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# The Value of Information in Salmon Farming Harvesting the Right Fish to the Right Time

by

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## Harvesting the Right Fish to the Right Time

**Running title: Value of information in Salmon Farming**

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# The Value of Information in Salmon Farming

## Harvesting the Right Fish to the Right Time

**Abstract**

Research regarding management practice in fish farming has traditionally focused on two topics: production planning and forecasting of prices. This article combine these two areas of research, and illustrate how information of price patterns can change production plans, and hence increase the value of the farm enterprise. We present a model farm and illustrate with different levels of price information how information of future prices alter the original production plan and hence create extra value for the farmer. The phrasing of the paper and the empirical application are on salmon and salmon farming, but the ideas and general results should be applicable to all farmed species.

**Keywords:** Value of information, optimal harvesting, prices,

**Introduction**

The salmon farming industry in Norway has during the last two decades transformed from a local small scale industry to a global, multinational billion dollar industry. However, despite its impressive growth the industry has experienced a high degree of turbulence and large cross-sectional variations in profitability. This has manifested itself in a large number of bankruptcies and restructuring of the industry (Tveterås 1999). This substantial cross-sectional difference in profitability can be explained by several factors such as output price, stochastic shocks, firm heterogeneity in terms of the quality of the farm location, the quality of management, etc. Most probably is it a combination of the above.

Salmon prices are highly volatile and are potentially a major factor in explaining the variability in profitability. In 2003, the highest price for 4-5 kilogram salmon was NOK[1] 22.49 (October) and the lowest price was NOK 14.46 (July). Price fluctuations translate into significant price risk, since the magnitude as well as the direction of the week to week changes is often unknown to producers. Volatile prices make the timing of production extremely important. Selling 4-5 kilogram salmon in July for NOK 14.46/kg will bring losses, while selling the same fish in October for 22.49 NOK/kg may be very profitable. The farmer has to assess frequently whether to harvest to capture a known price, or to continue to feed to deliver a larger salmon at an unknown future price. Salmon is to a large extent sold spot, and no formalized derivative market exists; consequently, participants cannot hedge prices.

While prices is an obvious source of uncertainty, there are also several other factors that can have consequences of a similar magnitude. Biophysical conditions vary substantially over a year and also between years and influence growth. For instance in normal summers growth is best in August and early September, but in warm summer that sea becomes so hot that the fish stops feeding and thereby its growth. Stocking and harvesting decisions influence growth and capacity utilisation rates and accordingly profits. For instance, turnover can vary from a factor under one for good producers in good years to a factor close to two for a bad producer in a bad year. This difference in turnover can lead to almost a doubling in production cost for the bad producer in a poor year.

The substantial variation in profits indicates that if there is information that at least partly can improve the producers decisions, this information will have value to the producers through the higher profits it creates. A way to measure the potential value of forecasting and decision support tools is accordingly to asses the value of the information they provide. The maximum value of any such model is then if it provides certain information, and this situation can then be used as a benchmark when assessing the maximum value of information.

We will in this article primarily limit the discussion to the value of information on price relationship, and discuss how such information can create value for the fish farmer. However, it should be noted that the same type of considerations can be carried out with respect to any factor one think contributes to the variability in profits. The topic will be addressed theoretically, but we will in addition attempt to illustrate the value of price information for a full scale fish farm.

The paper is organized as follows; first we present some theoretical considerations and illustration on the possible value of price information for farmers. We discuss the behavior of salmon prices in section three, and present a theoretical model for optimal harvesting in section four. A full scale farm example of the value of information is presented in section five, before we conclude in section six.

**Value of information**

The expected value of information is the expected increase in the value (or decrease in the loss) associated with obtaining more information about quantities relevant to the decision process. The expected value of information can be thought of as a measure of the importance of the uncertainty about a quantity in terms of the expected improvement in the decision that might be obtained from having additional information about it. Perfect information removes all uncertainty about the outcomes for the decision alternatives. While there is rarely an option in real-world business decisions that would actually remove all uncertainty, the value of perfect information provides an easily calculated benchmark about the worth of collecting additional information. If all the available options for collecting information cost more than the value of perfect information, then these options do not need to be analyzed in further detail. This is because imperfect information cannot be worth more than perfect information.

Value of information analysis is useful because it makes the losses associated with decision errors explicit, balances competing probabilities and costs, helps identify the decision alternative that minimizes the expected loss, prioritizes spending on research and quantifies the value of the research to the decision maker.

**Example**

To illustrate the potential value of information in salmon farming, a relatively simple example will be provided. We start by assuming that the fish-farmer has a pen with $n$

number of fish of size 4 kilogram. The market price for 4 kilogram salmon is 25 kr per/kg, and the value of the fish is hence nx4x25. Price next month is uncertain. The farmer must then decide if he shall harvest the fish today, or wait a month or two. We continue to simplify, and assume that the fish farmer only has two choices; harvest today or harvest next month, we also assume that the fish will not grow anything the next month and that prices next month can take three different values. The price can stay at NOK25, it can go up to NOK30 or it can go down to NOK20. The farmer initially believe that there is 30% chance of increase, 30% chance of steady state, and 40% chance of decrease in prices. His decision problem can then be illustrated as in figure 1

**[Figure 1 approximately here]**

Hence he can harvest and get NOK 25 per kilogram or wait one month and get 20, 25 or 30 with respectively probabilities 0.4, 0.3 and 0.3. A risk neutral farmer will maximize net present value, NPV. For the harvest decision NPV is 25NOK/kg and for the wait and harvest next month decision NPV will be 0.4x20+0.3x25+0.3x30=24.8. He will then decide to harvest, and the value of the fish is 25 NOK/kg. Let’s then assume that someone with perfect insight offered to forecast the exact prices next moth. The question is then how much is that information worth, i.e., how much would the farmer pay for that information. Hence we look at the NPV with information. Instead of first take action and then see state of nature, we will now first see state of nature, and then take action. We can invert the decision tree. However since we know the outcome before decision, we can rule out some of the decisions. If we knew prices would go down or stay still, we would harvest immediately, and if we knew prices would go up, we would postpone harvest. Looking at figure 2 net present value will now be 0.3x30+0.7x25=26.5. Hence probabilities have not changed but the expected value of the swimming fish has increased from 25 to 26.5. The value of complete price information is hence 1.50 per kilogram fish.

**[Figure 2 approximately here]**

**Imperfect Information**

Perfect foresight about future salmon prices is only possible for farmers selling on contract. However there exist several papers indicating that it is possible to create forecasting models for fish prices that at least outperform naïve predictions (i.e., the price next month is the same as today). For instance Guttormsen (1999) argued that relatively simple time series models could predict direction of salmon price changes for 4, 8 and 12 weeks ahead period with up to 80% correctness. We will therefore illustrate that also imperfect information can create value for the farmer. We simplify the above example by saying that prices only can go up to 30 or down to 20. Based on the farmers a priori believes the probabilities for up is 0.4 and for down is 0.6. Present value is hence NOK24 for wait and NOK25 for harvest. The farmer will then harvest.

Someone offer to predict prices claiming that he predict correct direction if prices goes up 80% of the time, and correct direction if prices goes down 70% of the time. How much should the farmer pay for that price information? Let's say that H1 is price increase and H2 is price decrease, "H1" is the test signal (what the forecaster say) saying prices should increase and "H2" is the test signal saying prices should go down.

**[Figure 3 approximately here]**

The Simultaneous probability is then the probability for a price increase given that the forecasting model predicts so. This tree can also be inverted, such that the signal (forecast) comes first. We can calculate the probability for the signals from the forecaster, and by the use of Bayes theorem get the aposteriori probabilities for price increase and price decrease. The aposteriori probabilities are presented in table 1.

**[Table 1 approximately here]**

We should harvest if the price forecaster say that prices will go down, and wait if the price forecaster say that prices will go down. Based on these new probabilities we can then recalculate NPV of the harvesting decision, and illustrate the decision as in figure 4.

**[Figure 4 approximately here]**

The expected value of imperfect information in this situation is hence 0.70 NOK/kg.

## Salmon price information

We have in the examples above illustrated that information about future salmon prices has potential to create value for the fish farmer. We will in this section briefly examine whether it is possible to obtain price information just by examining historical prices. There exist a relatively large amount of studies analyzing supply and demand as well as market structure for salmon. These studies offer valuable insight into markets and how consumers behave, but such models may have limited value for producers' short-term decisions. In this article we will therefore focus on the possibilities to find price characteristics that can be identified without advanced times series technique

Salmon prices are like other prices determined by the law of supply and demand. Hence the correct salmon price is the price consumers are willing to pay for the quantity supplied. Furthermore, a company will, over time, produce up to the point were the cost of producing the last unit equals the price it is being offered in the market. This is intuitive since prices higher than operating costs, will attract new entrants and stimulate existing producers to increase their production. With prices lower than cost, the situation will be reversed: high cost producers will exit the industry and those still producing will attempt to decrease their production. This rule holds for competitive industries, and history indicates that it also holds for salmon farming. Figure 5 presents real market prices together with operating cost, and one can see that the price-cost margin have been fairly stable. Costs of production have decreased substantially, and this again has lead to lower prices.

**Short-term dynamics**

In contrast to the relatively stable long term price pattern, salmon prices exhibit large week to week fluctuations. In addition, prices for salmon of different weight classes do not move synchronously. Week to week fluctuations are of more interest for management decisions in general and for the harvesting decision especially. We will therefore in this section discuss some factors that might affect demand and supply in the short term, and hence influence on short term price determination. The discussion will be divided in two parts, one part focusing on absolute prices, and one part focusing on relative price relationships.

The strong week-to-week fluctuations are illustrated in figure 6. So while the long trends, relatively speaking, showed a rather stable pattern, we cannot say the same about short term price movements.

**[Figure 6 approximately here]**

*Absolute prices*

Deterministic factors are reoccurring cycles or phenomena that independently of other market conditions alter supply or demand. We will discuss in this section such regularities and especially examine whether any of those substantial within-year fluctuations can be explained by deterministic calendar dependent events such as Christmas, Eastern, summer or winter. We will examine whether there are any pattern in how salmon prices behave during the year. This is interesting since such factors might explain price increases/decreases that are difficult to explain in other ways. From time to time people involved in the business for instance claim that prices goes up around Christmas. There are numerous reasons for why there could be seasonalities in salmon prices. The main reason being that salmon production is a biological production strongly dependent upon weather and climatic conditions. Hence cost of production will vary dependent upon when the fish is ready for harvesting, i.e. the cost of producing a salmon ready for marketing in May might differ from the cost of producing a similar fish ready for marketing in October. Also, calendar-dependent changes in demand can influence on prices, however if these changes in demand is expected, farmers might adjust their production to them.

There exist several statistical tools for revealing seasonalities in prices. A relatively simple and illustrative way is to draw yearly plot of normalized prices. Prices can be normalized to the price in week one. i.e., if prices in week 12 are higher than in week one, the normalized price will be higher than one, if prices in week 12 are lower than prices in week 1, the normalized price will be less than one. Such a graph is presented in figure 7 with normalized prices for all the year from 1995 to 2003. However with so many years, the illustrating effect of the figure would be rather limited, so we have therefore aggregated a little by presenting three year averages together, so as to make the picture a little clearer.

We argue that there are relatively distinct seasonal patterns. For most years, prices peak some time between week 20 and 24, i.e., salmon prices seems to reach its yearly top some times between May 15 and June 15. Prices are then decreasing to around week 27, increasing again before lowest prices are reached sometimes between week 45 and week 50, i.e., sometimes during November. We can further see from the figure that prices in the best period is on average 20% higher than in the "low price" period. Based on the graph, boosted Christmas prices are not actually present. However, since increased demand before Christmas is an indisputable fact, it seems like farmers have adjusted to the increased demand, with a complementary increase in supply.

***Relative Prices***

We have until now treated salmon as the aggregate product: salmon, i.e., not discussed the large variations in prices for different types or sizes of salmon. Such aggregation work fine when discussing the fundamental trends, but disaggregating might reveal even more information about the underlying factors, and is of major importance for harvesting decisions. We will therefore also examine the relationship between prices for fish with different size. Figure 6 illustrates the importance of disaggregating prices. There are relatively large variations in prices for the different sizes. While the large fish tend to fetch a somewhat higher price than small fish, this result is not unambiguous. There also seems like there are even stronger seasonalities in the disaggregated data compared to the aggregated data.

Asche and Guttormsen (2001) argue that there exists a stable pattern in the relationship between prices for different sizes of salmon. Based on the model presented in Bjørndal (1988) they further argue that this price relationship should have consequences for harvesting models. Figure 8 is an updated version of a similar figure as the one presented in Asche and Guttormsen (2001). We have constructed relative prices by dividing the prices for 1-3 kg, 5-7kg by the benchmark 3-5 kg. The insight from the figure is clear. The pattern first recognized by Asche and Guttormsen (2001) still exists. However the relationship between different sizes has changed slightly. One can observe cycles lasting for approximately one year. Salmon in the higher weight classes are relatively more expensive during August and September. In these months 5-7 kilograms salmon are sold for about 115% of the price for 3-5 kilograms. In February and March the price of large salmon is slightly lower priced than 3-5 kilograms. The pattern for the smaller salmon is different. The smallest weight classes are relatively most expensive in November, December, and relatively cheapest in July. For an explanation of this pattern, readers are referred to Asche and Guttormsen (2002).

**Optimal harvesting**

We will in this section illustrate that the question about optimal harvesting time is closely related to the development of prices. The general answer to the harvesting question is that you should not harvest when the marginal revenue from waiting is greater than the marginal cost. Bjørndal (1988) establishes the link to the classical forestry problem and uses static optimization and comparative statics in order to explain what happens with the time of harvest under different assumptions about costs. Bjørndal based his model on a constant relationship between the unit price and fish size. In particular, he assumed that unit price was a positive linear function of the weight of the individual fish. Mistiaen and Strand (1998) recognized that the relationship between individual fish weight and unit prices may not be continuous, but rather subject to discrete jumps at given thresholds (i.e. the price function is piecewise continuous). However, Mistiaen and Strand (1998) as well as Bjørndal (1988) base their definition of the price processes on observations from one single market day, but fail to observe the dynamics in relative prices. Hence, all these studies assume that the relationship between the prices (per kilogram) of different sizes of fish is stable, i.e. that relative prices are constant over time.

We have shown the relationship between unit prices for different sized Norwegian salmon to vary over time with yearly cycles. At some times of the year small fish have higher unit price than large fish, while the relationship is opposite at other times of the year. This seasonality will likely impact the determination of marginal value of delaying harvest and consequently the optimal harvest time. This is because when the relative prices are not constant over time, the marginal value of delaying harvest is dependent upon future prices as well as future weight of the fish. This implies that the optimal harvest decision for e.g. a 2.5 kilogram fish might be to harvest if the month is January, while it might be to wait if we are in June.

To better illustrate the importance of knowledge of relative price relationships, we will present a simplified and shortened version of the model provided in Bjørndal (1988). The model concerns one cohort of fish, a one-time investment and starts with the value of a yearclass of fish. This value, *V(t)*, is found by multiplying price times quantity, defined by

$$V(t) = p(w)B(t) = p(w)Re^{-Mt}w(t) \tag{0.1}$$

where $p(w)$ is the price per kilogram fish of weight *w*, $B(t)$ is the biomass, *R* is number of recruits released, and *M* is natural mortality. *M* can be treated as constant or vary through time with respect to fish size and/or time of the year. Assuming zero cost, the fish farmer will harvest at the time that maximizes the present value of the biomass value as considered at the time of releasing the fish.

$$\underset{\{0 \le t \le T\}}{Max} \; \pi(t) = V(t)e^{-rt} \tag{0.2}$$

The first order condition is

$$\pi'(t) = V'(t)e^{-rt} - rV(t)e^{-rt} = 0 \tag{0.3}$$

and the optimal harvesting time thus satisfies

$$V'\left(t^*\right) = rV\left(t^*\right) \tag{0.4}$$

By finding the changes in $V\left(t\right)$ over time and evaluating the separate elements in the biomass value more closely, a better understanding of the harvesting rule is acquired. This rule says that the fish must be harvested when the marginal increase in the value of the "natural capital" (i.e., fish in the sea) equals the opportunity cost:

$$V'\left(t^*\right) = \left\{ \frac{p'\left(w\right)}{p\left(w\right)} w'\left(t^*\right) - M + \frac{w'\left(t^*\right)}{w\left(t^*\right)} \right\} V\left(t^*\right) = rV\left(t^*\right) \tag{0.5}$$

The above expression can be rewritten as

$$\frac{p'\left(w\right)}{p\left(w\right)} w'\left(t^*\right) + \frac{w'\left(t^*\right)}{w\left(t^*\right)} = r + M \tag{0.6}$$

Equation (0.6) illustrates the importance of relative prices, here in the form of change in prices as a function of changes in weight $p'\left(w\right)$. The results presented above indicate that the sign of $p'(w)$ varies through the year, making $p'\left(w\right)$ dependent of time (i.e. $p'\left(w,t\right)$. This changes the optimization problem, and might have important implications for calculation of optimal harvesting time. However, the fact that the relative price changes between different sizes over the year makes the mathematics less tractable. If one is to take the pattern in relative prices between sizes into account, it will be impossible to find analytical solutions, and numerical methods must be applied.

The above model are rather theoretical, but included to illustrate how closely linked the optimal harvesting decisions are to the development of prices. The model also illustrates that optimal harvesting time is determined not only by the price level but also by the relative prices between different sizes of fish. The optimal harvesting time calculated in the model will never be *the* optimal time unless the farmer has perfect foresight about future price level and future relative price relationships.

**Salmon farm examples**

Theoretical models as the model presented above, provide important qualitative insight about harvesting times. However they have severe shortcomings when it comes to practical implementation in full scale fish farming. The models do not include several important features of fish farming, such as the capacity limit of the farm, seasonal fluctuations in market prices, multicohort management or the optimal harvesting of the various size-classes.

Pascoe, Wattage and Naik (2002) examine actual harvesting strategies employed by commercial aquaculture producers with theoretically optimal strategies derived from standard bioeconomic models. Their main result is that actual harvesting strategies differ significantly from the theoretical models. They discuss several possible reasons for that, but conclude that "it is more likely that the models are not sufficient in identifying the appropriate strategy given the risks and uncertainties faced.." and further "different modelling approaches may be more appropriate, such as the dynamic programming approaches…"

The production planning model presented in Forsberg (1999) is a practical production planning model that has the ability to take all the restrictions into considerations. We will therefore use that model, to illustrate possible value of price information. We will hence construct a model-farm and optimize harvesting, based on assumptions on cost, growth etc. To illustrate the importance of price information, the harvesting plans are optimized based on different price scenarios. Profit is then evaluated ex post.

*The Forsberg (1999) harvesting model*

The model is carefully described in Forsberg (1999) so we will only present some key features here. Forsberg (1999) present two types of harvesting management strategies batch harvesting (BH) and graded harvesting (GH); only batch harvesting will be considered here. BH strategy operates by: (1) stocking individual fish group at given time intervals into the grow-out system; (2) feeding the individual fish group in isolation from other cohorts; and (3) harvesting the entire individual fish group or a part of the cohort, as their mean size reaches market size. Various approaches to BH strategies are described in Lewis & Benham (1973), Hilge (1979), Paessum & Allison (1984), Watten (1992), Forsberg et al. (1993) and Summerfelt et al. (1993).

BH is operated by crowding the standing stock in the production cage and hauling a batch containing the preferred number of harvested fish, and transferring those into separate cages ('starving cages'). Harvested fish placed in the starving cages are starved for about 10-14 days before being transferred to well-boats and shipped alive to the processing plants and slaughtered. The harvested fish are, by this method, randomly sampled from the standing stock, which implies that mean size and standard deviation of harvested fish is assumed to be equal to those of the standing stock. This is the most common harvesting method in salmon farms.

*The model-farm*

Important assumptions are listed in table 2. We start the planning period January first, with three fish groups, respectively 2.0, 2.5 and 3.0 kilogram. Each group contains 25 000 fish, and starting biomass is hence 187.5 metric tones. To make the situation as comparable as possible with the real situation in Norway feed supply is restricted to 250 metric tones per year for the three groups, as total feed used on each farm is regulated by a government set quota.[2] The objective is to maximize net present value.

**[Table 2 approximately here]**

Based on the above presentations of salmon prices, we have constructed harvesting plans on the basis on the following price scenarios:

Scenario 1: Constant price per kilo regardless of fish size.

Scenario 2: Seasonal adjusted prices, same price regardless fish size.

Scenario 3: Seasonal adjusted prices, dynamic weight dependent.

Scenario 4: Actual prices.

Scenario 1 is hence the no information scenario while scenario 4 is the perfect information scenario. Scenario 2 and 3 includes different amount of historical information about price behavior. The value of historical price information is hence the extra profit that is gained by including the information. An upper bound for the value of price information is the profit from scenario 5 minus profit from scenario 1. Scenario 1 to

3 are constructed based on real historical prices, from the 2001-2002 period, actual prices are based on prices from 2003.

**Harvesting plans and value of information**

Harvesting plans, profit and the value of information are presented in table 3. The first impression is that the plans don't change very much between the different scenarios. For three out of four scenarios all the fish are harvested during September and October. The only large outlier is scenario 2 were all fish are harvested in May. This is an interesting result since the only difference between scenario two and three, is that we in scenario 3 have taken into account that the relative price relationship between different sized fish varies thought out the year. Prices on 3-5 kilogram fish are the same in both scenarios. These results emphasize the point made by Asche and Guttormsen (2002) saying that pattern in relative price relationship have important implications for the calculations of optimal harvesting times.

**[Table 3 approximately here]**

To calculate the value of information, profits from operation in the planning period, January first to harvest, is calculated. Only two variable costs are considered, videlicet feed and harvesting cost. These simplifications overestimate profit, but should not alter the conclusion about information value. Based on the results from the model, there is no doubt that perfect information has relatively high value. A farmer that could predict exactly the prices for all weigh classes in all months the next year, would nearly triple his profit compared to the uninformed farmer.

However perfect foresight is not possible, so it is maybe more interesting to look at the value of sample information, i.e., scenario 2 and 3. We see that both plans outperform the no-information scenario. Value of information is NOK 165 000 and 313 000 respectively.

**Concluding Remarks**

The substantial variability in the profitability of salmon farms indicates that information which improves decision has substantial value. A good decision support model provides information that allows the farmer to time the production and harvesting decisions well in relation to the factors that primarily contributes to the volatility. Prices are among the most volatile factors in the farmers decisions process, and is really the only of the factors that contributes to the variability in profits that has received any attention in the academic literature. Bringing the information from forecasting models into the harvesting decision pulls together the two main research topics regarding management practice in fish farming: production planning and forecasting of prices.

Volatile salmon prices make the timing of harvesting an important factor for profitability in salmon farming. The fish farmer has to decide whether to harvest and market the fish at a known price, or to continue to feed to harvest and market a larger salmon at an unknown future price. When prices vary between NOK 14 and NOK 22 for different sizes at different times, harvesting the right fish at the right time is potentially one key factor for success in the fish farming industry.

The theoretical examples and the results from a simplified full scale model farm, emphasize that price-information has the potential to create extra profit for the farmer. In our salmon farm example based on the model presented in Forsberg (1999), the fully informed farmer more than tripled his profit compared to the farmer basing his decision on a fairly naïve decision model. Also the farmers utilizing only historical price information improved their results substantially, indicating that also sample information creates value. However it is important to have in mind that our examples are based on one year, and that the choice of another time period for the construction of price scenarios could alter the results.

The harvesting model used in this article is more complex than most of the theoretical models presented in the literature. However, the example is still simplified, and the results should be taken as indications, and not as *the* correct value of information. In practice, fish farmers do also add several other restrictions into the harvesting decision problem in order to make the operations practically feasible, such as (i) using the full capacity of a well-boat when the farmer decides to harvest; (ii) harvested biomass must balance the operation workload, transportation and processing capacity; (iii) harvest fish over a limited size range in order to meet market demand; and (iv) reducing the number of harvest operations in order to avoid stress in fish, etc., Forsberg (1999). Including more restriction in the harvesting model would probably increase the cost of providing the higher valued fish, and hence reduce the value of price information.

New innovations which allows fish farmers to size-grade the most profitable size class from the live stock prior to harvesting (GH strategy), will undoubtly give fish farmers a better tool to exploit the variation in relative prices more optimally, and to better take account of price peaks. Forsberg (1999) have demonstrated that GH strategies can be as high as 10% more profitable than batch harvesting strategies where both small and large fish in a stock will be harvested simultaneously. The differences in GH and BH strategies are however a subject of further studies.

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**Tables and Figures**

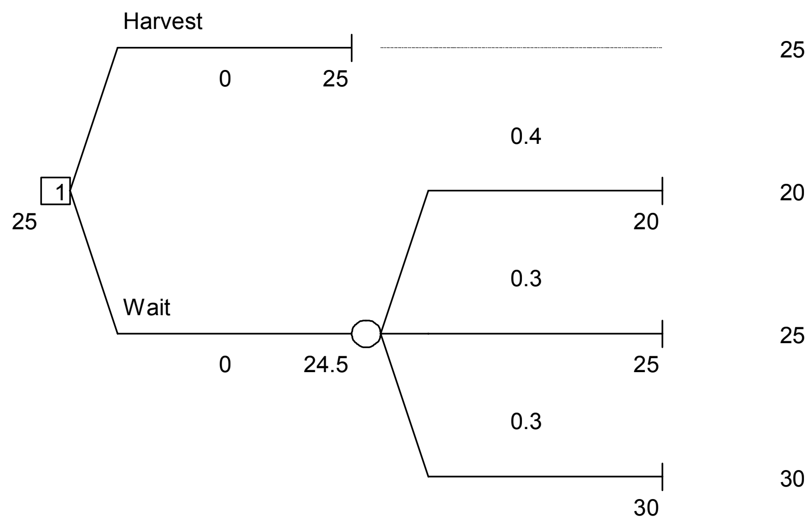


**Figure 1** Decision tree for the fish harvesting example

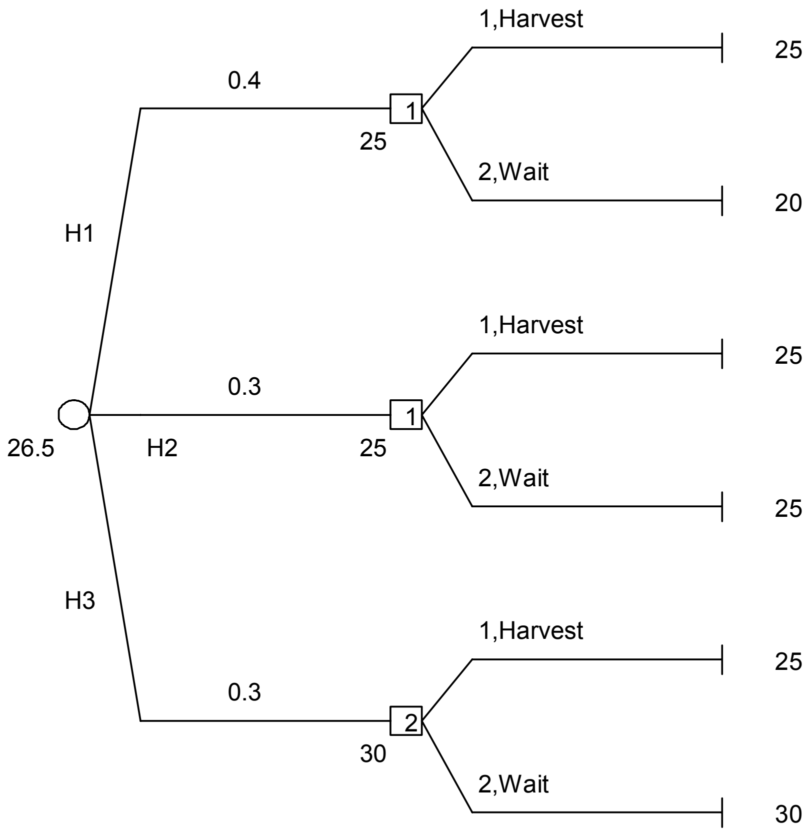


**Figure 2** Value of perfect information

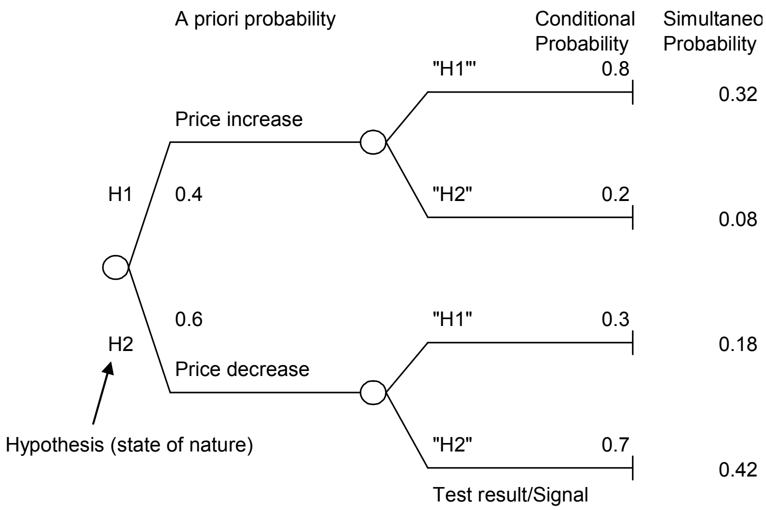


**Figure 3** Decision tree for the fish harvesting example with sample information.

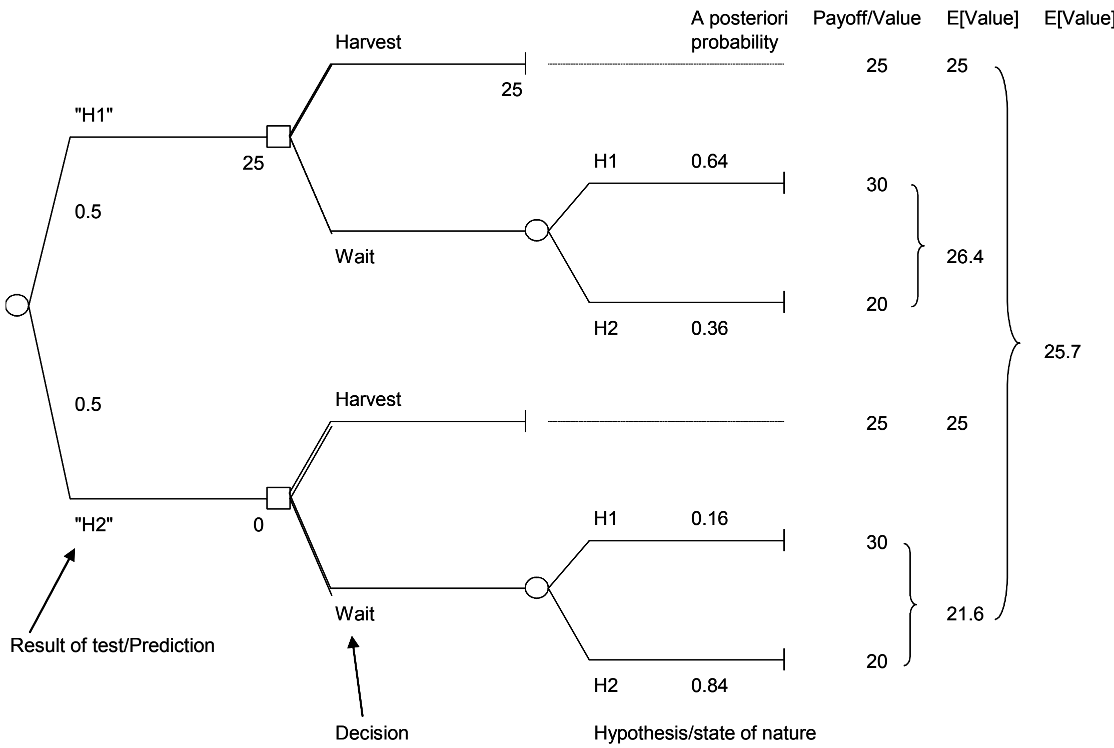


**Figure 4:** Inverted decision tree for the fish harvesting example with sample information

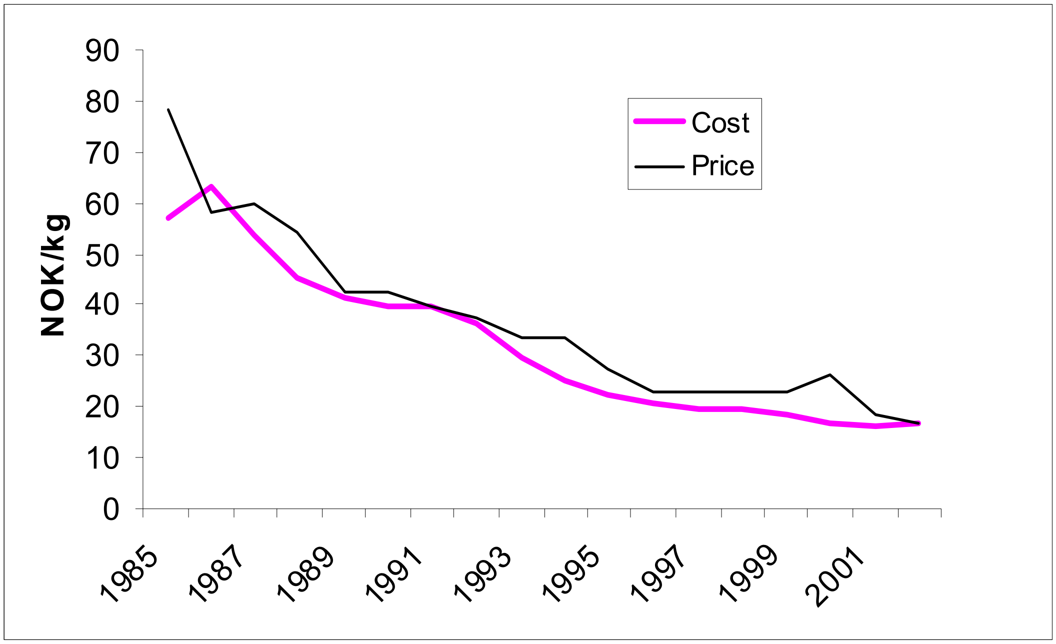


**Figure 5** Operating cost versus prices for Norwegian salmon

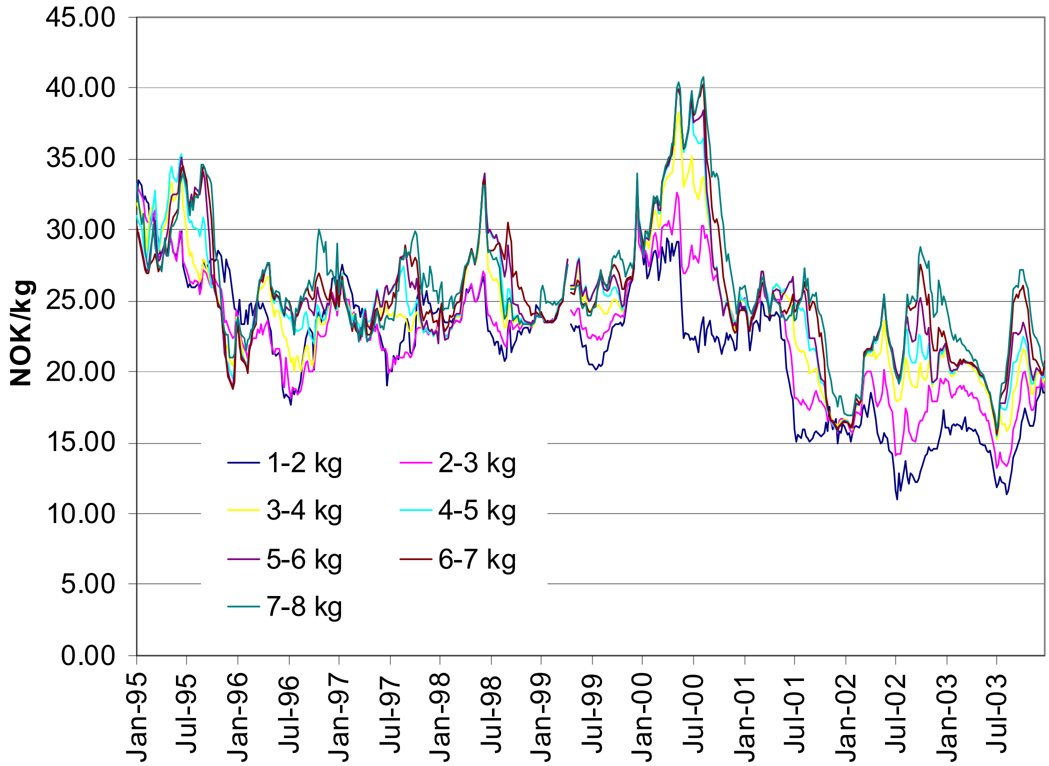


**Figure 6** Weekly salmon prices 1995-2003, different weight classes.

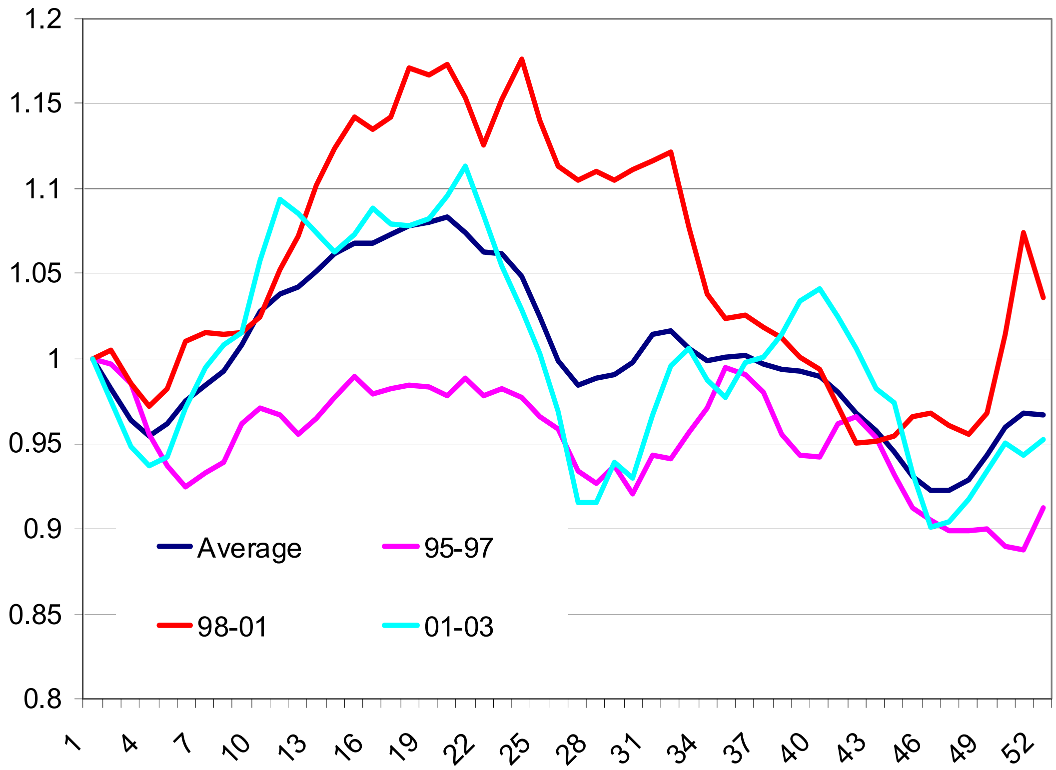


**Figure 7:**Normalized prices week by week, by periods of three aggregated years.

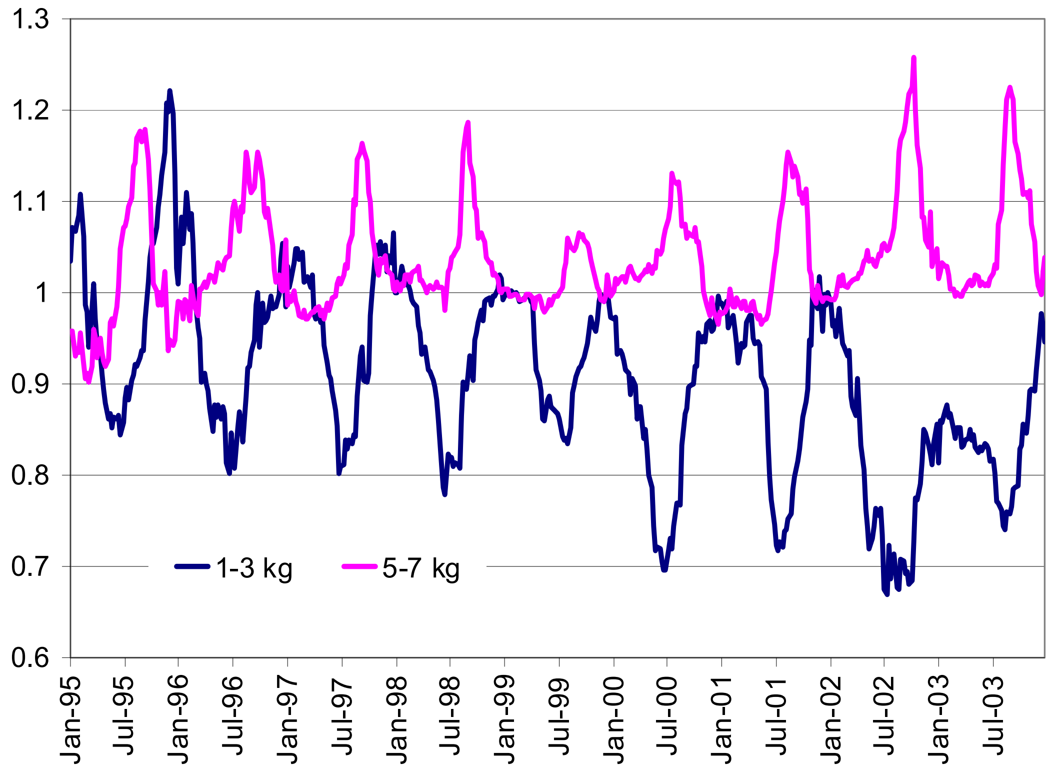


**Figure 8**: Prices of 1-3 kg and 5-7 kg Norwegian salmon relative to 3-5 kg.

**Table 1: Aposteriori probabilities**

| State of nature | Prior | Posterior given prediction up | Posterior given prediction down |
|---|---|---|---|
| Price up H1 | 0.4 | 0.64 | 0.16 |
| Price down H2 | 0.6 | 0.36 | 0.84 |

**Table 2:** Assumptions, model farm

- Three fish groups: 2.0, 2,5 and 3.0 kg at 1th Jan
- Fish number: 25 000 for each fish group
- IB biomass: 187.5 metric tonns
- Growth and mortality as usually found in South west Norway
- Restricted feed supply (250 mt/yr for the three groups)
- Only two variable costs considered:
- Feed costs increase with increasing fish size;
    - ranging from 8.00 NOK/kg fish at 2 kg to 9.50 NOK/kg at 7 kg
- Slaughtering cost (3,50 NOK/kg harvested)
- Objective: Maximize net present value (r=1%/month)

**Table 3:** Harvesting plan, profit and value of information, VOI for different price scenarios and fish groups.

| | | May | September | October | Profitt in 1000[a] | VOI[b] |
|---|---|---|---|---|---|---|
| Scenario 1 | Group 1 | | | 103 (5.3 kg) | 279 | 0 |
| | Group 2 | | | 122 (6.3 kg) | | |
| | Group 3 | | 68 (6.4 kg) | 64 (7.2 kg) | | |
| Scenario 2 | Group 1 | 54 (2.6 kg) | | | 444 | 165 |
| | Group 2 | 66 (3.2 kg) | | | | |
| | Group 3 | 78 (3.8 kg) | | | | |
| Scenario 3 | Group 1 | | 62 (4.7 kg) | 34 (5.3 kg) | 592 | 313 |
| | Group 2 | | | 122 (6.3 kg) | | |
| | Group 3 | | | 139 (7.2 kg) | | |
| Scenario 4 | Group 1 | | 92 (4.7 kg) | | 1279 | 1000 |
| | Group 2 | | 109 (5.6 kg) | | | |
| | Group 3 | | 125 (6.4 kg) | | | |

Average weight of the harvested fish in parentheses.

[a] Profits from operation in the planning period, i.e., (Sales income-Variable cost)-Value of the fish by January 1.

[b] VOI, value of information is extra profit compared to scenario 1.

**Footnotes**

[1] NOK = 100 = EUR 11.95 = USD 14.65. September 22, 2004. (www.oanda.com).

[2] See Kinnucan and Myrland (2002) for a discussion of these regulations.