Timber Production Possibilities and Capital Yields from the Norwegian Forest Area

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How intensely should a forest be grown? This is a fundamental question in the process of formulating policy guidelines for the management of a forest area, both at the individual property level as well as at the national level. The question is related to a number of factors; the objective(s) of the forest owner, the productivity of the forestland, the initial growing stock, the accessibility within the forest, assumptions regarding future prices and costs and the required real rate of return. This paper presents an applied analysis with the objective of mapping possible future paths for the growing stock on, and timber harvest from the productive forest area in Norway. The analysis is deterministic. The regeneration strategy is a key factor for the long run development of a forest and is thus given particular attention. The analysis is restricted to deal with timber production only and maximisation of the net present value of the forest area is used as the objective function. The required real rate of return is varied and used as the driving force to find the best (optimal) level of intensity in silvicultural management and thus optimal paths for harvesting and growing stocks.

Keywords timber production possibilities, rate of return, capital yield, forest management

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1 Introduction

How intensely should a forest be grown? This is a fundamental question in the process of formulating policy guidelines for the management of a forest area, both at the individual property level as well as at the national level. The question is related to a number of factors; the objective(s) of the forest owner, the productivity of the forestland, the initial growing stock, the accessibility within the forest, assumptions regarding future prices and costs and the required real rate of return ($\bar{p}_r$).

The regeneration intensity is fundamental for the long run timber production. When an even-aged stand is established an upper bound on the number of trees per area unit is given for the proceeding rotation. From a biological point of view, a large number of different regeneration options are available, from "pure" natural regeneration to intensive treatments of the land including e.g. site preparation, planting, weeding and other measures to control the number and composition of tree species. Regeneration conditions and results may vary with vegetation type, altitude, temperature, precipitation, dominating species and species composition in the previous timber rotation. The relation between the total volume production and the number of trees in a stand is one important factor in predictions of future volume production given different intensities in regeneration investments. Growth studies of Norway spruce (*Picea abies* (L.) Karst.) indicate that total volume production is moderately affected by changes in the total number of trees for a wide range of tree numbers (Braastad 1975). The regeneration lag, i.e. the time from final felling of an existing stand until a new stand is established, is another vital factor in predictions of long run timber production. An increased regeneration lag will ceteris paribus lead to decreased mean annual volume production for a timber rotation.

The other end of the chain of silvicultural treatments constitutes the final harvest. Key factors in this decision relates to expected timber price development, the biological vitality of the stand (i.e. growth and mortality) and $\bar{p}_r$. The forest economic tradition has typically studied questions related to the profitability of timber production at stand level, thus assuming that each individual stand can be managed independently of other stands in the forest. The forest planning tradition has typically been occupied with estimating harvest paths based on forest inventory data and growth and yield estimates. The concept of non-declining harvest flow has been central in this tradition. Emphasis has been on finding management strategies that could "guarantee" a certain, non-declining, level of harvest. Developments in computer technology have made possible a much more detailed representation for the forest area, compared with the situation only 15 years ago, facilitating analyses with greater richness in underlying assumptions.

Hofstad (1991) reports on an optimal control theory model for the determination of the optimal path from the initial state to an optimal steady state situation. Based on aggregate Norwegian data, he applies a simple logistic growth function, and assumes timber growth to be a function of the inventory. Demand is modelled as a downward sloping function of price, i.e. the value of the harvest is assumed to be a logarithmic function of the quantity supplied. Within this framework Hofstad (l.c.) is able to calculate the optimal harvest path through time and simultaneously determine the optimal level of inventory given the interest rate. An earlier, and similar approach is presented by Lyon and Sedjo (1983). They apply a discrete time optimal control model and solve it by means of a gradient search in order to establish the optimality conditions. The objective function they apply is the sum of consumers' and producers' surplus, which is maximised subject to the initial conditions and the dynamics of the forestry system. The model treats both the harvesting decision and decisions about the silvicultural investment level endogenously, i.e. it is capable of simultaneously determining the optimal steady state solution and the optimal path, within a predetermined time period, from the initial state to the steady state.

Nersten et al. (1982) analysed the timber production potential in Norway. Five different scenarios were defined, with different intensities in silvicultural management as well as different harvest paths. A heuristic algorithm was applied to solve the decision problems numerically. The study was based on sample plot data from the

Norwegian National Forest Inventory, aggregated to fairly few management units.

This analysis quantifies possible development paths for the productive forest area in Norway, south of Saltfjellet. The main emphasis is put on studying consequences for future timber production of varying the intensity in the silvicultural management. We assume that the forest will be managed with an even-aged silvicultural regime; timber production is the only output considered and the analyses are done at forest level. The study is based on a detailed description of a large forest area, thus rendering possible a fairly detailed representation of the variation in key factors in forest management decisions. The paper is organised as follows: The next section first discuss the economics of regeneration briefly, and then presents the data, assumptions and methodology of the study. After that, the results from the analysis of timber production potentials on the productive forest area of Norway are presented. The main uncertainties of the study are discussed and finally conclusions are drawn.

2 Material and Methods

2.1 Regeneration Investments

From an economic perspective, the appropriate level of intensity in silvicultural management, such as regeneration, is crucially depending on $\bar{p}_r$. The issue have been treated by a number of authors; see e.g. Johansson and Løfgren (1985) or Chang (1983, 1998). Changes in $\bar{p}_r$ will impact the management of the current growing stock, as well as the level of intensity in regeneration and management of new stands. Forests have the unique attribute of being able to regenerate naturally. Given that a naturally regenerated stand, if left unmanaged, at some future point in time will have a positive stumpage value, the net present value of the land will be positive for any strictly positive, $\bar{p}_r$. This value represents a pure profit (economic rent) if the cost of land is set equal to zero. Alternatively, it represents the value of land in timber production when all other input factors are paid at competitive market prices. This (residual) value represents a lower bound on the value of forestland. If a more intensive management program is applied, this should generate a higher land value, compared with the ‘no input’ land value, to be defensible economically. We will use a graphical illustration from Svendsrud (1990) to discuss the economically efficient intensity in regeneration investments.

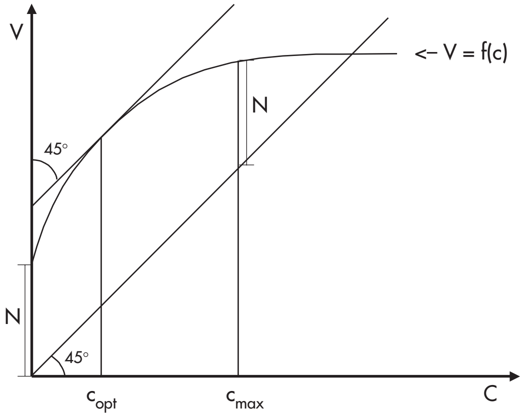

Fig. 1. How much should be invested in stand regeneration efforts? (Based on Svendsrud 1990). Explanations given in the text.

The curve V gives the present value or expectation value, of a timber stand immediately after establishment. V is given as a function of the level of investments, c, in regeneration operations and it is assumed that the investment expenditures are used efficiently. When c equals zero, this implicitly means that a stand is established naturally and N gives the present value of this option. Since investments are assumed to occur immediately, we can map c (as an investment cost line) in terms of V as the straight line with a 45° angle starting from origo. Thus the net value of land is V – c. In Fig. 1 this value increases as regeneration expenditures are incurred. The optimal level of investments is indicated by c_{opt}, where marginal revenue equals marginal cost, thus the last unit invested in regeneration obtains a profitability exactly equal to $\bar{p}_r$. At c_{max} the level of investments is so high that the net land value is brought down to N, thus no extra profit is gained by the regeneration efforts. When V intersects with the cost line, the net present value (NPV) of the established stand is zero. In this case the level of investment is far too high since the value N, i.e. the pure profit or land value that could be obtained assuming natural regeneration, is foregone. We implicitly assume that the marginal profitability of regeneration investments is declining, as can be seen from the proposed curvature of V in Fig. 1. The shape of the curve V (and the size of N) will i.a. be affected by $\bar{p}_r$. An increase in $\bar{p}_r$ will reduce the size of N and make the curvature of V more flat. At a certain $\bar{p}_r$, the slope of V will be less than 1 even when c approaches 0, thus implying natural regeneration to be the best choice.

2.2 Data and Assumptions

The sixth national forest inventory was carried out in Norway in the period from 1986 to 1993 (Statistics of … 1993). The sample plots from this inventory are used to explain the initial state of the forest area. 24 077 sample plots were measured on productive forestland. Mainly due to computational limitations the sample plots were aggregated into 10 000 management units (1000 in each of 10 regions) by using cluster analyses. Ten variables were used in the clustering procedure and they represent the explanatory variables in the diameter growth function, variables used for calculating logging costs, vegetation type and altitude.

The computations were done with the forestry scenario model Gaya-JLP. This model applies standard methodology (Johnson and Scheurman 1977, Garcia 1990, Siitonen 1993) of simulating treatment schedules (Gaya) for each management unit (Hoen and Eid 1990, Hoen and Gobakken 1997) and solving the management problem at forest level (JLP) by linear programming (Lappi 1992). Projections of the forest development, and the corresponding economic calculations, were provided by using a stand growth model

Table 1. Forest area in 10^3 hectares and volume of growing stock in $10^6\,m^3$ grouped in site index classes and development-classes after aggregation into 10 000 management units.

Site quality class (H$_{40}$ – m)	Development-class						
	I	II	III	IV	V	Sum	%
	Forest area (1000 ha)						
6	16	39	25	180	376	635	10
8	87	287	70	450	490	1385	22
11	93	407	221	459	499	1678	26
14	83	389	289	236	289	1286	20
17	69	170	316	136	147	838	13
20	29	83	131	115	85	444	7
23	21	19	63	36	12	152	2
Sum	399	1395	1114	1612	1898	6418	100
%	6	22	17	25	30	100	
Site quality class (H$_{40}$ – m)	Development-class						
	I	II	III	IV	V	Sum	%
	Volume of growing stock (mill. m^3)						
6	0.00	0.00	0.66	11.62	33.77	46.05	7
8	0.00	0.00	3.33	36.41	59.30	99.03	16
11	0.00	0.30	11.67	52.35	87.12	151.44	25
14	0.00	0.77	21.20	39.32	71.87	133.16	22
17	0.00	2.72	33.45	26.81	39.36	102.34	17
20	0.00	0.90	14.93	21.67	20.23	57.72	9
23	0.00	0.47	9.95	8.64	4.53	23.60	4
Sum	0.00	5.16	95.19	196.81	316.18	613.34	100
%	0	1	15	32	52	100	

Development-class: I – forest under regeneration, II – young forest, III – young thinning forest, IV – advanced thinning forest, V – mature forest with the basal area mean diameter and mean height weighted by basal area as the basic entities, and number of stems ha^{-1} as a scaling factor. Diameter increment functions (Blingsmo 1984), height development models (Tveite 1976, 1977, Braastad 1977) and a mortality model (Braastad 1982) drive the biological projections. Tree volumes are calculated by functions of Braastad (1966), Brantseg (1967) and Vestjordet (1967). Timber (stumpage) values were estimated from gross price functions (Blingsmo and Veidahl 1992), and harvest costs from functions based on a tariff agreed upon by employers' and employees' organisations (Overenskomst … 1996).

The price and cost level were chosen subjectively with the aim of reflecting a realistic expectation of future (stumpage) prices and corresponded roughly to an average of the prices in the period 1985–94 (Hoen et al. 1998a). Three levels of timber prices were applied, resulting in average gross prices (total for all species and qualities) of roughly 250 NOK m^{-3}, 325 NOK m^{-3} and 400 NOK m^{-3} (1 US$ = 8.96 NOK, August 2000). No relative changes for prices and costs over time were assumed, implying $\bar{p}_r$ to be in real terms. Three levels of $\bar{p}_r$ (1.5%, 2.5% and 3.5%) were applied to study the sensitivity of this factor. The land expectation value of the ending inventory was estimated for each treatment schedule and included in the cash flow.

$$npv_{ij} = \sum_{t=1}^{t=T_h} (h_{ijt} - c_{ijt}) \cdot (1 + \bar{p}_r)^{-tl} + LEV_{ijT_h} \cdot (1 + \bar{p}_r)^{-T_h l} \tag{1}$$

where npv_{ij} is the NPV of management unit i if assigned treatment schedule j, h_{ijt} and c_{ijt} are value of outputs and inputs, respectively, from period t, l is the number of years in each period, $\bar{p}_r$ is the required real rate of return pro anno, LEV_{ijT_h} is the land expectation value of management unit i as it reaches the planning horizon, denoted by T_h, when assigned treatment schedule j. When calculating the LEV_{ijT_h}, i.e. the value of the ending inventory, predetermined treatment schedules, given for each dominating specie and varying with site index and $\bar{p}_r$, were applied (Hoen 1990, Hoen and Gobakken 1997).

The planning horizon was 100 years, divided into 10 periods of equal length. Any treatments were assumed to take place in the middle of each period. The following treatments were defined for the simulation:

1. Young growth tending
2. Thinning (one alternative for spruce and one for pine)
3. Establishment of seed-tree "stand" for pine
4. Establishment of shelterwood "stand" for spruce
5. Final felling
6. No treatment ("undisturbed growth")

Final felling is always followed by regeneration of a new stand. For any stand two regeneration options were available, one "intensive" option involving planting and one "extensive" involving natural regeneration. Vegetation type was used to group the area into regeneration classes, assumed to represent good, moderate and difficult conditions for natural regeneration. A fourth type requires natural regeneration of spruce-dominated stands to be done by establishing a shelterwood "stand", and keeping it for a period of 20 years. Two main features are used to specify the new stand, the regeneration lag and the tree number of each species. The regeneration lag as well as the tree number and species distribution varied with vegetation type, dominating tree specie and altitude. With spruce as the dominating specie, natural regeneration is assumed to be established by bordercuttings or small clearcuts, or by a shelterwood-procedure as explained above. For spruce the regeneration lag is set to 8, 14 and 20 years for the vegetation types classified as good, moderate and difficult for natural regeneration. Corresponding figures for broadleaf trees (birch) are 2, 5 and 8 years. Above a given altitude (600 metres above sea level in South-East Norway and 500 and 400 metres above sea level in Western and mid-Norway) the regeneration lag is increased by 10 years. With pine as the dominating specie, natural regeneration is assumed done by retention of seed-trees, which are kept for 10–20 years. For pine the regeneration lag (the time from establishment of seed-trees until the new stand is established) is set to 5, 10 and 15 years, for altitudes below 300 metres above sea level, and 25, 30 and 35 years at higher altitudes. The variation in the tree number and species distribution is fairly modest among vegetation types

(±5%). For high-altitude forests, the tree number is reduced 20–40% compared with the lower altitudes. The establishment costs are appropriately varied for the "intensive" (4000–10 000 NOK/ha) and the "extensive" (0–1500 NOK/ha) regeneration alternative.

A priori feasibility requirements were specified for each of the five first treatment options, while the 6th (undisturbed growth) always would be feasible. It is crucial that the final felling treatment is feasible over a fairly wide range of rotation ages, and an interval of 60–70 years around the anticipated economically efficient (Faustmann) rotation age was applied. Within the limits of the feasibility requirements, all possible combinations of the treatments were simulated. In total for the 10 regions, 1 415 600, 1 345 861 and 1 282 363 treatment schedules were simulated for $\bar{p}_r$ of 1.5%, 2.5% and 3.5%, respectively. This means that each management unit in average was represented by 128–142 different treatment schedules in the optimisation of the forest management problems. All forest management problems were solved at regional level, while the country level results were obtained by summing over the individual regions.

Three different management scenarios were analysed for each $\bar{p}_r$. In all problems the objective function was maximisation of the NPV of the forest area. The first Scenario I was a pure NPV maximisation (a Faustmann approach), while the second (Scenario II) included constraints guaranteeing a non-declining felling path over time. The third problem (Scenario III) restricted the first period harvest not to exceed the "historic" level and allowed a maximum change of ±10% in harvested volume from any period to the following.

Formally, the decision problems would consist of the objective function (2), the area-constraints (3), the non-negativity constraints (4) and eventually some of the constraints (5)–(8):

$$\max\ z_p = \sum_{i=1}^{n} \sum_{j=1}^{J_i} npv_{ij} \cdot w_{ij} \tag{2}$$

s.t.

$$\sum_{j=1}^{J_i} w_{ij} = 1, \forall i \tag{3}$$

$$w_{ij} \geq 0 \text{ for all } i \text{ and } j \tag{4}$$

$$\sum_{ij} ef_{ijt} \cdot w_{ij} \leq 0,\ \forall t = 1,2,\ldots,T-1 \quad \text{when } ef_{ijt} = uvol_{ijt} - uvol_{ijt+1} \tag{5}$$

$$\sum_{ij} uvol_{ij1} \cdot w_{ij} \leq H \tag{6}$$

$$\sum_{ij} uvol_{ijt} \cdot w_{ij} \cdot 1.1 - uvol_{ijt+1} \cdot w_{ij} \geq 0, \quad \forall t = 1,2,\ldots,T-1 \tag{7}$$

$$\sum_{ij} uvol_{ijt} \cdot w_{ij} \cdot 0.9 - uvol_{ijt+1} \cdot w_{ij} \leq 0, \quad \forall t = 1,2,\ldots,T-1 \tag{8}$$

symbols:

npv_{ij}	the net present value of management unit *i* if assigned treatment schedule *j*
w_{ij}	the weight (proportion) of management unit *i* assigned treatment schedule *j*
$uvol_{ijt}$	the harvest volume in period *t* from management unit *i* if assigned treatment schedule *j*. Thus ef_{ijt} is the difference in harvested volume between period *t* and *t* + 1.
H	"historic" level of timber harvest, i.e. the harvested volume in the 10 years from 1983–1992

In Scenario II constraints (3), (4) and (5) were imposed, while Scenario III imposed constraints (3), (4), (6), (7) and (8). When none of the constraints (5)–(8) are imposed, the best strategy will always be for each management unit *i* to apply the treatment schedule *j* that maximises the NPV. Then Scenario I reduces to picking the treatment schedule with the largest NPV for each management unit and may thus trivially be solved without being formulated as a LP-problem.

Table 2. NPV of the forest area, total timber production, productive forest area, 0-area and annual production and growing stock in a fully regulated forest (explanation given in the text).

		Unit	Required real rate of return, $\overline{p}_r$ 1.5%	2.5%	3.5%
NPV in Scenario I		$10^9 \cdot$ NOK	185.59	106.80	78.82
NPV in Scenario II		$10^9 \cdot$ NOK	185.52	106.39	77.07
NPV in Scenario III		$10^9 \cdot$ NOK	182.51	100.84	69.03
Total production in Scenario I		$10^6 \cdot \mathrm{m}^3$	2201.03	2042.40	1920.10
Total production in Scenario II		$10^6 \cdot \mathrm{m}^3$	2202.48	2019.08	1866.19
Total production in Scenario III		$10^6 \cdot \mathrm{m}^3$	2190.58	2033.58	1922.63
Productive area		$10^5 \cdot$ hectare	64.177	64.177	64.177
0-area		$10^5 \cdot$ hectare	3.302	3.635	4.063
Fully regulated forest	Annual production from managed areas	$10^6 \cdot \mathrm{m}^3$	20.81	19.25	18.58
	Annual production from 0-areas	$10^6 \cdot \mathrm{m}^3$	0.68	0.74	0.84
	Growing stock managed areas	$10^6 \cdot \mathrm{m}^3$	688.59	579.11	507.00
	Growing stock from 0-areas	$10^6 \cdot \mathrm{m}^3$	20.25	23.12	21.49

Note: The total timber production over the planning horizon is defined as the sum of harvests in each period, plus the difference in growing stock between the time of inventory and the end of the 100-year-period. 0-areas, or economically non-accessible areas, are defined as management units for which all simulated treatment schedules have a NPV less than or equal to zero.

3 Results

The NPV of the forest area is presented in Table 2. For the two lowest $\overline{p}_r$'s, there is a negligible drop in NPV when the non-declining felling path constraints are added (Scenario II) while for $\overline{p}_r$ of 3.5% the NPV drops with 2.2%, compared with the unconstrained problem (Scenario I). By imposing the constraints in Scenario III, the NPV is reduced by 1.8%, 5.6% and 12.4% for $\overline{p}_r$ in ascending order. These figures represent estimates of the value of the intitial tree capital (growing stock), and the land it occupies, at different $\overline{p}_r$. Multiplying the NPV's with $\overline{p}_r$ gives the theoretical income (annual profit) in real terms, which is found to be in the interval $2.7–2.8 \cdot 10^9$ NOK for Scenario I and Scenario II, and $2.4–2.7 \cdot 10^9$ NOK for Scenario III. Increasing $\overline{p}_r$ clearly reduces the annual profit of Scenario III. In Scenario I (Scenario II) the total timber production (see Table 2 for definition) during the 100-year period increases by 15% (18%) when $\overline{p}_r$ is lowered from 3.5% to 1.5%. In Scenario III the corresponding increase is 14%. All of the figures presenting timber volumes, are so-called 'forest-volume', i.e. the volume of the treetop, expected in-forest waste and losses, and bark are included. This typically amounts from 15%–25% of the total volume. The 0-area, i.e. forest area which is economically non-accessible for timber production, were estimated to be roughly 6% of the productive forest area. The four rows at the bottom of Table 2 presents results based on the theoretical assumption that the forest area was covered by a fully regulated forest with respect to the rotation ages specified for estimating the value of the ending inventory. These figures resemble the steady state solution known from optimal control theory.

3.1 Timber Harvesting Potential and the Required Real Rate of Return ($\overline{p}_r$)

The results clearly demonstrate that the time-profile of growing stock and timber harvesting are very sensitive to $\overline{p}_r$. The potential annual harvests in the first ten-year period were $13.2 \cdot 10^6 \mathrm{m}^3$, $24.0 \cdot 10^6 \mathrm{m}^3$ and $32.3 \cdot 10^6 \mathrm{m}^3$, respectively, for $\overline{p}_r$ 1.5%, 2.5% and 3.5%. The low $\overline{p}_r$ (1.5%) gave a relatively low potential harvest at the start of the planning period, and a relatively high potential towards the end, while the high $\overline{p}_r$ (3.5%) gave a relatively high potential in the beginning, and a lower one towards the end. The non-declining harvest path for the two first 10-year periods increases with the $\overline{p}_r$, from $11.6 \cdot 10^6 \mathrm{m}^3$ to $17.7 \cdot 10^6 \mathrm{m}^3$ and $19.1 \cdot 10^6 \mathrm{m}^3$,

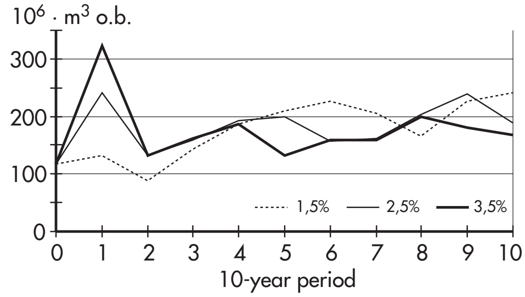

Fig. 2. Harvest paths for Scenario I and different $\overline{p}_r$.

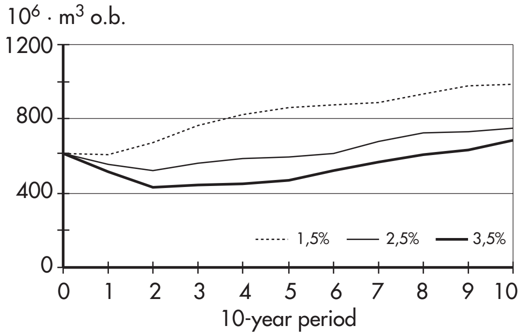

Fig. 3. Growing stock paths for Scenario I and different $\overline{p}_r$.

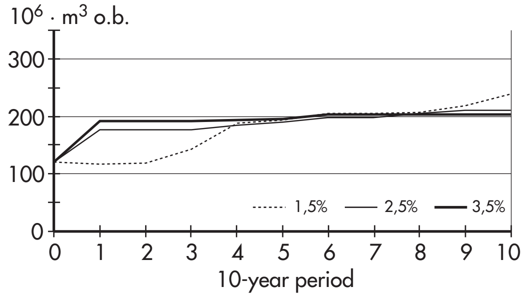

Fig. 4. Harvest paths for Scenario II and different $\overline{p}_r$.

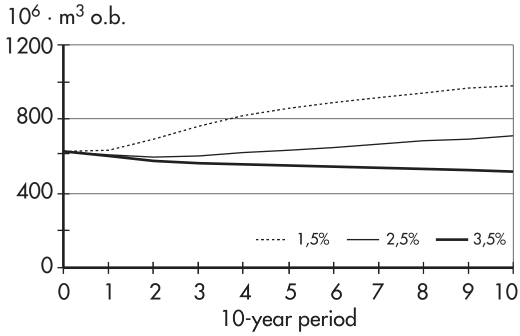

Fig. 5. Growing stock paths for Scenario II and different $\overline{p}_r$.

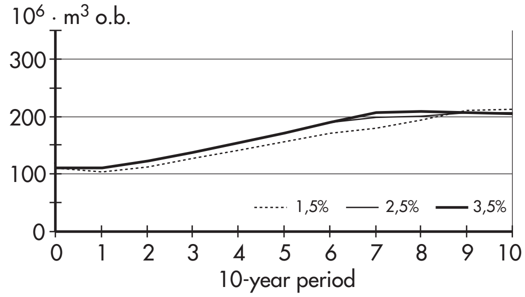

Fig. 6. Harvest paths for Scenario III and different $\overline{p}_r$.

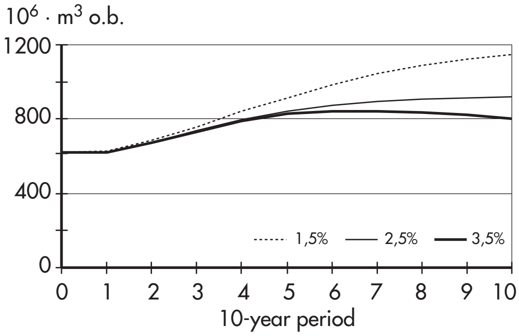

Fig. 7. Growing stock paths for Scenario III and different $\overline{p}_r$.

while the last period harvest is $23.8 \cdot 10^6 \mathrm{m}^3$, $21.0 \cdot 10^6 \mathrm{m}^3$ and $20.3 \cdot 10^6 \mathrm{m}^3$. In Scenario III the harvest level constraints are binding from period 1 through 6 for the two highest $\overline{p}_r$, while they are binding in period 3–5 with $\overline{p}_r$ of 1.5%. The time-profiles, or paths, for the periodic timber harvest and growing stock are presented in Figs. 2–7. The appendix presents the results in greater detail.

3.2 Intensity in Silvicultural Management, $\overline{p}_r$ and Timber Price Level

The intensity and extent of silvicultural management applied on the forestland changes with $\overline{p}_r$. This can be verified by inspecting the average area assigned to the different silvicultural treatments as $\overline{p}_r$ increases from 1.5% to 3.5%. From Table 3 we see that the area assigned for final-felling increases by roughly 30%, which is due to reduced rotation ages and more frequent harvesting. The area regenerated by planting is virtually unchanged, while the naturally regenerated area increases by 30%. Thus, the proportion of natural regeneration increases. For the area being regenerated by planting, the reduction in rotation ages involve more frequent planting at the best sites, which just compensates for the increase in the marginal site quality class with planting as the most profitable regeneration option. The area treated by young growth tending show a clear decrease. The area assigned to thinning and regeneration by retention of seed- or shelterwood-trees show a slight increase in absolute terms. The expenditures related to silvicultural management decrease by nearly 35%, supporting the claim that the intensity in silvicultural management will decrease as $\overline{p}_r$ increase. At the highest $\overline{p}_r$ the area planted and thinned is clearly higher in Scenario II than in Scenario I. This relates to the non-declining harvest path constraint, as more planting and thinning makes feasible a larger immediate harvest.

Changes in the permanent price-level of timber also impact the timber management strategies in the expected way. A reduction in timber prices will decrease the profitability of silvicultural investments and thus reduce e.g. areas regenerated by planting or treated by young growth tending. On the part of the forest area where some silvicultural investments are done, a decrease in timber prices will change the ratio between output-prices and input-costs. This will have two effects; i) the intensity in silvicultural management will decrease, ii) the value of forestland and thus the soil rent will decrease, implying the optimal rotation age to increase. Both effects will reduce the activity in terms of average planting expenditures and average area planted. The results presented in Table 4 supports these claims. The proportion of the area established by planting after final felling is reduced from 34% to 27%, while the area treated by young growth tending decrease by 21% when timber price changes from the "high" to the "low" level. The expenditures related to silvicultural management decrease by 31%.

Table 3. Average area in 1000 hectare per 10-year period assigned different treatments and average expenditures in silvicultural treatments in 10^6 NOK per 10-year period for Scenario I. Values for Scenario II and Scenario III are given as percentage of Scenario I for the corresponding $\overline{p}_r$.

		Area assigned different treatments							
	$\overline{p}_r$	No trt.	Planting	Nat.regen.	Y.gr.tend.	Thinning	Seed-/sh.	Final-felling	Silv.exp.
Scenario I	1.5%	5345.4	179.9	341.5	323.9	66.3	160.7	481.5	1600.6
Scenario II	1.5%	100.1	99.8	100.2	99.0	97.3	100.5	100.1	99.7
Scenario III	1.5%	101.8	90.6	88.8	94.2	89.9	90.9	88.6	91.0
Scenario I	2.5%	5261.5	182.8	432.7	290.0	81.9	168.9	575.5	1315.5
Scenario II	2.5%	99.7	102.1	101.2	100.0	103.5	101.9	101.6	101.3
Scenario III	2.5%	103.3	89.5	82.3	89.6	65.7	87.3	83.3	88.5
Scenario I	3.5%	5287.8	182.7	466.6	216.0	87.7	177.0	609.4	1059.3
Scenario II	3.5%	98.3	111.1	104.8	99.3	140.4	108.3	107.0	107.3
Scenario III	3.5%	104.0	89.8	80.1	83.0	59.2	85.6	81.7	87.3

Note: Explanation of column titles: No trt.: No treatment, Nat.regen: natural regeneration, Y.gr.tend.: Young growth tending, Seed-/sh.: Establishment of seed-tree and shelter-wood stands, Silv.exp.: Silvicultural expenditures.

Table 4. Average area in 1000 hectare per 10-year period assigned different treatments and average expenditures in silvicultural treatments in 10^6 NOK per 10-year period for Scenario I with different timber prices. Values for Scenario II are given as percentage of Scenario I for the corresponding price-level. $\overline{p}_r = 2.5\%$.

				Area assigned different treatments					
	Price	No trt.	Planting	Nat.regen.	Y.gr.tend.	Thinning	Seed-/sh.	Final-felling	Silv.exp.
Scenario I	high	5174.8	227.8	435.0	317.0	92.4	170.7	622.9	1562.6
Scenario II	high	99.4	102.0	101.1	101.3	109.3	104.8	101.5	101.2
Scenario I	medium	5261.5	182.8	432.7	290.0	81.9	168.9	575.5	1315.5
Scenario II	medium	99.7	102.1	101.2	100.0	103.5	101.9	101.6	101.3
Scenario I	low	5402.6	144.3	395.4	252.1	63.1	160.2	499.8	1080.7
Scenario II	low	99.8	101.4	100.5	99.3	105.7	101.8	100.8	100.7

Note: Explanation of column titles: No trt.: No treatment, Nat.regen: natural regeneration, Y.gr.tend.: Young growth tending, Seed-/sh.: Establishment of seed-tree and shelter-wood stands, Silv.exp.: Silvicultural expenditures.

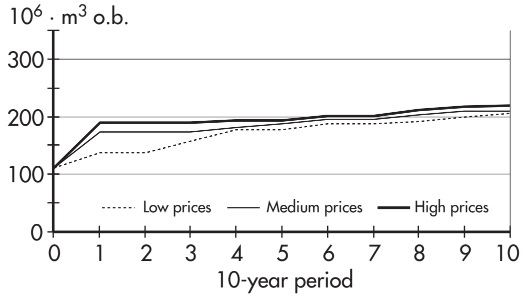

Fig. 8. Harvest paths for Scenario II and different price levels. $\overline{p}_r = 2.5\%$.

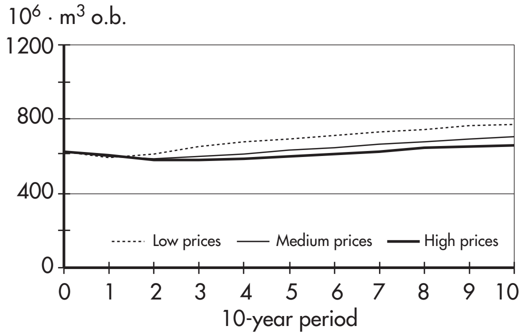

Fig. 9. Growing stock paths for Scenario II and different price levels. $\overline{p}_r = 2.5\%$.

3.3 Cash Flow, Capital Accumulation and Capital Yields

Table 5 present the cash flow's for the three levels of $\overline{p}_r$. Naturally, there is a close connection between the time-profile of the timber harvest and the cash flow. In Scenario I, the first period cash flow is roughly 2.5 times larger when $\overline{p}_r$ of 3.5% is compared with 1.5%. From period 3 and through the rest of the 100-year period, the lowest $\overline{p}_r$ generates the largest cash flow from the forest area. This relate to the basic fact that the lower $\overline{p}_r$ the more attractive will capital investments in silvicultural management and accumulation of growing stock be. Over time this will lead to a larger production of timber in absolute terms as long as rotation ages don't exceed the maximum sustainable yield rotation (i.e. the rotation age when marginal and average growth equals). The last row in Table 5 gives the NPV, when the cash flows from the forest area managed according to $\overline{p}_r$ of 1.5%, 2.5% and 3.5% respectively, are valued with a $\overline{p}_r$ of 3.5%. Comparing these NPV's may give an estimate of the renounced capital value, if the forest is managed according to a lower $\overline{p}_r$ than what may actually be obtainable in alternative projects or the capital market. This may be a quite plausible situation, e.g. due to effects of the tax system. Let us assume that the forest area is managed according to a $\overline{p}_r$ of 1.5%, while the capital market yields 3.5%. Thus, the capital yield (released profit) from the forest area may be invested outside the forest and thus obtain an annual real rate of return of 3.5%.

Table 5. Net cash flow from the forest area per 10-year period and net present value of future cash flow at time 0 (NPV$_0$) and 100 (NPV$_{100}$). Figures in 10^9 NOK.

	Scenario I			Scenario II			Scenario III		
		$\overline{p}_r$			$\overline{p}_r$			$\overline{p}_r$	
10-year period	1.5%	2.5%	3.5%	1.5%	2.5%	3.5%	1.5%	2.5%	3.5%
1	18.1	35.2	45.6	15.8	27.1	30.7	15.8	19.7	21.0
2	12.8	17.5	15.8	17.6	24.7	26.3	18.2	20.7	21.7
3	22.2	21.4	20.4	21.2	24.1	24.6	20.5	22.3	22.8
4	28.7	26.8	24.4	28.8	25.1	26.0	23.1	24.7	25.0
5	32.1	27.9	16.0	29.6	27.1	24.9	25.8	27.5	27.8
6	36.3	21.9	21.7	33.2	27.4	26.6	29.0	30.7	28.8
7	33.4	24.0	21.1	33.4	28.6	25.2	30.7	30.3	30.9
8	27.0	30.9	26.2	33.2	30.1	23.6	33.3	32.3	30.9
9	37.2	35.8	22.3	35.9	30.7	22.7	36.1	32.7	29.4
10	39.1	25.9	19.2	39.1	28.7	20.1	35.9	31.0	26.9
NPV$_0$	185.6	106.8	78.8	185.5	106.4	77.1	182.5	100.8	69.0
NPV$_{100}$ in	231.6	111.9	68.32	230.6	104.8	48.6	234.8	117.6	69.7
NPV$_0$ at $\overline{p}_r$ 3.5%	65.4	76.8	78.8	65.3	75.7	77.1	61.6	67.5	69.0

Comparing the figures of column four and two (Scenario I) in the last row of Table 5 gives the difference in NPV of $13.4 \cdot 10^9$ NOK or 17%. The harvest path with 1.5% $\overline{p}_r$ in Scenario II and Scenario III has a gradual increase over the planning period, different from Scenario I with the same $\overline{p}_r$. The difference in NPV for e.g. Scenario III (column four and eight of Table 5) is $17.2 \cdot 10^9$ NOK equivalent to an annual theoretical income of $0.6 \cdot 10^9$ NOK. This estimate comprises the combined effect of 1) harvest path constraints and 2) design of forest management at an inapproriate required real rate of return, on the contributing profit from the forest area.

4 Discussion

The aim of the analyses has been to map the timber production possibilities of the productive forest area of Norway and how it relates to the $\overline{p}_r$. In general, the results correspond well to intuitive reasoning based on forest economic theory.

4.1 Data and Empirical Models

The analyses have been accomplished within a frame of objective criteria and long empirical experience. They were based on a large and representative data set describing the productive forest area of Norway. The number of management units was considerably larger than in earlier studies done in Norway (Nersten et al. 1981, Klargjøring av … 1999). The moderate aggregation of sample plots was done in a way that secured a minimum loss of information for the selected cluster variables (e.g. Eriksson 1983, Hoen 1996, Weintraub et al. 1997). The cluster variables included biological state variables as well as economically related variables like terrain accessibility and terrain transportation distance. The large number of management units and the method used for aggregation provided for a broad variation of treatment schedules, i.e. a comprehensive decision-space. This is believed to be particularly important in analyses pretending to map the sensitivity of the timber production potential to changes in the $\overline{p}_r$. The treatment options that were eligible when simulating treatment schedules cover the most relevant and frequently applied silvicultural treatments in Norway, see Hoen et al. (1998a) for details.

The analysis tool (Gaya-JLP) builds on a long tradition of development and application of comprehensive models for long-range timber production analyses in Norway and in the other Nordic countries, cf. e.g. Eid and Hobbelstad (2000) in Norway, Eriksson (1983) and Lundström and

Söderberg (1996) in Sweden and Lappi (1992) and Siitonen (1993) in Finland. Empirically based stand growth and timber valuation sub-models were applied to calculate alternative treatment schedules for each management unit. The largest uncertainties were related to (i) assumptions for regeneration of forest stands, (ii) modelling of tree mortality and (iii) limited possibilities for simulating silvicultural practices based on selective cutting.

Among the set of assumptions defining regeneration-options, establishment of new forests based on natural regeneration were particularly burdened with uncertainty. Any bias in the assumptions for natural regeneration will influence the choice of regeneration method, while the resulting bias on timber production affects growing stock and harvesting potentials in a fairly distant future. Mortality was modelled as a fixed proportion of the number of trees (Braastad 1982) in established stands (i.e. dominant height above 9 metres), and this might be especially critical for strategies involving substantial extension of the rotation age. The longest rotation ages are applied in Scenario III (all $\bar{p}_r$) and for Scenario I and Scenario II with $\bar{p}_r$ of 1.5%. Assuming a larger mortality in old forest would reduce the net growth and the harvesting potential, which in turn would reduce the NPV of these strategies. A silvicultural regime based on selective cuttings was approximated for high-elevation forests. This involved two consecutive thinnings before final felling, and then a new stand was assumed established in the next 10-year period with an age of about 50 years. Better solutions would be possible, however, if single-tree growth models, similar to those used in HUGIN in Sweden (Söderberg 1986) or MELA in Finland (Hynynen 1995, Siitonen et al. 1996), could be implemented (Nersten 1997). This would also facilitate the specification of silvicultural regimes based on all-age management or selective cuttings for the whole forest area.

When estimated growth was compared to actual growth based on tree ring measurements on the NFI-plots, the growth estimated for the first 5 years by the GAYA-model was found to be 7–8% lower than the measured growth. This is not considered to be critical for the conclusion of this study. Even if there should be biases in the estimation of production potentials, the differences between alternatives, and thus the relative impact of changing e.g. $\bar{p}_r$ or the timber price level, are believed to be reasonably consistent and unbiased.

4.2 The Decision Model

A straightforward decision model is applied, with the objective of maximising the NPV of the forest area. The NPV was calculated within the Faustmann-tradition. It is implicitly assumed that the management units can be treated independently, since output is a linear function of the area assigned to the treatment schedules for each management unit. This also implies that any quantity of timber could be sold without affecting the price-level of timber, which is obviously a simplistic assumption. Applying downward-sloping demand would tend to smooth the harvest path through time and thus bring the solution to Scenario I closer to that of Scenario II or Scenario III. Imports of pulpwood to Norway have been significant during the last 30 years, indicating that the Norwegian round-wood market is closely linked to the international. Thus, the world-market price of round-wood, adjusted for transportation costs, can be regarded as a price-floor/-ceiling for the domestic round-wood price. In this perspective the price-taker assumption is more defensible.

4.3 Comparison with Other Studies

There are several examples of national or regional analyses based on a representative sample of the productive forest area with focus on timber production carried out in the Nordic countries (e.g. Nersten et al. 1981, Hofstad 1991, Skogspolitiken inför … 1992 and Siitonen and Nuutinen 1996). Given the differences in methodology and the way of specifying assumptions for silvicultural management and biological development, the results from the present study conform well to what Nersten et al. (1981) obtained. Hofstad’s (1991) “steady state” results conform quite well to comparable results in this study with $\bar{p}_r$ of 1.5% (Table 2). For the higher $\bar{p}_r$ there are significant differences, as Hofstad’s (1991) results imply much lower levels of harvest and growing stock. One explanation may be that the function estimating forest volume differs from the growth model applied in this study.

Hofstad's (1991) logistic function is not capable of adjusting growth according to the age-structure of the forest, as the growth model in Gaya does. Assuming that volume growth and profitability of timber production decrease with age over the relevant range of rotation ages, Hofstad's model may, compared with Gaya, underestimate the marginal growth rate and profitability of timber production when the growing stock is relatively small. With Gaya a small level of growing stock will imply a relatively young forest and thus a high annual growth, a high marginal growth rate and a relatively high marginal profitability of extending the rotation age.

4.4 Non-timber Outputs

The forest area in Norway provides a large variety of outputs in addition to timber. As pointed out by Hofstad (1991), concerns related to the provision of non-timber outputs significantly affect forest management practices. The general trend is that non-timber concerns in the short-run reduce harvest-levels and thus increase levels of growing stock. In the long run this will lead to increased removals, either by harvests or natural mortality, and possibly temporarily to lower growing stocks than if less constraints were imposed initially. The impact of some selected environmentally oriented constraints, using the same data and model as this study, is analysed by Hoen et al. (1998b).

4.5 Policy Implications

In 1997–98 the Ministry of Agriculture in Norway prepared a report to the Parliament on the forest policy. The report was presented to the Parliament in Dec. 1998 and was discussed in the Parliament in May–June 1999. The report represented a departure from tradition, as no explicit target was proposed for the desired level of future timber harvests. Neither was any quantitative figures presented in the report, showing possible consequences of different policies as regards e.g. the level of intensity in silvicultural investments. The findings presented in this paper were provided to the Ministry of Agriculture while the report to the Parliament was in preparation. The observation made by Hofstad (1991) that "*Forest economists also have pointed at the connection between harvest, inventory and the social discount rate (Svendsrud 1988),* ***without really being able to bring the point home to policy makers***" (bold characters added) remain valid and may still be repeated.

The growing stock represents a huge capital. The growth-rate of this timber volume, a key indicator in evaluating the rate of return obtained from this capital, is in the range of 1.5–2.5% pro anno for the oldest part of the forest (Statistics of … 2000). If we assume that the stumpage price of timber will follow the general price level (CPI), then this growth-rate will constitute a sound indicator of the real rate of return obtained by holding capital in old forest. The key question is whether this rate of return is satisfactory, or if more attractive alternative investments, yielding higher real rates of return, exist. Consideration of, and attitudes towards, risk will be crucial in this setting. Despite the apparent size of potential losses in capital yield, these questions were not addressed or discussed explicitly in the recent Report to the Parliament on the forest policy prepared by the Ministry of Agriculture.

5 Conclusions

The analyses confirm that the timber production possibilities, and the corresponding time-profile of timber harvests and growing stock, heavily depend on the chosen $\bar{p}_r$. In Norway, the current state of the productive forest area provides a solid basis for timber production far into this century. The non-declining harvest path (Scenario II) is, compared with a historic level of timber harvests, estimated to be 50–60% larger for the first three 10-year periods and it increases further to be roughly 70% above the historic level given the $\bar{p}_r$ of 2.5% and 3.5%. The harvest potential with $\bar{p}_r$ of 1.5%, equals the historic level for the first two 10-year periods, while it is increasing dramatically to twice the historic level by the end of the planning horizon. The harvest paths of Scenario III, when harvests are restricted not to exceed the "historic" level in period 1 and allowed to fluctuate ±10% from period to period, are almost identical for all $\bar{p}_r$ and show a steady increase throughout the whole planning period. These harvest paths (Figs. 6 and 7) are accompanied by an increasing growing stock, most pronounced and persistent for the lowest $\bar{p}_r$. If we adjust for the differences in total harvest through the planning period, the growing stock increases by $99.5 \cdot 10^6\,\mathrm{m}^3$ ($242.7 \cdot 10^6\,\mathrm{m}^3$) when $\bar{p}_r$ decrease from 3.5% to 2.5% (1.5%). These differences may be attributable to changes in optimal silvicultural management as the $\bar{p}_r$ changes. These results uniformly affirm, that if not the removal increases drastically from the historic level, either by harvest or by natural mortality, the growing stock will continue to increase.

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Appendix 1. Growing stock (standing) and total harvest in $10^6 \cdot m^3$ on area assigned for timber production and on areas not economically accessible for timber production (0-areas) for every 10-year period. Harvest for each species (Spruce, Pine, Broadleaves – S/P/B) and amount of saw timber (S.t.) in % of total harvest for every 10-year period. Scenario I maximises NPV without any constraints on the harvest path, while Scenario II maximises NPV with a non-declining harvest path constraint.

			Scenario I						Scenario II			
Per.	Standing	S/P/B	0-areas	Harvest	S/P/B	S.t.	Standing	S/P/B	0-areas	Harvest	S/P/B	S.t.
			$\bar{p}_r = 1.5\%$						$\bar{p}_r = 1.5\%$			
1	543.9	54/27/20	20.1	131.5	50/34/16	60	560.6	53/27/20	20.1	114.8	50/33/16	61
2	628.1	55/24/21	24.8	87.5	56/27/18	59	617.6	55/24/21	24.8	117.0	58/27/16	60
3	689.6	56/22/21	30.0	143.5	62/21/18	59	679.6	56/22/21	30.0	141.4	60/21/19	59
4	731.2	57/20/22	35.5	187.0	59/24/17	59	716.8	57/21/22	35.5	188.1	60/23/17	59
5	752.9	57/21/22	41.2	210.6	65/16/19	57	751.5	57/21/23	41.2	193.8	65/16/19	56
6	761.0	56/22/22	47.3	225.7	64/15/21	60	781.9	56/22/22	47.3	204.7	64/14/21	60
7	784.9	54/23/23	54.3	205.6	66/16/18	60	811.1	54/22/23	54.3	204.7	66/17/17	60
8	849.1	54/23/23	61.3	165.1	60/19/21	61	838.5	54/23/23	61.3	206.5	61/17/22	59
9	862.7	51/25/24	67.4	225.5	67/15/17	61	858.5	52/25/24	67.4	217.7	67/15/18	61
10	861.0	50/26/24	73.4	241.4	63/16/21	63	858.9	50/26/24	73.4	238.3	65/15/20	63
			$\bar{p}_r = 2.5\%$						$\bar{p}_r = 2.5\%$			
1	435.1	51/26/23	20.2	240.2	56/32/13	58	498.6	52/27/22	20.1	176.8	57/32/12	61
2	458.5	52/24/25	24.9	132.9	60/23/17	52	487.9	51/25/24	24.8	176.8	61/23/16	55
3	481.3	53/22/26	30.5	158.3	60/21/19	53	496.2	52/23/25	30.4	176.8	59/22/19	53
4	488.4	55/19/26	36.4	192.7	54/23/22	55	510.2	55/20/26	36.3	184.0	53/24/22	54
5	491.9	54/19/27	42.7	200.0	62/17/21	56	523.1	55/18/26	42.6	189.6	60/19/21	57
6	538.0	54/19/27	49.8	156.5	61/16/23	56	534.6	54/19/27	49.6	196.2	61/16/22	55
7	597.4	50/22/28	57.6	160.9	66/12/22	58	553.9	50/22/28	57.4	196.6	66/12/22	57
8	622.0	47/24/29	65.6	203.5	63/14/23	59	564.9	47/24/29	65.4	204.7	62/14/25	59
9	613.1	43/27/30	72.5	239.6	62/17/20	60	575.7	43/26/31	72.3	209.5	63/17/20	59
10	652.5	43/28/30	79.4	188.8	52/20/28	56	589.2	42/27/30	79.1	209.5	52/20/28	56
			$\bar{p}_r = 3.5\%$						$\bar{p}_r = 3.5\%$			
1	352.8	47/27/25	20.2	322.5	59/28/12	56	486.3	50/27/23	18.6	190.5	60/29/11	62
2	363.5	48/24/28	24.9	131.2	56/25/19	49	460.1	49/26/26	23.1	190.5	60/23/16	54
3	366.1	50/21/29	30.7	160.8	55/24/21	52	447.8	51/23/27	28.2	191.4	55/24/21	51
4	359.1	50/18/32	36.8	186.9	57/21/22	54	440.9	51/20/29	33.6	193.9	56/23/21	53
5	405.6	51/17/32	43.4	131.2	55/17/28	52	432.8	52/17/30	39.2	195.4	53/21/25	52
6	439.8	46/19/35	50.9	159.1	67/11/21	55	421.4	47/19/34	45.6	203.3	66/13/21	53
7	488.5	41/21/37	59.4	159.8	61/13/26	54	414.8	40/21/39	52.8	203.3	60/15/25	53
8	505.1	37/24/39	67.9	199.4	56/15/29	55	407.1	36/23/41	59.9	203.3	52/18/30	51
9	542.7	35/27/39	75.3	180.8	53/17/30	51	398.4	33/25/43	66.2	203.3	48/20/32	47
10	601.7	36/27/37	82.6	167.5	42/22/36	48	395.5	32/26/42	72.5	203.3	42/22/36	44