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ABSTRACT

The objective of the paper is to simulate behavior of economic agents with a special emphasis on the use of the time resource in economic processes. The case studied, is brought from the fishing industry. With an aid of simulations, the study analyzes behavior of economic agents as they lead their processes through time. The paper estimates the value of time in a fishery operation, and shows that the time cost is essential in clarifying some phenomena in economic behavior of agents. Among the conclusions is that difference in economic efficiency between strong and weak ownership is due to difference in time costs. The secondary goal of the paper is to develop a simulation tool that can be of use in analyzing a range of problems in the fishing industry, ranging from decision situations onboard fishing vessels to serve as a tool for fishery managers and legislators.

KEYWORDS: Economics; Natural resources; Value of time; Fishery management; Simulations.

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1. Introduction

The objective of this study is to analyze with aid of a simulation model the decision behavior of economic agents with special emphasis on the value of the time resource. In this paper time is regarded as a resource and is treated in a same manner as other resources i.e., labor, land or fish stocks. Consequently, the use of the time resource will yield costs, time costs. The center of attention is the economic behavior under individual quota fishery management (IQ). The paper analyzes behavior of economic agents in the fishing industry as they lead their processes through time with special emphasis on estimating the cost of time. A secondary goal of this paper is to develop a tool that can be of use, not only in academic analyzes but also in a range of decision situations in fisheries, from aiding captains in their daily decision situations to use as an aid in fishery management processes. A simulation model of a factory trawler is well suited for this task, because almost all types of production processes that occurs within the fishing industry can be fitted within it's operational concept.

Trawlers, at least in the more developed fisheries of the world, catch a great and an increasing deal of the global fish resources. These are mainly stern trawlers, towing the trawl from the stern of the ship. Typically, the trawl is towed for a few hours, and then hauled and emptied and set again, possibly after some relocation of the vessel. Trawlers with onboard processing capabilities (beyond gutting and heading) are called factory trawlers. Examples of the products processed are various types of frozen fillets and surimi[2]. The main production stages in fillet production are gutting, heading, filleting, skinning, trimming, packing and freezing. Some or even most of these stages can be skipped, and therefore the process has the capability of yielding a range of products differing in price and in processing speed. For many of these products different operations strategies can result in different quality grades that will have an impact on which market segments the products will be shipped and sold to. The operation strategies will therefore have an impact on the final sales prices for the products.

The focus here is on a single fishing year, during which several trips may be taken. Each trip consists of a number of hauls and a trip ends when the fish hold capacity or some other determinant of the maximum trip length is reached. Factory trawlers can vary in size but are usually between 200 to 5.000 gross registered tons (35-1000 meters long), and in crew size from 15 to 150 men. The length of trips varies from say 20 days to many months. The average catch rates are also very different at the various fishing grounds of the world, and

[2] Surimi is a minced fish product.

might range between zero and more than 100 tons/hour. In most cases, the freshness of the raw material is important for processing. Hence, the catch of one haul is usually processed while the next haul is being towed, even though some storage time is possible.

The operation of a modern factory trawler is a complex management process. In addition to the better-known tasks like navigating and fish finding, many important decisions regarding the onboard processing have to be made. A factory trawler can be viewed as two separate enterprises, a harvesting, and a processing unit. In many cases, the crew is assigned to service in either operation but on smaller vessels, the labor is often moved between the two functions. Each haul (the time the trawler drags the net) usually lasts between two and six hours, dependent on fish availability and operational surroundings, such as the structure of the ocean floor. After each haul, the catch is stored in a fresh fish hold awaiting processing and the trawl is set to make a new haul. While the crew is processing the catch and storing it in the freezing hold, the vessel is fishing for more. Then, the economic agent for the operation of the process (production manager, captain or whoever is in charge) has to decide if more time should be used to produce the most valuable, and usually the most time-consuming products, or if "faster" but less valuable products should be chosen.

There are number of factors an agent in fisheries has to take into consideration each time there are changes in his operational environment. At times, when catch rates are high, the size of the fresh fish hold may become a bottleneck in the production process because it has to be cleared for the contents of the next haul. Otherwise, the trawling operation has to be brought to a halt, resulting in reduced total catch and losses in total revenue. The random fluctuations in catch rates, and in many cases weather conditions, add to the complexity of the decision process. The agents are never sure of the quantity and what mix of fish species will be in the next haul. In planning the process, the best information available to the agent is the content of previous hauls, historical data, and information from his colleagues.

The scenario laid out in this paper has its basis in the Icelandic fishing industry. A description of the Icelandic fisheries for this period can be found in Arnason (1995). Sigvaldason et al. (1969) describes a similar model to the one presented here. Their model describes a wet fish trawler and the objective is to study the supply of raw material to freezing plants in Iceland. Furthermore, vessels of different sizes are compared in the study. In Jensson (1981), a simulation model of the Icelandic capelin fleet is reported, emphasizing the decisions regarding the choice of harbor and congestion problems.

2. Simulating the Behavior of an Agent in an Economic Process in Time. The Fishery Management Case

In this paper, by *economic process in time* we mean an ongoing dynamic process driven by rational economic agents. The process can occur either in the state of affairs or it can be simulated with an aid of computers or by other means (in a laboratory, for example). Once a process has been defined and put in motion, i.e. necessary resources allocated to achieve the projected objective, the process will keep running as long as it is feasible, or as long as the outcome requirements for the process are met at each decision point in time. An economic process in time is irreversible. At various points in time however, a change can occur in the economic space due to exogenous factors such as the random catch generator presented in this paper. Such change may alter the allocation between the resources and the projected outcome of the process may no longer be the optimal one. By reallocating the resources of the process through manipulation in price and quantity, the agent may readjust in order to maintain the maximum output. The window of opportunity for an agent to readjust his process in time according to changes in his economic space will depend on how the resources and their variables are interrelated in the process[3]. A change in one resource will have an impact on use of other resource(s) in the process. Resources (use of them) in economic processes in time are therefore interdependent and so are their values. Use of resources generates costs and the objective of the economic agent of an economic process in time is naturally, to reduce the resource costs. In general, the agent will tend to use less of resources in the process that are relatively more valuable (more costly to use).

In static analyses the time resource does not exist, it is only when the process starts to run in time that it can emerge as a resource (Arnarson, 2002). The idiom *time resource* should not be confused with the parameter *time*. The time resource in economic processes can be measured by time and a monetary value in a same way as, for example, the fish resource can be measured in metric tons and a monetary value. While the process is running, unforeseen events may change the quantity of time available to carry through the process. The weight of a change in quantity of available time in a process will depend on its value and the availability and values of all other resources in that same process (the interdependency of the resources). For instance, if the value of the time resource in a process is relatively high compared to other resources, the agent will tend to use relatively more of other resources. The value of the time resource, or time costs, should not be

[3] For example, how many units of labor, capital, fish and other resources are needed to yield certain revenue.

confused with the term *opportunity costs*. The rational agent will at all time allocate the resources (including time) of the economic process optimally. There exists only one optimal decision solution in the economic space of the rational agent. There are no alternatives for an agent within the economic process in time and therefore there are no opportunity costs.

The analyses in this paper focus on a time horizon of a one-year operation of a factory trawler (see Section 4). The annual operation is divided into three cycles (focuses), year-, trip-, and haul cycles. In our case, the focus is on the innermost cycle, the haul cycle. When the trawl is hauled onboard with its contents of raw material (fish), the catch has to be processed at once, or else it will deteriorate. The agent has therefore to make an instant decision on how to utilize the raw material, i.e. what product(s) to manufacture from the catch. The Catch Generator provides the content of each haul through a random simulation of the catch rates (see Appendix 1). Due to the randomness in amount of raw material in each haul, the time allocated to production may vary from one point in time to another. Dependent on the accumulated results from each decision point through time, the quantity of the remaining time resource (the available time to carry the processes through) of the process may also vary relatively to other resources. Divergence in the time resource left to carry through the process, results in divergence in projected outcome of the process (POP) of that same process (see section 5). Changes in economic space at each point in time may also change the POP of the process.

So far, we have discussed matters concerning the endogenous parts of the agent's economic space. The exogenous part of the agent's economic space consists of a number of restrictions or frontiers. Conveniently, we can divide them into technical-, ecological-, or social frontiers. In this paper we will analyze the impact of variation in two frontiers on the decision making of an economic agent, the catch-rates (an ecological frontier provided by the catch rate generator) and variation the fishing quota, allocated to the vessel (a social frontier). The impact of different quota systems and their economic efficiency of firms and industries are central issues in the natural resource literature. Within the fishery literature, the most debated systems are those that are usually associated with individual quota (IQ) and total quota (TQ). Under IQ management system, each agent (vessel or firm) is allocated a seasonal share of the total quota for the respective fish stock. Under the TQ system, all agents are allowed to harvest as long as the total seasonal quota for the respective stock is not reached. The TQ management system is in the literature often referred to as "the Olympic system".

Arnarson and Johnston (1991) simulated economic behavior of agents operating under a TQ fishery management system. A multi-species, multi-products linear programming model was used as a decision engine to simulate the output from the Newfoundland's shore based fishing industry, in a stepwise optimization through time. Arnarson (2002) used similar approach in simulating the Alaskan fishing industry, but the analyses were extended to include the fishing fleet. Among the conclusion of that paper is that the different behavior of agents under various fishery management schemes can be explained by the difference in the value of time resource. Within the TQ fishery management system, the value of the time resource is usually much higher than within the IQ system and consequently, the economic efficiency of that system (TQ) is usually lower. In this paper, we will in part explore this difference by increasing the individual quota. Increasing the quota resource will relatively reduce the available time in the economic process, and thus make the time resource relatively more expensive and less feasible to use. The agent will compensate (in this case) by using more of the fish resource in his process (by choosing to produce products that move faster through the production lines).

In this paper, we will make use of a linear programming as a decision engine in simulating behavior of an agent in an economic process in time (see section 6). The simulations assume that the agent is operating under the IQ fishery management system, although as mentioned above and the following analyses will be evidence for, that it is the value of the time resource that is the cause for the difference in economic behavior rather than the management system itself.

3. Model Description.

In this study, we assume that the fishing fleet consists of identical fishing vessels, factory trawlers. The vessels in the fleet are all restricted by similar frontiers and operate within similar economic space. We will focus this study on one vessel that will act as a representative for the rest of a fleet. Within the year, there are three occasions or milestones, where the agent's economic space is altered and he has to re-optimize his process. This repeatedly occurs every time the net is hauled and the quantity and the mixture of the catch becomes apparent. In the case simulated in this paper, this can happen several times per day during a trip that can last up to 24 days. The catch generator provides for the quantity of fish in each haul (see Appendix 1[4]). The next occasion for revision of the

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[4] In the simulation described in this paper, we use only one stochastic generator, the catch generator. Other random generators could be included i.e., generators for weather, engines breakdowns and damages to the fishing gears.

POP is the beginning of the next trip and the third at beginning of the year. Figure 1 illustrates the main body of the model and its three cycles; *year-, trip-,* and *haul* cycles.

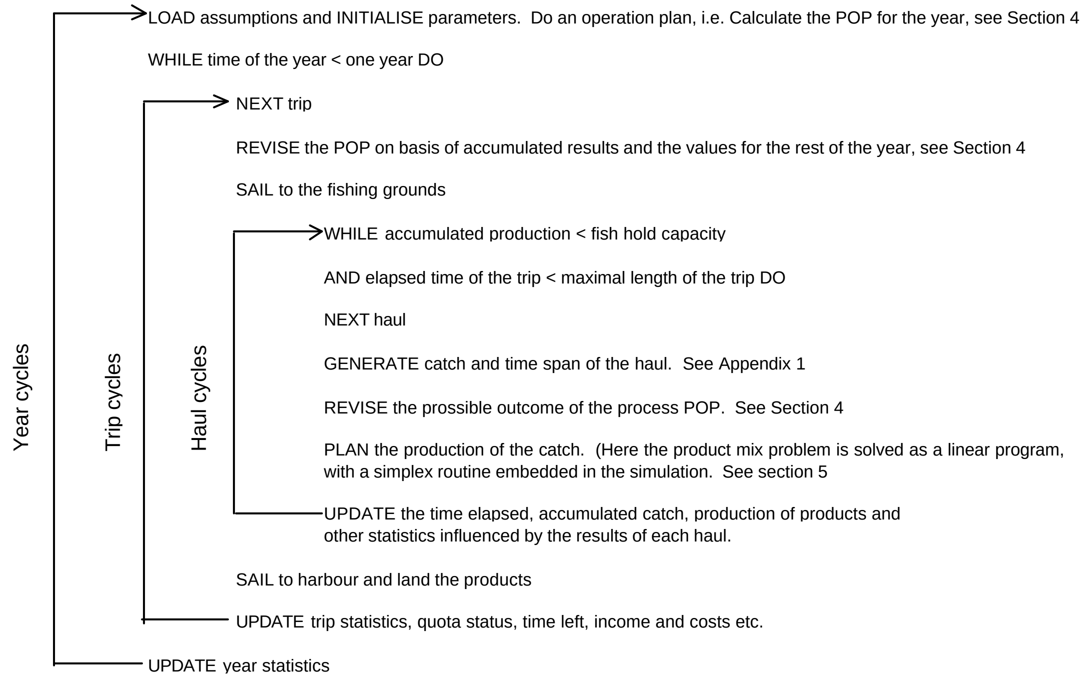

Figure 1. The Factory Trawler Simulator, a Structure Chart.

Figure 1 shows that there are two variables that control the trip lengths of the vessel; the fish hold capacity and the maximum length of the trip. The maximum length of the trip is simply set to 24 days being the average bunkers capacity of the vessel type used in the simulations (fuel, water etc.). In periods with high catch rates, the fish hold may become fully loaded and forcing the vessel to steam to harbor and deliver the products. With increasing catch rates the vessel will spend relatively more time steaming and in harbor than fishing and processing. Increments in catch rates will therefore not necessary yield a proportional increase in revenue.

Technically the model structure is composed of modular units, in a flexible manner so that units can be added or removed. Those units deserving further discussion in the context of this paper are explained in the following two sections and Appendix.

The model presented in this paper is tailor-made to analyze and answer specific questions regarding the time resource. The model can however easily be adapted to address a variety of issues, ranging from a specific decision problems onboard fishing vessels, such as production planning, to more general fishery management problems, such as the impact of implementing various types of legislations.

A simulation model like this serves as a laboratory, where experiments can be made without the costs of real life. Following is an overview of the potential users:

- Naval architects and engineers, comparing alternative design of equipment and production facilities onboard.
- Operators of factory trawlers, planning the year or single trips, or deciding whether to invest in a certain processing line or not, or to buy more quota.
- Fisheries management authorities, evaluating the consequences of quotas or other management schemes for the firms and the sectors of the fisheries.
- Educators and trainees in fisheries operations management. By using simulators, principles of management can be taught and trained.
- Researchers in fisheries management and economics, and developers of decision support systems for operators and captains.

4. Revising the POP as the Process Moves Through Time

The simulations assume that the POP (projected outcome of the process) is a dynamic variable that can change as the economic process progresses through time. At the beginning of each cycle (year-, trip-, or haul cycles), the agent will revise the POP. The modeling approach used is as follows:

1. Revision of available resources in the *operation plan* for the remaining part of the year. This is done at the beginning of each trip. If the catch rates generated were lower than average in the last trip the captain has to try to compensate by fishing and processing more per time unit in the next trip.

1.1 Plan *number of trips left*, NTL:

NTL = (Year - time elapsed of year)/maximal trip length (hours). (1)
Rounded up (unless excess time is very small if rounded down).

1.2 Find *average quantity per trip*, AQT:

AQT = (Vessel quota - accumulated catch)/NTL (in tons). (2)

1.3 Modify AQT with a seasonal (by months) *index of catch rates* ICR_t (see Appendix 4), describing how the next month is compared to the remaining months of the year. This gives the *planned quantity for the (next) trip*, PQT (tons):

PQT = AQT * ICR_t (in tons). (3)

If PQT < Minimum for a trip, then reduce NTL by 1 and do 1.2 again. This means one or more trips will be skipped. This condition applies when the remaining quota is too small to make it profitable to start a new trip.

If PQT > Maximum for a trip, then use the maximum value. This could be the open access case, where vessel quota is infinite, or a case where the annual vessel quota cannot be reached.

2. Revise, after each haul, the *projected outcome of the process* (POP) for the next haul.

2.1 Find the *planned processing rate* for the remaining part of the trip, PPR in tons/hour, in accordance with the operations plan and the planned quantity for the trip:

PPR = (PQT - accumulated catch of trip)/time left of trip (tons/hour). (4)

PPR is, however, never less than a given minimum rate.

2.2 Revise, if necessary, according to possible changes in prices and variable costs, the *estimated net revenue per ton of fish caught*, NRF:

NRF = Reference sales price * raw material requirement - variable costs (IKR[5]/ton). (5)

The sales prices for the products may vary by seasons as the catch rates figures do. It also applies to raw material requirement for the products[6], and various variable costs, such as fuel-, and fishing gear costs.

2.3 Estimate the *expected catch rate*, ECR, for the next few hours. The estimates can be based on the content of previous hauls and other relevant data. Here, various sophisticated forecasting methods could be applied. In our model, we simply use the last haul:

ECR = Catch rate observed in last haul (tons/hour). (6)

2.4 Revise the *projected outcome of the process*, POP:

POP = NRF * MIN(PPR, ECR) (IKR/hour). (7)

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[5] Icelandic currency.
[6] The reciprocal of the raw material requirement is often named yield recovery rate (from whole fish to finished product). In Appendix 3, this variable is named R_j.

In this way, the value of PPR "sets the pace" for the assessment of the POP. It would be an irrational decision of an economic agent to assume that he can fish and produce at rate PPR when ECR is lower. The ECR is based on the best information available on what will happen in the near future. When the PPR is lower than ECR, the agent can possibly use more time to produce. If the situation ECR<PPR repeats itself through the process in time, the value of POP will increase (projected available time will be reduced and simultaneously the quantity of remaining quota will increase).

5. The Decision Engine

Each time a trawl is hauled onboard, the agent has to make a decision on how to allocate his resources within the economic process. As stated earlier, the agent can choose between the use of the two interdependent resources i.e., the raw material (fish resource) and the time resource, or more specific:

- How much of the time resource should be allocated to processing, i.e. should he wait to start the next tow, or should the agent allocate the expected trawling time for the next haul to processing and go on with the towing operation?

The key to this is the decision on which products should be produced, i.e. the product mix decision after each haul.

Given a certain projected outcome of the process (POP), this is a reasonably well-defined decision problem. Here, we assume that the agent is a rational optimizer, and we model the decision behavior by solving a linear program (LP), similar to the one reported in Jensson (1988), Arnarson and Johnston (1991) and Arnarson (2002).

Decision variables in the LP model are:

X_j - Quantity produced of final product j (tons of product).
TR - Amount of the time resource allocated to processing (hours).

Coefficients:

P_j – Net sales price for product j (IKR/ton). Sales prices minus direct variable costs, such as wrappings. In this case, most of the variable costs of a factory trawler can be regarded as fixed costs and thus, will not have an impact on the results of this study. For example, the crew of the factory trawler is a fixed number regardless of which production process is chosen. The labor costs are therefore the same for all quantities and types of products and are therefore regarded as exogenous in this study.

$\mathbf{W_j}$ - Work requirement in processing for product j (man hours/ton of product).
$\mathbf{R_j}$ - Raw material requirement for product j, i.e. the reciprocal of the yield coverage (tons of fish/ton of product).
POP - Projected outcome of the process, see last section (IKR/hour).
MEN - Crew size of shift working in processing.
RAW - Raw material, i.e. catch of last haul (tons of fish).
FRC - Freezer capacity (tons of products/hour).
ETT - Expected time for trawling the next haul. In this study simply set equal to the trawl time of last haul (hours).

It should be noted that the Icelandic factory trawlers are usually equipped with several filleting machines and the filleting operation does not restrict the operation. We have therefore chosen to omit that restriction in our model but if one whishes, it is easy to add.

The model therefore maximizes the net sales value of the products minus the cost of time, with respect to limited work force, raw material, freezer capacity, and the time resource:

$$MAX\ \mathrm{Z} = \sum_j P_j * X_j - POP * TR \quad (\mathrm{IKR}) \tag{8}$$

With respect to:

$$\text{Manpower}: \sum_j W_j * X_j \leq MEN * TR \quad (\text{Man hours}) \tag{9}$$

$$\text{Raw material}: \sum_j R_j * X_j \leq RAW \quad (\text{Metric tons of fish}) \tag{10}$$

$$\text{Freezing}: \sum_j X_j \leq FRC * TR \quad (\text{Metric tons of products}) \tag{11}$$

$$\text{Time allocated to processing}: TR \geq ETT \quad (\text{Hours}) \tag{12}$$

$$X_j \geq 0 \tag{13}$$

6. Analyzing the Impacts of Individual Quotas

A simulation system can never be more than an outline of a real decision situation. In an efficient simulation model the number of variables has to be limited and include only those that have a considerable impact on the problem domain that is to be analyzed. In this paper, the number of fish stocks are limited to one and the economic agent has a limited number of products that he can chose to produce. Fixed costs are not included in the analysis as well as a number of variable costs that do not have an impact on the overall conclusions. The analysis is limited to a maximum of one year and there is no opportunity for technical improvements.

Data for our case is given in Appendices 2, 3 and 4. The key data for a typical Icelandic factory trawler is given in Appendix 2. Appendix 3 shows data on products that the simulated agent can choose from along with key data (yield, man power requirements etc.). As can be calculated from Appendix 2 and Appendix 3, the trawler has a nominal capacity of producing from ca. 3.900 metric tons of raw material of the most valuable product (AM11), assuming 8 men per shift and 350 operating days a year. Data for the seasonal catch rates of Cod is shown in Appendix 3. The average catch rate is 1079 kg per trawling hour. Using the same operating numbers as for the production and furthermore assuming that the trawler operates it's trawl 70% of the operating time gives the annual harvesting capacity of ca. 6.000 metric tons of round fish.

An annual allocation of quota, from 1.000-, to 5.500 metric tons was simulated 20 times for each value of the quota at 500 metric tons intervals. The sum of the 20 runs made was used to generate average values at each quota level (1000 Mt., 1500 Mt etc.). The calculated average results are shown in Appendix 5. In order to make the line of arguments simpler we chose to divide the products listed in Appendix 3 and 5 in two major groups. A high priced products for the USA market (AM11 and the by-product MAR1) and lower priced products for the European markets (RL11, OSN1, HEI1). The results for these two major product groups are presented in Figure 2.

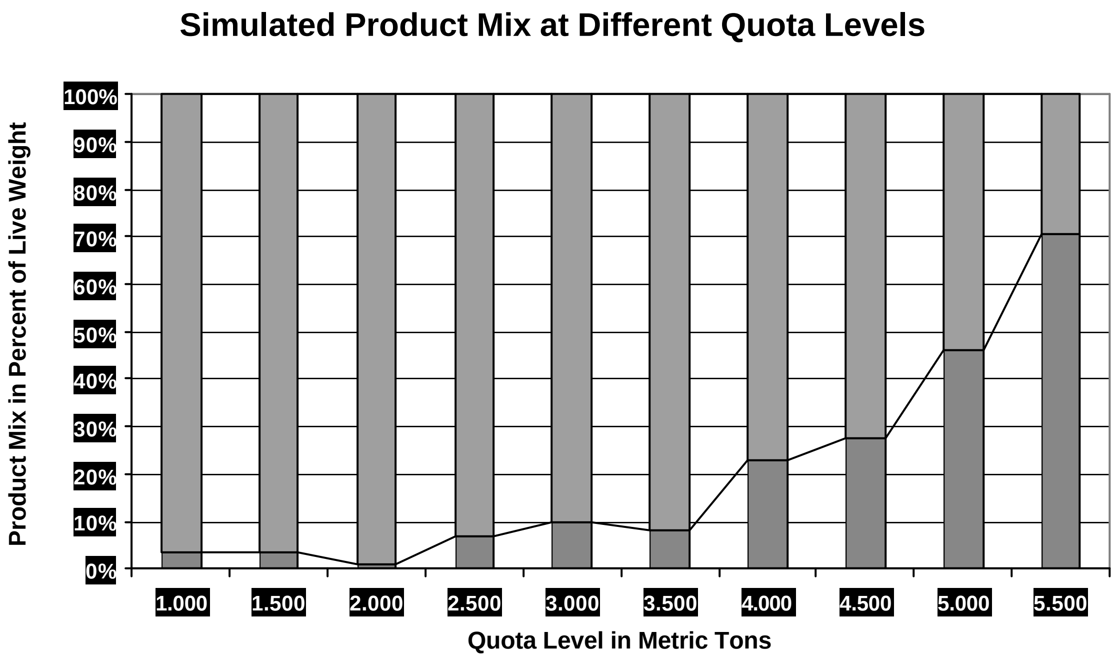

Figure 2. Simulated Product Mix at Different Quota Levels.

Figure 2 shows that when the quota level is increased, the share of the less valuable products increases as well. This is as expected, by increasing the quota, planned processing rate (PPR) increases along with projected outcome of the process (POP), with an inevitable reduction in the use of the time resource (TR) on the right hand sides of the constraints in the LP model. *Ceteris paribus*, increasing the quota will reduce the time available to process each unit of raw material. The agent responds to this reduction in available time by producing the less valuable and "faster" products. The AM11 product for example (see Appendix 5), decreases its share from 83,2% at quota level 1.000 metric tons, to 24,4% at level 5.500. At the same range, the product OSN1 has increased its share from 0% to 49% at quota level 5.500 metric tons. Increasing the available time in the economic process would create an opposite effect. The production will shift to the favor of the more valuable and "slower" products at all quota levels.

By increasing the quota level in a fishery, we can expect to change the product output and therefore marginal revenue of the output from that same fishery. In static analyzes we would expect the production to shift from more valuable products to less when the quota reaches the average capacity for the most valuable products (around 3.900 metric tons). The results from the dynamic analyzes in Figure 2 show that this starts earlier or around 2.500 metric tons. Steadily increasing the quota will result in gradual reduction of the marginal revenue of the process.

This is shown in Figure 3. The simulated total revenue for each quota level Q, is calculated from tables in Appendix 3 and 5 using the expression:

$$\sum_j P_j * X_j . \qquad (14)$$

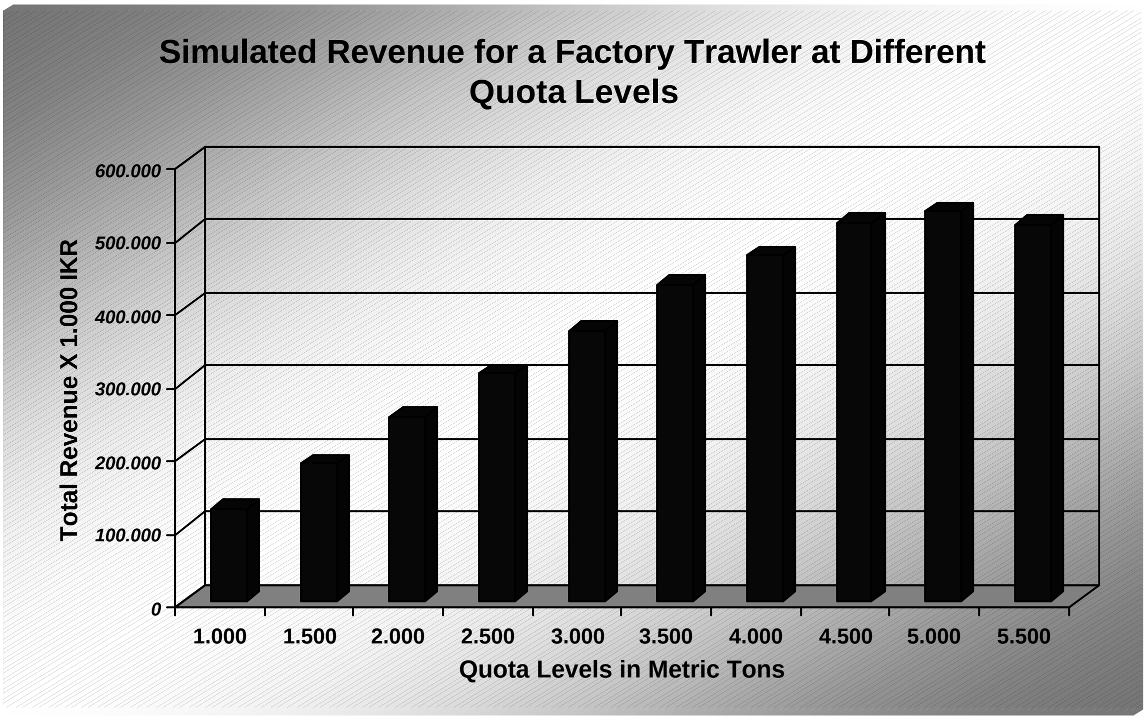

Figure 3. Simulated Annual Revenue for a Factory Trawler.

Figure 3 shows that the total revenue is at its peak at 5.000 metric tons and is in fact reduced at 5.500 metric tons. The difference in marginal revenue at different quota levels expresses a cost, caused by difference in available time to process, or a time cost. This cost of time can be estimated by comparing how much the total revenue would have been at a given quota level if the agent had been able to (had time available to) produce all of the raw material into the most valuable product (AM11 plus it's share of the by-product MAR1). At every point in time, the agent has made a correct decision when he optimized the use of the resources in the economic process. The analyses of the process in hind side however, show that the results are below the maximal output of the process. The reason for this difference is as stated earlier, that the time costs exists only in the state of affairs or in simulations. In analyses of processes, the time costs are usually put equal to zero.

The cost of time is illustrated in Figure 4. The time cost is shown as a percent of total maximum possible revenue per unit of raw material. The numbers in Figure 4 are calculated using Appendix 3 and 5 and following expression:

$$1-\frac{\dfrac{\sum_j P_j * X'_j}{Q}}{\dfrac{P_{AM11}}{R_{AM11}}+P_{MAR1}}, \qquad (15)$$

In the expression above the P_{AM11} and $P_{MAR1,}$ represent prices per kilogram product. R_{AM11} expresses yield from product to raw material. X'_j is the average quantity of the product j in the simulation runs.

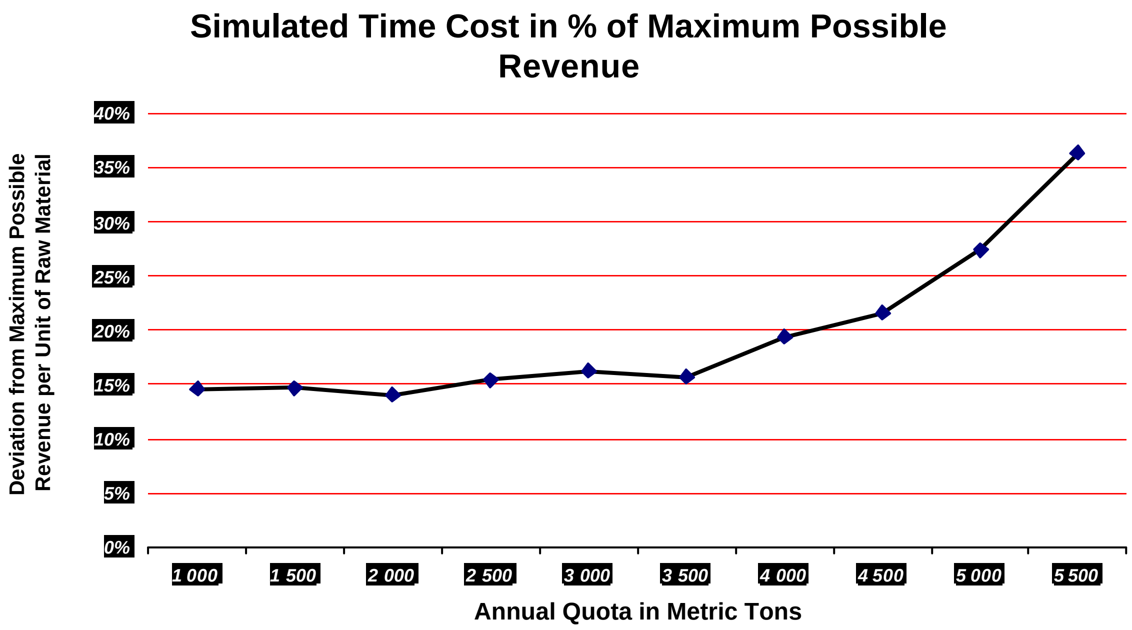

Figure 4. Simulated Time Cost. Deviation from Maximum Possible Revenue per Unit of Raw Material.

Figure 4 shows that the time cost, due to the stochastic behavior of the catch generator alone, is initially about 15 percent. The reason for this is that even at lowest quota levels a portion of the catch is produced into low-priced "fast" products as shown on Figure 2. There exists more than one explanation for this behavior. If in longer periods, the catch the catch has been less than the planned processing rate (PPR), the projected outcome (POP) of the process will increase. Then, if at some later stage in the process the catch rates increase such that the expected catch rate (ECR) becomes much larger than the planned processing rate (PPR), the time resource will probably be more valuable than at the beginning of the economic process. The agent will therefore choose to process relatively more of the “cheaper” and “faster” products. The rate of increase will be dependent on the length of the period with low catch rates, and quantity compared to the original POP. This can most clearly been seen in an “end of the year” situations. If the catch rates have been relatively low for the most of the year, the result may be that it will be difficult to catch and process the required quantity to maintain the POP in the remaining time.

Figure 4 illustrates that when the quota is increased to the production capacity limits of the vessel, the time cost increases significantly. There is only one random generator embedded in the simulations presented in this paper. By introducing additional random effects, we could expect that the curve in Figure 4 to shift upwards and to the left, with an increase in time cost as a result. The shapes of the curves in Figure 2-4 are well known in the economic literature. The gradual reduction in the marginal revenue is often referred to as “the law of diminishing returns (LDR)”. In our case, the LDR effect is due to an increase in time cost. When the cost of a resource in a process in time is increased, other resources have to be reallocated accordingly, in order to maintain the maximum efficiency.

7. Comments on Economic Processes in the “Long Run”

With a realistic simulation model of fisheries operations, we have demonstrated the importance of the value of time in decision processes, i.e., the impact of time cost on total revenue of an economic process. In the simulations, we have conveniently included only those variables that have a vital impact on the time-to-time decision process of an economic agent.

Economic processes are often divided into *short*-, and *long* run periods, where the variable costs are associated with the short run and fixed costs are associated with the long run. This division is in the literature credited Alfred Marshall (1920), who however claims that there exists no such natural boundaries between the long and short processes. In this paper, we have focused on the processes in the short run. We have assumed that the shape of the economic space will be the same, either if it is expanded in time (to include years, decades etc.) or if it is expanded in space (to include fleets or industry sectors). “Zooming the focus” of the process out to include several years or decades will in most cases result in including new variables or resources. In the case of the factory trawler, “zooming the focus out” will result in including in the process expansions of the technical frontiers and re-investments. Changing the focus may therefore change the economic space. The frontiers will be different and the estimation of POP will be done in a different economic space. The POP for an agent for a fishery management process may therefore differ from that of an agent for a fishing vessel, but the same analytical approach may be used in both cases. As stated by Marshall there is no boundaries between “short” and “long” run, they are just expressions of a certain types of focuses.

Simulations of agents and their use of resources in economic processes in time can contribute to uncover behavior that at first glance appear to be economically inefficient or irrational. Within the most TQ fishery management systems in the western world the fleet capacity has expanded as the fishing seasons have become increasingly shorter. This process was especially visible in the development of the Americanization and development of the Alaska fishery in the last two decades of the 19th century. In the 1980’s, the industry gained access to cheap foreign capital (see for example Arnarson and Trondsen 1990). As a result, the agents kept on investing in new capacities despite the common knowledge that the next season(s) would be shorter due to a steady increase in harvesting and processing capacity. As long as the process does not meet any blockage, the agents will pursue their processes. To quit the process and invest in other trades is not an option. Their capital stock is constantly becoming obsolete and other valuables in the process like expertise, may have limited value in other processes or trades. As long as the cheap capital is available and other obstacles are not present, the process will go on with steadily increasing capacity. In the end, this spiral ended with mass bankruptcy, an end most of the agents within the Alaska fishery had anticipated. In static views of foresight and/or hindsight, this behavior may seem economically inefficient or irrational, but within an economic process in time and for each single agent, participating in the process this behavior is rational. It is only when we zoom the focus out in time and space to include the POP of a fishery management body that the results become economically inefficient.

8. Some Concluding Remarks on Fishery Management

There are number of frontiers in the economic space that can be manipulated in order to change the relative interdependency between the time resource and the raw material, and thus, change the outcome of the process. These changes in the operational environment can be caused by natural fluctuations as well as social and fabricated adjustments. The impact of these manipulations is dependent on what resources are scarce and how they are interdependently related in the process. For example, reduction in catch rates due to natural fluctuations would increase the time allocated to the production and thus, stimulate increased production of the more valuable products. On the other hand, strikes, bad weather, engine breakdowns etc., could decrease the available time, and stimulate the production of products of less value.

If fisheries authorities for example, shorten the fishing season, the time costs may rise and the total revenue may be reduced resulting in increased production and harvesting capacity, as in the TQ case. Altering technological frontiers, size of the vessels, production methods, labor etc., may also result in changes in the optimal use of resources and contribute to change the economic outcome of the process. Similarly, making changes in the fishery management schemes, relaxation on transferability restrictions between vessels or between years, may also contribute to alter the resource costs and the outcome of the economic process in time.

By strengthening the ownership (property rights) i.e., allocating quota to single vessels (IQ fishery management), the fishery management may give the economic agent the opportunity to lower his time costs through planning his economic process. Potentially the IQ fishery management should therefore provide a higher economic efficiency than the TQ system. This potential will however not deliver itself automatically to the economic process. When the economic process starts running in time there are numerous things that can alter the interdependency between the resources and thus, the economic outcome of the process.

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Appendix 1. The Catch Generator

The probability distribution for hourly catches was estimated by sampling statistics from reports of some Icelandic trawlers, which are required to keep and send to the Icelandic fisheries authorities, a diary recording information (date, start of haul, trawling time in minutes, fishing grounds, depth, catches in kg by species etc.,) on every haul.

The statistical work is based on Sigvaldason (1969). The Lognormal, LN (a, b), distribution was found to be a convenient model of catches per hour. It is interesting to note that Sigvaldason et al. 1969 used the LN distribution for catches per day, which was the unit of time in their study. The daily catch of a trawler is simply the sum of catches from several (a fluctuating number) hauls, however probably too few to give the daily catch a typical Normal distribution form.

Another and even a more likely explanation for this is the high degree of autocorrelation observed in the catches from haul to haul. The catch per hour series was modeled as a first order autoregressive process:

$$\text{Catch}_t = A * \text{Catch}_{t-1} + \text{Residual}_t \qquad (1)$$

The Least Squares Estimate for the coefficient A is the correlation coefficient, in this case estimated to be 0.26. This would also be the Maximum Likelihood estimate if the residual were normally distributed, which however is not the case here. Higher order coefficients were found not to be significantly different from zero.

The residuals provide the random fluctuations in the process above. By using the well known relationship between LN and Normal distributions we can generate the fluctuating catches by (1) and:

$$Residual_t = EXP(Mean_t + StDev_t * Normal(0,1)) \qquad (2)$$

Where

Normal(0,1) is a realization of the standardized normal distribution with mean = 0 and standard deviation = 1. This is can for example be generated by calling and summing 12 uniformly (0 to 1) distributed numbers and subtracting 6 to get a mean of 0.

$Mean_t$ is the mean value of the normal distribution, which will give the desired mean value of the Lognormal according to seasonal catch fluctuations scenario described in Appendix 4.

$StDev_t$ is the standard deviation of the normal distribution calculated in a similar way as the mean value.

The high autocorrelation in catch rate from hour to hour makes it more difficult to plan the production and smooth out the randomness. In addition, it is in accordance with the fact that the captains often change fishing grounds rather frequently, as soon as they observe low catches. This is simulated in the model by a threshold criteria, such that whenever catch rate lower than the threshold is observed, then the vessel is relocated, which takes time from fishing. This time is simulated by an exponential distribution, so that moving the vessel short distances is most common.

The trawling time for each haul is dependent on the catch rate. Modern techniques allow the captains to see on a graphical computer screen approximately, how much is in the trawl. When catch rate is high, he will haul the trawl earlier, sometimes even after one or two hours of trawling. If catch rates are low, however not under the threshold criteria, he might trawl for say 4 to 6 hours. This is modeled by a set of rules, reflecting the behavior of captains found by examining the diary recordings.

Appendix 2. Factory Trawler Data

Annual quota in metric tons	1.000-6.000
Maximum trip duration in hours	576
Maximum number of operating days per year	350
Fish hold capacity in metric tons.	250
Crew size.	24
Number of factory workers pr. shift. (MEN)	8
Freezing capacity, kg/minutes. (FRC)	49

Sources: Ægir, periodical, 1960-1985. The Icelandic Fishery Society. Reykjavik, Iceland.
The Cooperation of Icelandic Freezing Plants, 1985. Reykjavik, Iceland.

Appendix 3. Products and Processing Data

j	P_j	M_j*	W_j	R_j
AM11	350.3	0.16	2.79	2.67
RL11	213.3	0.05	2.56	2.26
OSN1	149.0	0.0	0.41	1.96
HEI1	69.0	0.0	0.13	1.0
MAR1	97.0	1.0	0.13	1.0

Table 1. Products and processing data.

j - Product name.

P_j - Sales price.

M_j - Percent of the product produced to minced blocks %.

W_j - Labour requirements. Minutes per kilogram of product.

R_j - Raw material requirements. Raw material per kilogram of product.

AM11 - Without bone and skin.

RL11 - With bone, without skin.

OSN1 - With bone and skin.

HEI1 - Whole fish.

MAR1 - Minced fish.

*In the case of the Icelandic factory trawler operation the minced product, MAR1 is solely a by-product of other products.

Source: The Cooperation of Icelandic Freezing Plants, 1985. Reykjavík, Iceland.

Appendix 4. Catch Rates

Month	Catch rate*	Index of catch rates
January	858	0,79
February	942	0.87
Mars	1.177	1.09
April	1.139	1.06
May	1.369	1.27
June	1.184	1.10
July	1.256	1.16
August	1.385	1.28
September	1.020	0.95
October	941	0.87
November	882	0.82
December	799	0.74
MEAN:	1.079	1.00

Table 2. Average catch rates per month in kilogram per trawling hour. Source: Ægir, periodical, 1960-1985. The Icelandic Fishery Society. Reykjavik, Iceland.

Appendix 5: Product Mix. Results from the Simulations

Q					**j**					
	AM11		RL11		OSN1		HEI1		MAR1	
	X'*R	%	X'*R	%	X'*R	%	X'*R	%	X'*R	%
1000	832	83	33	3	0	0	0	0	135	13
1500	1244	83	54	4	0	0	0	0	202	13
2000	1704	85	22	1	0	0	0	0	274	14
2500	1997	80	175	7	0	0	0	0	328	13
3000	2323	77	245	8	48	2	0	0	384	13
3500	2755	79	290	8	0	0	0	0	455	13
4000	2631	66	770	19	140	3	0	0	459	11
4500	2782	62	651	14	590	13	0	0	478	11
5000	2272	45	1030	21	1216	24	68	1	415	8
5500	1343	24	980	18	2700	49	213	4	264	5

Table 3. Simulated Product Mix at Different Quota Levels.

Q	-	Quota level.
j	-	Product.
X'*R	-	Quantity in metric tons of raw material allocated to produce j.

The AM11 product is the most valuable as can be seen in Table 1. This product was sold at the highest prices on the US market at the time the data was collected. The other products RL11, OSN1, and HEI1 are not as labor intensive than AM11 (as is shown in Appendix 2) and consequently sold at lower prices. These less labor intensive and lower priced product where usually sold to the European market. Minced fish or MAR1 is a by-product in the filleting process but almost all of it will be a by-product of AM11. At the time of data collection, highest price for the product MAR1 was gained on the US market. The AM11 and MAR1 can therefore be categorized as a labor intensive and high priced product aimed for the USA market while the rest can categorized as less labor intensive and lower priced aimed for the European market.

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