, income taxes and social security payments were excluded. The average tax rate for semiskilled labour was 27% and for specialized labour 33% (Tilastokeskus...1997).

Intermediate goods

The short rule for pricing intermediate goods is that they should be valued at marginal social cost (Pearce & Nash 1989). The category of intermediate nontraded goods here was wide, including for example building materials, office equipment, elk fences, tools, fence poles, fertilizers, detergents and lubricants. However, because the intermediate nontraded goods formed at most only about 5% of the total costs in each subactivity, the same principles were applied in the shadow pricing to all goods in this category, although there were differencies with regard to prevailing market structures. It was assumed that all the intermediate goods were sold in oligopolistic markets where prices exceeded marginal costs with the extent that price adjustment mechanism was needed. In addition, because most of the goods included some sort of tax (e.g. from 1995 a value added tax, VAT, 22%) the tax was subtracted from *all* the goods prices before shadow pricing them. The estimated shadow prices were 0.7 times the market prices, and a sensitivity analysis on different price levels was conducted.

Contractors' fees

In some subactivities (e.g. initial establishment, management of the seed orchards) the contractors' fees resulted in a large proportion (30% to 60%) of the total costs. The fees included a tax which was removed before shadow pricing. The contractors' fees were shadow priced by the following procedure. The alternative use for these contractors is most likely in agriculture to some extent, although all of them cannot be directed into that area (because some of them are already working as farmers, they are only "part-time contractors"). On the other hand, at the time of cone collections (autumn and early winter) there would not be much work in the farm, so the contractors would most likely be unemployment. Further, the fee paid in the seed orchards is presumably higher than the contractor could earn in agriculture or the unemployment benefit since otherwise some of the contractors would not have taken a second job as an enterpreneur in the seed orchards, but would have stayed in agriculture or unemployed instead. Thus an estimate (partly based on oral interviews) of the output forgone in agriculture is 0.8 times the market price of the contractor's fee. Another reason for this relatively high "salary" for a contractor (compared to the net salary in agriculture) is that among the contractors in the seed orchards there is an oligopolistic market structure, which leads to market prices (i.e. fees) exceeding marginal social costs.

Land

Theoretically the market value of the land required reflects the present discounted value of the future stream of benefits that could be obtained from the land in its next best use. In this study it was clear that the opportunity cost of the land should be valued as the output forgone in agriculture. The market prices of arable land are said to reflect well enough the future stream of benefits in Finland (e.g. Kiinteistöjen...1996). Thus the opportunity cost was the market price of the arable land, which was estimated to be the same as the value of the average purchase price of the land

(FIM 12 000 /hectare) in the provinces where the land was bought, i.e. the shadow price and the market price of land were identical here. On the other hand, there has been a tendency for the market prices of arable lands to decrease during the past ten years (Kiinteistöjen...1996), and this might have the effect of reducing the market prices as well as opportunity costs in the near future.

Rents

The opportunity cost of rents on properties in terms of some forgone alternative is estimated by assuming that the properties could be rented for purposes other than seed orchard activity *at the same* prices. By other purposes here is meant for example companies in other branches of industries which demand the same office buildings for renting. The market in which office buildings are supplied for renting in Finland is considered oligopolistic in the sense that there are relatively few actual suppliers, and this usually leads to market prices exceeding the social marginal costs. On the other hand, when evaluating the opportunity costs the next best alternative is what really matters, and in this connection the next best alternative is to rent the office building to another company at the same price. Thus here the shadow prices of the rents equalled their market prices.

"Miscellaneous"

This category included those services and "goods" which could not be divided into the existing input categories (e.g. labour, land, intermediate goods). The costs in this input category were the most heterogeneous, including for example employees' advanced training costs, recreational services costs, carage service costs, heating costs, water and waste water payments, printing costs and employees' health care costs. The market structures of these services and "goods" also differed widely, from a pure monopoly (carage services) to "perfect" competition (recreational services, advanced training). However, it was assumed that all the firms which supply the inputs (services and "goods") to the seed orchard activity fail to price at marginal costs, and thus price adjustments were needed. A relatively modest estimate on the shadow price was applied (0.7) due to the fact that in some markets of this category there was monopoly power involved. On the other hand, the major part of the total costs in this category (approximately 60-75%) occured under "perfect" competiti-on. Thus, a sensitivity analysis was conducted in order to find out how sensitive the final results were to shadow pricing procedure. In addition, difficulties arose in removing the transfer payments, because in the cost database (Tietopankki 1996): some of the services and "goods" included taxes and some did not. Thus a conservative estimate of the effect of taxes was included in the process by setting the average tax rate at 20%.

Genetic gain estimates for Scots pine's present and next-generation seed orchards

There are more than 1 300 progeny test trials of Scots pine (Pinus sylvestris L.) mostly long-term field tests (e.g. Mikola 1984) in conventional plantation forestry conditions, covering nearly 2 000 hectares (Yrjänä-Ketola & Karvinen 1997). However, the genetic gains (and breeding values of different plus trees) are last assessed by Venäläinen et al. in 1994 according to only 190 progeny test trials in breeding zones 1-4 (see breeding zones in e.g. Venäläinen et al. 1994, p. 16)

Venäläinen et al. (1994) studied the survival, height growth rate and so-called height sum of Scots pine plus tree progenies compared to reference material originated from natural stands. A height sum usually describes better the possible total yield than a height growth rate alone, because it also takes into account the survival of the seedlings (e.g. Marklund 1981). The survival of the plus tree progenies exceeded that of the natural stand progenies by 3.5%, and the height sum was 7.2% higher (Venäläinen et al. 1994). With progeny test results as a guide, the **3%** and **7%** were used as estimates for the possible genetic gains in stem volume in the assessments of present-generation (phenotypic) seed orchards. In addition, another figure, **10%** was introduced as an upper-limit, because the progeny test results might underestimate to some extent the attainable genetic gains due to the background pollination, i.e. when female flowers of the clones in seed orchards are pollinated by the surrounding natural stand trees (Pakkanen et al. 1991, Venäläinen et al. 1994, Pulkkinen 1995).

For the attainable genetic gains of the next-generation seed orchards the basic procedure is that only the best 10-20% of the present 1st-generation plus trees (according to progeny test trials) are accepted for the phase 2 (so-called 1.5 generation) seed orchards (Mikola 1995). It has been estimated that possible gain in an annual growth rate (which is further composed of combined height and diameter growth rates) might be approximately 12% compared to the present seed orchards (Venäläinen et al. 1996b), and thus even more when comparing to normal, unimproved stands. The genetic gains of the next-generation seed orchards in this dissertation are estimated to be **8%**, **12%** or **15%**. Possible genetic gain in a form of better quality is ignored, although there are some preliminary quality measurement results (Venäläinen et al. 1996a, b) available.

Genetic gain estimates for Silver birch's present and next-generation seed orchards

More than 160 progeny test trials have been established in order to evaluate the gains of selection on the whole and breeding values of different Silver birch plus trees. The progeny test trials cover nearly 300 hectares in breeding zones 1-3 (see breeding zones in e.g.Pajamäki & Karvinen 1996, p. 9), and they are in most part set up as field tests (Finnish Forest Research Institute: Forest Genetic Register 1998, unpublished).

The breeding of Silver birch has proceeded faster than the breeding of Scots pine. Reasons for faster advance in Silver birch breeding are many: all seed orchards are in polythene greenhouses (Viherä-Aarnio 1994), i.e. there is practically no background pollination, less time is needed for seed production (e.g. Hagqvist et al. 1991, Koski 1991) which enables among other things more crosses in the same time period and generally more controlled management of seed orchards (e.g. Hagqvist et al. 1991, Viherä-Aarnio 1994). However, because of the unfavourable soil conditions and severe damage caused by mammal herbivores (elk, hare and vole) several birch trials have been destroyed (Viherä- Aarnio 1989, 1994), which lessens the reliability of the results to some extent. Generally, most of the progeny test results in Scandinavia show that the obtainable genetic gain in stem volume with present seed orchards is between 10% and 30% (e.g. Rosvall & Palmer 1988, Viherä-Aarnio 1989, Danell & Werner 1991, Hagqvist 1991, Hagqvist & Hahl 1998). However, the genetic gain, e.g. in form of veneer at the final cutting, will not be known until the oldest progeny tests reach an adequate size (Viherä-Aarnio 1994). The genetic gain in Central Finland is expected to be less than the corresponding gain in South Finland (Hagqvist & Hahl 1998) due to, e.g. different structures in seed orchards established for different breeding zones (multiclonal vs. biclonal seed orchards). After due consideration following genetic gain levels were applied: for present seed orchards 7% and 5%, 10% and 8% or 15% and 12%, for next-generation seed orchards 10% and 8%, 15% and 12% or 20% and 14% (in each pair, the first figure is applied to South Finland and the latter to Central Finland).

Table. By the year 2019 60% (10 460 hectares) of the total annual Scots pine sowing area in South and Central Finland (temperature sum > 950 d.d) is sowed with the improved material.

Year	sowing, ha	planting, ha
2010	870	1800
2011	1740	3600
2012	2610	5400
2013	3480	7200
2014	4350	9000
2015	5572	10800
2016	6795	12600
2017	8017	14400
2018	9239	16200
2019	10460	18000
2020	10460	19800
2021	10460	21305*

** In the year 2021 all the planted areas are cultivated (21 305 ha) with the next generation seed orchard seed.*

Table. The establishment, procurement and additional costs of Scots pine and Silver birch breeding, estimated according to the calculations of the Finnish Forest and Park Service (Lahtinen 1995) and recent experience of, e.g. the purchases of the land and establishments.

Additional costs	Scots pine	Silver birch
Estimated annual costs after 2010 (including administration, progeny testing and annual management): derived from the deflated annual costs of seed orchards between the years 1990-1995	FIM 5,422 million	FIM 2,071 million
The procurement of the land for new seed orchards	FIM 12,00 thousand / hectare	Not significant because the seed orchards are in polythene tunnels
The establishment costs of the new seed orchards (including fences, roads, grafting)	FIM 52,00 thousand / hectare	Approximately FIM 7,00 thousand per 1 000m ^{2} *

**The approximation is based on the assumption that new polythene tunnels are not established (Lepistö 1996) until the year 2005.*

Table. The proportions of the main inputs in "key activities" (k) and subactivities (s). The percentages in parentheses represent average tax rate on each input category. The tax rates can differ within the same input category depending on the prevailing circumstances.

activity / *input*	social security payments	*labour*	*intermediate nontraded goods*	*contractor's fees*	*rents*	*land*	*"miscellaneous"*	Total, %
procurement of the land (s)	3	5 (27%)				90 (10%)	2	100
initial establishment (s)	3	15 (27%)	5 (12%)	63 (27%)			14	100
grafting (s)	11	80 (27%)	4 (12%)				5	100
administration (k)	9	65 (33%)	2 (22%)		5		19 (22%)	100
annual management of the seed orchards (k)	11	44 (27%)	3 (22%)	31 (22%)			11 (22%)	100

MELA simulation program and genetic gains

In MELA simulation the material was processed before feeding into the MELA software so that the growing stands were transformed by Weibull function to mean taper curves by diameter class (Laasasenaho 1982) of *eight* description trees. In Finland, each tree in the National Forest Inventory (NFI) sample plots represents 2 m^2/ha (relascope factor 2) resulting in an average of *eight* trees per sample plot (Kilkki & Päivinen 1986). The Weibull function has been widely used to describe the diameter distribution of the trees (e.g. Cao & Burkhart 1984, Green et al. 1984, Kilkki et al. 1989, Hökkä et al. 1991). For the Weibull distribution, if the median diameter is known (median diameter is particularly measured in the NFI sample plots), one of the Weibull parameters can be estimated from the two other parameters and from the median diameter (Kilkki & Päivinen 1986). This makes the Weibull function applicable for the estimation of the basal area dbh-distribution.

The growth prediction (with genetic gain) under breast height (young stands, average height<1.3m) was separatively simulated from the growth prediction of the higher, i.e. h >1.3m, trees (Ahtikoski 1997). The effect of the genetic gain in young stands (trees <1.3m) was here taken into account by decreasing the achievement ages of breast height (Ahtikoski 1997, p. 242). This manner of proceeding indicated the possible faster growth rates in young stands cultivated with the orchard seed compared to those young stands cultivated with natural stand seed (e.g. Ackzell 1994, Venäläinen et al. 1994). The decreases of the achievement ages of breast height did not change the harvest scheduling models considerably, given the initial harvest criterion (Ahtikoski 1997, p. 242).

The effect of genetic gain on the growth of higher (older) trees was simulated by increasing the annual growth level according to the percentage reflecting the genetic gain (Ahtikoski 1997). The criterion for the thinnings (and final cut) was set by the Forestry Development Centre Tapio (Silvicultural recommendations 1989). The criterion was fulfilled when the basal area and the average height of the pine stand exceeded the standards. This criterion indicates mainly the silvicultural aspects, and did not mean that the net present value of the stand is optimized (cf. e.g. Pesonen & Hirvelä 1992, the "Faustman solution"; Löfgren 1995). Some of the initial parameters of MELA software were changed. These changes reflected more properly the regional differences in the silvicultural practices in Finland than the initial parameters (Ahtikoski 1997).

Table . Study material (Study 2) used in the MELA simulation. Standard deviation and number (n) of sample plots in each local unit are given in parentheses.

local unit	forest site type	number of stems per ha	height (meters)	breast diameter, cm	age (in years)
Hämeenlinna	MT (n=38)	1937 (792.4)	3.6 (1.13)	4.9 (1.58)	14 (3.25)
Hämeenlinna	VT (n=47)	2238 (1078.35)	3.9 (1.12)	5.2 (1.72)	15 (3.97)
Jyväskylä	MT (n=36)	1827 (488.50)	4.01 (1.01)	5.3 (1.60)	14 (3.0)
Jyväskylä	VT (n=44)	1950 (530.61)	3.9 (1.24)	4.6 (1.47)	15 (4.01)
Karstula	MT (n=28)	2018 (341.95)	3.8 (0.82)	5.2 (1.02)	14 (2.49)
Karstula	VT (n=46)	1571 (325.69)	4.2 (0.54)	5.6 (0.69)	16 (2.21)
Nurmes	MT (n= 24)	1771 (246.13)	3.3 (0.82)	5.0 (1.30)	13 (2.05)
Nurmes	VT (n=21)	1590 (341.91)	4.2 (1.04)	6.9 (1.22)	13 (2.83)

Figure. Growth regions 1-4, Scots pine.

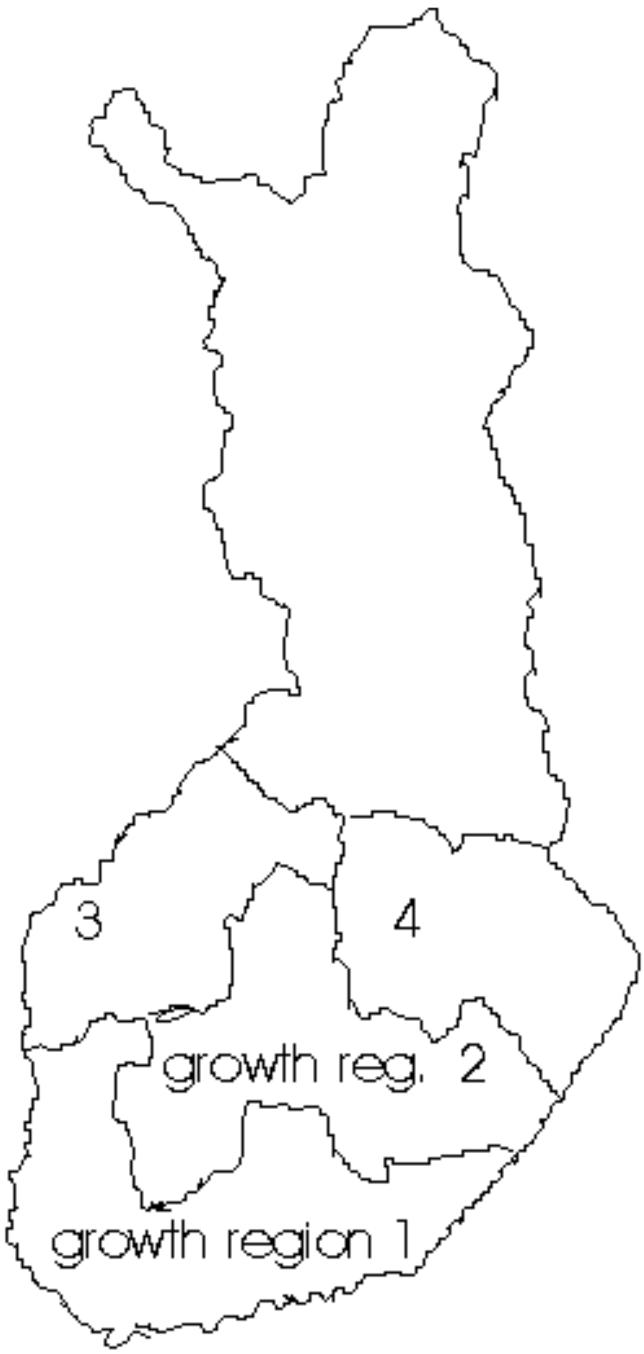


Table. The proportions of the growth regions in annual sowing and planting (Scots pine, Study 2), e.g., 27.2% of the annual total sowing area is sowed in growth region 2. Former forestry board districts (by numbers: see, e.g., Statistical yearbook...1995, p. 34) belonging to the particular growth region are given in parentheses. According to these percentages, the annual adjusted sales of the orchard seed were directed to the growth regions (in hectares).

Growth regions	Planting, %	Sowing, %
growth region 1 (1, 2, 3, 4, 6 and 8)	21.3	21.1
growth region 2 (5, 7, 9 and 12)	27.7	27.2
growth region 3 (13, 14 and 15)	31.4	28.0
growth region 4 (10 and 11)	19.6	23.7
growth regions 1-4	100.0	100.0

Supplementary analyses

The effect of harvest scheduling model on the NPV of next-generation seed orchards was examined by constructing two alternative models incorporated with genetic gains. First, the original MELA models (altogether 4* 2 different models) were altered by hypothetically assuming that genetic gain would affect harvest scheduling only through increasing outturns, leaving the times of thinning and final cut unchanged (denoted as "modified MELA"). Second, the assessments were recalculated with Vuokila & Väliaho's growth and yield models by increasing outturns of the harvest scheduling models with a percentage reflecting the genetic gain. The analysis, however, involved assumptions which should be studied in detail. Vuokila & Väliaho's (1980) region " Pohjanmaa-Kainuu" was equalled with growth region 4 (see Appendix 15), assuming that in Vuokila & Väliaho's models height index H_{100}= 21 m indicates on average *both* Myrtillus and Vaccinium type forests of Nurmes. Basically, this "drastic" assumption originates from the results in which the site classification system and height-over-age system are compared (Vuokila & Väliaho 1980, Table 2 on page 26).

The region "southern Finland" in Vuokila & Väliaho's models was equalled to combined area of growth regions 1, 2 and 3 (see Appendix 15), assuming further that pine forests in "southern Finland" grow on only two height indexes, H_{100}= 24m and H_{100}= 27m, the former indicating Vaccinium, the latter Myrtillus type. This resulted in that the region "Pohjanmaa-Kainuu" covered approximately 20% of the annually cultivated area, and 80% of the total hectares were cultivated in "southern Finland". In Vuokila & Väliaho's harvest scheduling models 25% average removal percentage in thinnings was applied (Vuokila & Väliaho 1980, pp: 208, 221, 231). In the sensitivity analysis of harvest scheduling models (modified MELA and Vuokila & Väliaho's models) only a 15% genetic gain was applied , because it can *a priori* be expected that the highest percentage of genetic gain results in the highest difference between the NPVs.

Furthermore, an analysis concerning the magnitude of the establishment was conducted. The initial purpose of the analysis was to examine how many hectares are required to be established in order to that the anticipated annual cultivation area (app. 32 000 hectares) is fulfilled by the orchard seed, given an annual average seed production of 10 kg/hectare. There were two underlying assumptions in the analysis. First, the calculations were based on the original time schedule with a 5-year postponing, and second, the annual total orchard seed production was assumed to be divided into seedlings and direct sowing by the following. 40% of the total annual orchard seed (expressed in kilograms) is directed to nursery planting (to make seedlings), and 60% to direct sowing in terrain. The percentages reflect the averages in Patama nursery between 1978-1995. In the calculations the principle was that when the annual planting area (21 305 ha) is fully supplied by the orchard seed, then each new seed orchard produces seed for direct sowing, given the original time schedule. The time horizon was the same as in the original assessment. Another purpose of the analysis was to examine how much the annual total costs (incl. administration, progeny testing and annual management) can be increased (within the original time period for costs: 1995-2035) in order to attain the annual average seed production of 10kg/ha so that the new NPVs would still break-even with the NPVs of the original assessment. The result would give insight about whether the increase in annual average seed production is worth pursuing in an economical sense.

Appendix 18

Compensation schedule between present and next-generation orchard seed, Silver birch

The production time of the next-generation seed orchards is estimated to last 17 years. The linear compensation between the present-generation and next-generation orchard seed takes 5 years. In South Finland the next-generation orchard seed starts to compensate the present-generation orchard seed in year 2004, and the present-generation orchard seed is fully compensated by the year 2009. In Central Finland, the compensation would not start until in 2010 (due to differences in seed orchard compositions), and in 2015 the present-generation orchard seed is fully compensated by the next generation. The total annual cultivation area is estimated to be app. 1 700hectares. Thus, in each year during the compensation period (5 years) the next-generation orchard seed compensates the present-generation orchard seed by app. 170 hectares in South and Central Finland ([1700/2] /5). In the light of present knowledge this compensation rate can be seen reasonable (see Män-nyn...1997).

Table. Proportions of the inputs in subactivities, Silver birch (Study 2). Key activities are presented in parenthesis. The percentages do not necessary add up to 100% due to the rough division into input categories and to inaccurancies in the initial book-keepings.

subactivity/input	social security payments	labour/ semiskilled	labour/ skilled	intermediate nontraded goods	"miscellaneous"
test maintenance (progeny testing)	16%	28%	45%	8%	5%
selection (progeny testing)	16%	23%	45%	5%	6%
crossings (progeny testing)	16%	28%	45%	3%	8%
roguing (annual management)	16%	28%	40%	3%	6%
fertilization (annual management)	16%	28%	40%	10%	4%
genetic thinning (annual management)	16%	28%	40%	5%	8%
artificial lightning (annual management)	16%	28%	40%	10%	3%
supervision (administration)	18%	22%	48%	3%	7%
planning (administration)	18%	22%	48%	3%	5%

Specific assumptions of Study 3

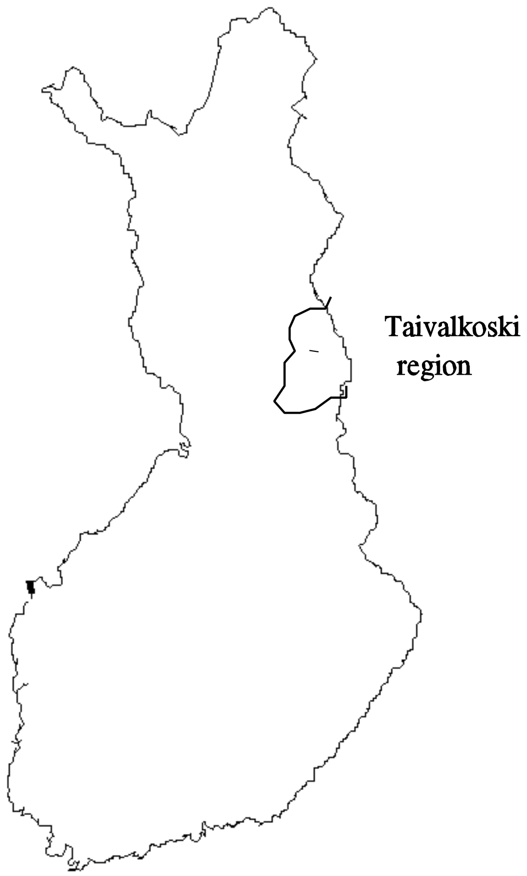
There were principally two underlying assumptions in the calculations. First, contradictory to the original report the annual average seed production was *not* fixed to 7kg/hectare (Männyn...1997), but varied instead between 5.8 and 6.7 kg/hectare. This was due to the following ground: the primary goal with regard to next-generation seed orchards is to ensure the annual seed supply within the time period of 2024-2045 (establishment year 1999 plus 25 years) so that *all* the seed required for nursery planting and *half* of the seed needed for direct sowing (Männyn...1997) would be produced by the seed orchards by the year 2045. The importance of seed supply was emphasized in this connection due to "chronic" lack of seed material in northern Finland during recent years (see, e.g. Salmi 1995). Second, the hectares between 2024 and 2045 were assumed to increase by the following: the total area, 15 107ha (planting 11 484 ha, sowing 3 623 ha), was divided by the amount of establishments which was 14 (modified from the original report; see Männyn...1997, p. 14, Table 5) assuming further that each establishment would increase the cultivation area by the same absolute figure *regardless* of the establishment area. This assumption can be considered to be reasonable with the caveat that along the establishment process, during 1999- 2020, the annual average seed production can be expected to increase due to e.g. experience and technical and biological innovations. Furthermore, the annual average seed production never exceeded 7kg/hectare.

In addition, in order to estimate the annual average seed crop (which was, however, not of the primary interest) the annual cultivation hectares were converted into produced seed by the following coefficients: seed-to-plantable seedling ratio was 1kg to 75 000 seedlings (indicating that 1kg of orchard seed suffices for 30 hectares, the planting intensity being 2500 seedlings per hectare), and 1kg suffices for 3 hectares in direct sowing (i.e. app. 330g of seed used per hectare). The seed-to-plantable seedlings ratio applied here was different than the figure in the original report (Männyn...1997). The figure used here was based on a recent inquiry (Ahtikoski 1996b) which indicated that higher than 50 000 seedlings from 1 kg are attainable due to a new "single seed patch" method. Contradicting a recent study (Ahtikoski & Pulkkinen 1998) it was further assumed that the same amount of orchard seed and stand seed was used in direct sowing.

Table. Tree stand characters of the young stands in Taivalkoski-region, Study 3. The number of sample plots and the standard deviations (SD) are presented in parenthesis.

forest site type	number of stems per hectare (SD)	height, meters (SD)	breast diameter, cm (SD)	age, years (SD)
Myrtillus (n=28)	1543 (394.08)	4.09 (0.80)	5.61 (1.21)	14 (2.05)
Vaccinium (n=24)	2036 (809.20)	3.05 (0.58)	4.77 (0.87)	12 (1.10)

FIGURE



LAC curves incorporated with past establishment and management costs, Scots pine

Past establishment and annual management costs were taken into account as combined fixed cost variable with 5 per cent interest rate. In practice the establishment and past annual management costs were prolonged to the base year 1997 and added to existing average costs. Prior to prolonging the costs were deflated by the wholesale price index. In this context the total amount of established seed orchards was 656 hectares (Lahtinen 1998), indicating the amount of "active" seed orchards (*n* > 30) which have produced the particular amount of orchard seed during 1993-1997. The combined fixed cost variable of establishment and annual management costs was formed by the following:

$$C_f = \left[\sum_{n=26}^{32} E_n (1.05)^n + \sum_{n=5}^{32} M_n (1.05)^n \right] \Big/ \sum_{t=1993}^{1997} KG_t \qquad [1]$$

where C_f = fixed cost variable, FIM/KG

E_n = establishment costs in year *n* so that "32" indicates the year 1965, FIM

M_n= annual management cost in year *n*, FIM

KG_t= the produced orchard seed in kilograms in year *t*

(1.05)= prolonging factor, discount percent 5

By applying formula [1] the past establishment and annual management costs could be directed so that their effect on the LAC was taken into account properly. It should be pointed out that formula [1] overestimates the long run average costs, because the realized costs of these producing seed orchards are taken into the calculations since 1965, but the produced seed only since 1993, although the particular seed orchards had produced meaningful amounts of seed also before 1993. However, long-run average costs with the fixed cost factor according to formula [1] can be considered as "upper boundary", and the procedure as sensitivity analysis.

An estimated market demand curve for Scots pine orchard seed

The sales from Patama nursery were estimated to correspond to approximately 75-80% of the total annual orchard seed demand in Finland (Myyntikirjauslistat...1995, Statistical yearbook...1990/91-1996). The sales data were based on several dozens of purchase events each year, 1993-1997. The prevailing unit prices (FIM/kg) were expected to be the same as the prices of Patama nursery due to *price rationing* which occured, especially between 1993-1997, in Finland. Some restrictive limitations, however, had to be made in the calculations. First, orchard seed is purchased in different "vitality classes" which each indicate different quality and thus different price, although all the seed go through the same manufactoring process (only one exception, which does not include large seed lots). Strictly speaking, these different vitality classes should be considered as different products, but the relaxation of this fact in this context does not alter the results essentially. In this study only the *two* most demanded vitality classes in each year were taken into account. By taking more than two vitality classes into the calculations would have resulted in even more hypothetical demand curve (cf. Parkin 1997) than the one obtained here. These two most purchased vitality classes in each year included approximately 75-90% of the total amount annually sold from Patama.

Secondly, the unit prices for the *two* vitality classes were estimated according to the majority of the prevailing purchase prices in those classes (the price was not homogeneous within a class). Then, the sold quantities of the two vitality classes (">95%" and "91-95%") were summed up, and further combined with the *weighted* (by quantity demanded) unit prices so that quantities would correspond to prices: a demand curve for Patama sales was constructed. In this connection, the approximation of demand curve was seen as a sufficient expedient - furthermore, a formal modelling would have required much more detailed data set, and given the accurary of sales book-keepings it appears that satisfactory modelling could not have been even possible to conduct. A linear fit (OLS method; e.g. Koutsoyiannis 1981) for the demand function was used for simplicity.

Finally, a market demand curve for Scots pine orchard seed was estimated by *shifting horizontally* (e.g., Varian 1987) the calculated demand curve (indicating the sales from Patama) *by 100%*.

Technically, this was conducted by halving the β coefficient ($Y = \alpha + \beta x$). The underlying assumption was that these two vitality classes of Patama correspond a half of the total annual demand of Scots pine orchard seed in Finland.

Due to the fact that the constructed demand curve was hypothetical (in a sense that no *actual* vitality class corresponded to the weighted price) the price elasticity was evaluated for the two vitality classes separately.

Table. Initial quantities of the two most purchased vitality classes and weighted unit prices of Scots pine orchard seed in 1993-1997 from Patama Seed Centre. Unit prices were deflated according to the base year 1997 by the wholesale price index of domestic goods.

Year	*1993*	*1994*	*1995*	*1996*	*1997*
quantity demanded	967.6 kg	1204.1 kg	1034.9 kg	831.7 kg	1102.4 kg
weighted[1] unit price	1936.9 FIM/kg	1551.6 FIM/kg	2163.3 FIM/kg	2517.9 FIM/kg	2311.4 FIM/kg

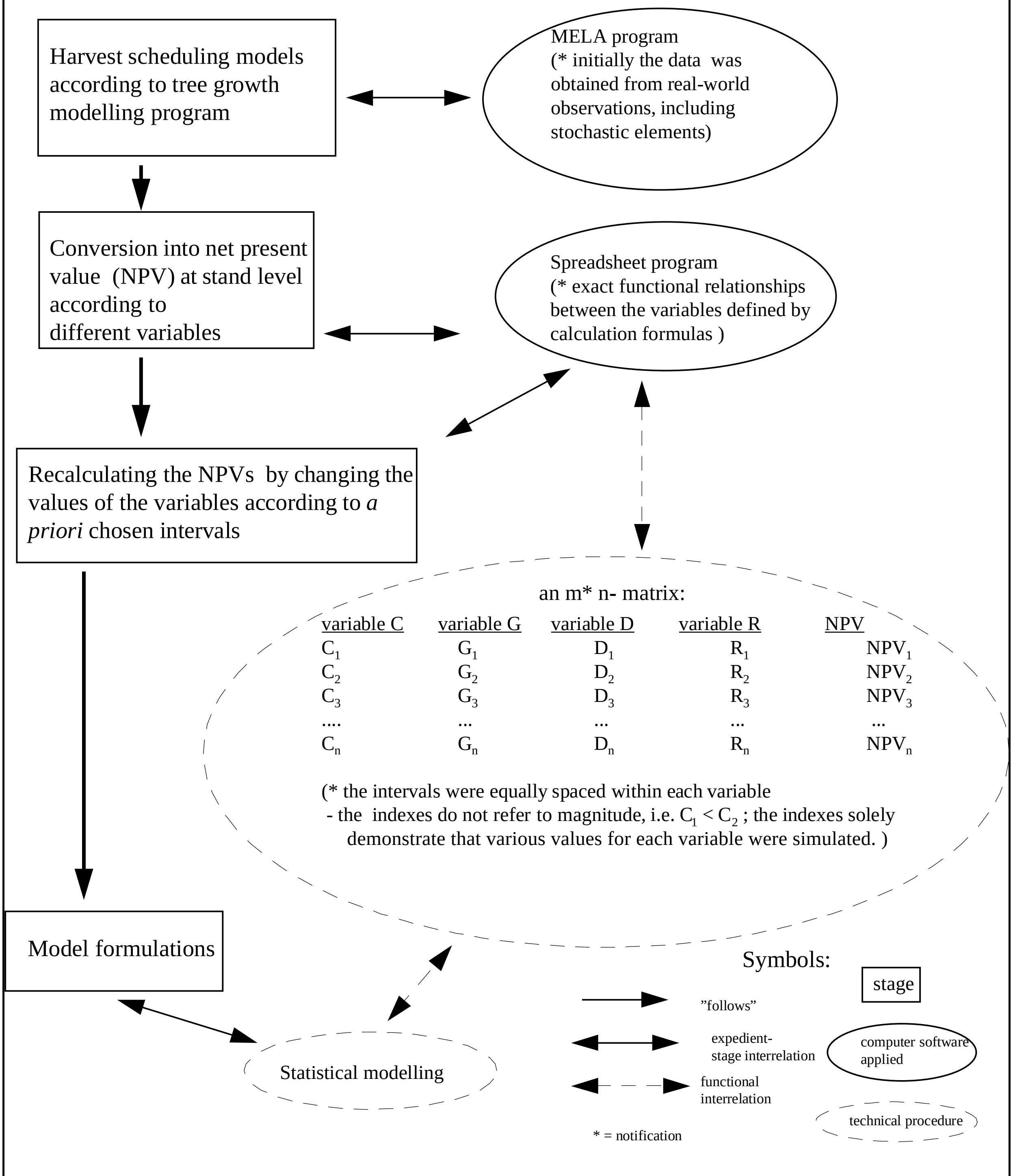
1 For instance, in 1993, 631kg of vitality class ">95%", and 336.6kg of vitality class "91-95%" were demanded, the deflated unit price for the former being 2003.4 FIM/kg and 1812.6 FIM/kg for the latter <--> [(631/967.6) *2003.4 + (336.6/967.6) * 1812.6 = 1936.9]

An estimated market demand curve for Silver birch orchard seed

Each year (1992-1996) only the most purchased vitality class of Haapastensyrjä Breeding Centre was taken into the calculations, and the average price (deflated by the wholesale price index) was estimated according to the "majority price" (also Silver birch's seed prices in each vitality class were not homogeneous) linked with that vitality class. Then these average unit prices were combined with the corresponding quantities in order to form a demand curve. This procedure was more simplistic than that of Scots pine, but was considered to give a sufficient approximation on orchard seed demand.

A market demand curve for Silver birch orchard seed was estimated by assuming that the sales of Haapastensyrjä Breeding Centre would correspond to 60% of the total annual Silver birch orchard seed sales in Finland (Finnish Statistical...1997, Sales report 1998, unpublished).

A flowchart on the different stages and applied expedients in a process of calculating the effects of different variables on the NPV. Scots pine, Study 5. In Study 4 there were no underlying harvest scheduling models,; instead the modelling was based on spreadsheet calculations



Underlying limitations in the simulation procedure

The simulations for estimating the effects of various variables on NPV (Study 4) were conducted under the following restrictions. The discount rate fluctuated from 4% to 10% (with 0.5% intervals), the amount of collected cones required for 1kg orchard seed was from 130 litres to 180 litres (with 15 litre intervals), average seed crop varied between 6kg to 10kg per hectare (with 1kg interval), collection costs from FIM 6 to FIM 10 per litre (with 1 litre interval), annual management costs were from FIM 800 to FIM 1200 per hectare (with FIM 100 intervals), and selling prices changed from FIM 1900 to FIM 2700 per kg. The abovementioned costs and prices reflect the 1996 and 1997 levels, respectively, and it should be emphasized that the future costs and prices in the modelling process were forecasted according to the linear equations mentioned earlier.

Solving the profit maximization conditions, Scots pine

The profit maximization condition was examined by the following procedure: long-run marginal cost function was obtained from the long-run average cost function (formula [3.20]) by first multiplying it with output *x* and then differentiating the total cost function (f_{TC}). Formally for LMC:

$$f_{TC} = f_{LAC} * output \begin{aligned} &= (0.00047x^2 - 2.212744x + 3771.02) * x \\ &= 0.00047x^3 - 2.212744x^2 + 3771.02x \end{aligned} \qquad [1]$$

$$\Rightarrow \frac{df_{TC}}{dx} = LMC = 0.00141x^2 - 4.25488x + 3771.02 \qquad [2]$$

Long run marginal revenue (MR) function was obtained by multiplying the demand function (now reflecting the sales from Patama nursery) by quantity (x), resulting a total revenue function f_{TR}, and then differentiating it. The demand function (a linear approximation, R^2= 0.73, residuals checked visually from e.g. scatterplots) where the price was expressed as a function of quantity (so-called inverse demand function; e.g. Deaton & Muellbauer 1980, Varian 1987):

$$p(x) = -1.93747x + 4088.22347 \qquad [3]$$
$$\Rightarrow f_{TR} = p(x) * quantity = -1.93747x^2 + 4088.22347x$$

$$\frac{df_{TR}}{dx} = MR = -3.87494x + 4088.22347 \qquad [4]$$

Finally, equating the long run marginal cost function and marginal revenue function, a profit maximization point was found, i.e:

$$LMC \begin{aligned} &= MR \Leftrightarrow 0.00141x^2 - 4.25488x + 3771.02 = -3.87494x + 4088.22347 \\ &\Rightarrow 0.00141x^2 - 0.37994x - 317.2034 = 0 \end{aligned} \qquad [5]$$

Solving formula [5] for *positive* x gives x= 627.8 kg.

Table a. Parameter estimates (and their asymptotic standard errors) of formula [3.19].

Parameter	Estimate	Asymptotic standard error
α_1	-809.12	63.584
α_2	130 248	1064.5
α_3	-15 586.7	688.51
α_4	-59 778.4	2 136.1
α_5	89.914	4.122
α_6	-15.842	1.568

Table b. Asymptotic correlation matrix of the parameter estimates of formula [3.19].

	α_1	α_2	α_3	α_4	α_5	α_6
α_1	1.0000	-0.2345	-0.1822	-0.1822	-0.2445	-0.2009
α_2	-0.2345	1.0000	-0.2853	-0.1954	-0.3843	-0.2881
α_3	-0.1822	-0.2853	1.0000	-0.0752	-0.2445	-0.1845
α_4	-0.1822	-0.1954	-0.0752	1.0000	-0.1124	-0.0981
α_5	-0.2445	-0.3843	-0.2445	-0.1124	1.0000	-0.2335
α_6	-0.2009	-0.2881	-0.1845	-0.0981	-0.2335	1.0000

Parameter estimates and technical details of formula [3.20]

Table. Parameter estimates and their asymptotic standard errors, formula [3.20].

Parameter	Parameter estimate	Asymptotic standard error
α	-843.42	15.89
α_1	422.13	8.986
α_2	858.9	28.13
α_3	-0.928	0.031

There were alltogether over 700 simulated values for the NB. Technically, all the parameters in formula [3.20] were estimated simultaneously using an iterative nonlinear regression algorithm in SPSS software applying Marquardt's method with the convergence criterion set to 10^{-8} (SPSS 1994).The asymptotic correlation matrix indicated that the model was certainly not overparameterized; correlation coefficients fluctuating between -0.03 and -0.65 (cf. SPSS 1994).

In addition, a Goldfeld-Quandt test (e.g. Greene 1997) for homoskedasticity, a Durbin-Watson test (e.g. Greene 1997) for autocorrelation and also a Shapiro-Wilks test (e.g. SPSS 1994) for the normality of residuals were conducted.The null hypothesis in Goldfeld-Quandt test was that residuals are homoskedastic, i.e. with equal variance. First, approximately hundred simulated Net Benefits, NBs, ("observations") were omitted, and the remaining NBs were divided into two sub-samples of equal size according to discount rates (chosen here as an explanatory variable). Then, the sum of squared residuals for both sub-samples were obtained, and these sums were further compared in order to attain the F ratio. The F distribution had 82 degrees of freedom for both the numenator and denominator, and the observed F^* was compared with the theoretical value of F with 82,82 degrees of freedom. The null hypothesis (i.e. equal variances) was accepted with the signifigance level of 5 per cent.

Because Goldfeld-Quandt test assumes normality and serially independent disturbances (e.g. Koutsoyiannis 1981), the normality of the residuals was tested by Shapiro-Wilks test and the possible autocorrelation between the residuals was tested with Durbin-Watson test. In the latter, the sample residuals were used to compute the empirical value of Durbin-Watson statistic, d^* which was 1.79 indicating a slight positive autocorrelation. However, further analysis was not called for, because the test statistic was between 1.5 and 2.5 which is a rule of thumb for not applying further analysis with regard to autocorrelation (SPSS 1995).

The normality of the residuals was tested by Shapiro-Wilks test (abreast with graphic plots such as stem-and-leaf plot). The test resulted in a significance value of 0.745 which indicated that the assumption of normality was not violated (SPSS 1995).

Figure. Residuals (+/- standard deviations) of the model [3.20] plotted against discount rates.