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Economic methodology is revisited to address issues in fishery management, and survival analysis is suggested as an analytical tool to solve the uncertainty problem in evolutionary economics. Survival analysis can clarify in statistical terms the impacts of fishery regulation and economic and biological changes on the fisherman's final decisions of entry and exit from the fishery. Two types of framework for survival analysis in fishery management are presented to show how this can be applied to fishery management. One type is the framework of the typical regression analysis for market competition and the other type is an extension to the dynamic fishery model. The evaluation of survival analysis in fishery management is provideded. An empirical application of the survival analysis, through the Icelandic trawl fishery data, is given to show how to apply the survival technique to fishery regulation.

Survival Analysis in Fishery Management

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Chapter 1

Introduction

One of the fundamental problems in the early development of renewable resource management was that socioeconomic factors were not explicitly incorporated into management activities. Management activities concentrated primarily on biological, ecological, and technical harvesting issues (Walters, 1986). Fishery managers have come to realize that a central responsibility is to allocate resources involving heterogenous services of human beings. The emergence of the term 'bioeconomics' is one example of this movement. The term 'bioeconomics' implies the interrelationships between the economic forces affecting the fishery industry and the biological factors determining the production and supply of fish (Clark, 1985).

Economic methodology can provide clear and comprehensive explanations about economic matters in fishery management. Theory and factual evidence play their own roles in making economic methodology a useful set of guidelines in studying fishery management. Unfortunately, theories and factual evidence are often inconsistent. These inconsistences may come from erroneous modeling or by observations of factual phenomena. Sources of these errors can be our ignorance of nature, irrational human behavior, emotions, myopic attitudes, incorrect intuitions, etc.

Errors in modeling procedure start from the initial assumptions on a given phenomenon and their related subjects' behavior. If initial assumptions fail to provide theory with the core descriptions of the concerned matter and/or the empirical evidence is not enough to confirm theory, then the final outcomes of modeling and interpretations are far from the truth. Therefore, an economic methodology must be judged with caution to decide whether it is really an appropriate way to analyze the given matter. This caution is much required in fishery economics and management because it also involves an uncertain, and to a large extent unknown biological world.

It has proved very difficult to model the biological world since there exist a large number of exogeneous and endogeneous uncertainties, available data are limited and measurement errors are prevalent. Consequently, it is important to understand the role of economic methodology in fisheries economics and regulations. Economists should keep in mind the limitations of economic methodology, how they can interpret the modeling results based on the economic methodology with those limitations, what the implications of the outcomes are, and what alternatives can exist if the adopted conventional or traditional methodology is not successful in analyzing the given matter.

This thesis explores the feasibility of so-called survival analysis in fishery management. One of the main sources of discrepancy between economic theory and practice in fishery management is that economic methodology has its own limitations due to many tenuous economic assumptions which are not satisfied in reality. Therefore, Chapter 2 reviews the mainstream methodology in economics. Problems with empirical hypotheses and data and problems with methodological individualism are discussed. Then, with a brief description of the need for new analytical method in fishery management, survival analysis is suggested as an analytical tool to solve the uncertainty problem.

Chapter 3 proceeds with a description of the basic concepts and models in survival analysis. Review of the literature on survival analysis in economics and the description of a general model of survival analysis in economics are also given in this chapter. Chapter 4 begins with a discussion of the various dynamics in fishery management. Then, the proposed framework for survival analysis in fishery management follows. A few applications of survival analysis to control theory in fisheries model are given first, and the framework to estimate the standard survival model is discussed. In Chapter 5, empirical applications of survival analysis in fisheries models are presented. A survival model is fitted to available fisheries data from the Icelandic trawl fishery.

Chaper 6 contains an evaluation of survival analysis in fishery management as a discussion and summary of the previous chapters. Finally, conclusion and suggestions for future research are given in Chapter 7.

Chapter 2

Statement of Problem

Are economists addressing the problems that most concern fishery managers? What concerns fishery managers most today is their inability to predict the behavioral response of fishing vessel operators to alternative management measures. Too much work has gone into the search for some idealized state and too little has been devoted to the linkages between design of regulation, enforcement, and behavioral response by those regulated (Wilen, 1979).

A central objective for the fishery economics analyst often is to provide an economic rationale for fishery management measures. Although good policy guidance can be developed through rhetoric and intuition, much available scientific work is based on several tenuous assumptions, such as homogeneity of fishermen (or fishing firms), self-interest theory of economic regulation, symmetric information among fishermen, and between managers and fishermen. These assumptions are typically violated in most fisheries (Karpoff, 1987). Also, data are limited, expensive, and poor in quality and economic analyses based on such data fail to consider industrial structure. Another practical problem faced by the regulatory authority is uncertainty about the responses of fishermen to the imposed regulations and economic and biological changes in the environment. In the short run, responses can include reduction of fishing effort, searching for alternative fisheries or fishing grounds. The long run responses can include entry or exit from fisheries.

Many different regulations, such as gear restrictions, season closures, catch restrictions, and entry restrictions, are combined since one tool alone cannot achieve the fishery manager's goals of efficiency, equity, and biological conservation. For example, the adoption of restricted access might overexploit the fishery stock because "the option value of a unit of capacity under restricted entry is high" (Clark, 1985). Therefore, some additional types of regulation such as taxes or quota allocations are required.

Another problem is the lack of emphasis on timing of regulatory imposition. According to Anderson (1986), fishery regulation should follow an appropriate time path for achieving the economic and biological goals since the difficulties of reallocating resources in the economy are compounded with economic, biologic, and sociologic factors. The exact timing of regulatory imposition depends largely on the growth rate of fish stock and the assimilated speed of released resources into other parts of the economy.

2.1 Mainstream Methodology

A current and widely held view of economic theory is that it is a hypothetico-deductive system subject to possible refutation by future experience or new data sets, the aim of which is to help researchers understand the characteristic uniqueness of reality. Methodological falsificationism and methodological instrumentalism have been mainstream to economics. These methodologies have been very convincing in that direct verification of hypotheses (or assumptions) is not necessarily needed and to some extent direct verification may even lead to incorrect understanding of reality (Friedman, 1953). For example, in methodological falsificationism, empirical hypotheses are first made by observing facts or data, followed by hypothetical tests about those data or observed facts. Hypotheses are then tentatively confirmed (or verified) or are disconfirmed.

If some hypotheses survive a number of efforts to refute them, then more confidence can be attributed to these hypotheses. That is, hypothetical generalizations about social events and situations are made in terms of their causes, effects, and interrelations and these generalizations are tested to determine whether the obtained observations about social phenomena can be matched with the given hypothetical generalizations. However, there is an argument that the verification or falsification of hypotheses cannot prove their correctness, adequacy or applicability, as stated in Friedman's (1953) argument, while the rejection of tested hypotheses is possible (Machlup, 1978). Finally, the hypotheses surviving a number of disconfirmations are used to explain reality, or to give predictions about the past and future for the purpose of policy recommendations.

Empirical tests, through which confidence in a hypothesis is enlarged if a hypothesis survives a number of efforts at refutation, are required to verify or falsify a hypothesis. According to Friedman (1953), empirical evidence is vital at two different stages. First, it is vital in constructing hypotheses for generalizations or explanations of phenomena, and second, it is vital in testing the validity of hypotheses. In other words, empirical evidence is important to deduce new observable but previously unknown facts, and in testing these deduced facts against additional empirical evidence.

Chisholm (1977) has argued that mainstream methodologies, or "modernism methodologies" would seem to favor pragmatism and instrumentalism since the truth of an economist's beliefs can be regarded as a kind of satisfaction and falsity as a kind of dissatisfaction. Then, questions about realism, or the connection between the true and the evident, can again be raised since it is believed that the mainstream methdology of economics is "to provide economists with reliable criteria for recognizing the theory which best approximates to the goals (other than truth) of economic theorizing, whatever they may be" (Mäki, 1988, p.92). Of course, empirical data serve in mainstream methdology as indications of the evident, in the sense that a proposition is certain and beyond reasonable doubt (Chisholm, 1977).

While regarding advantages of the mainstream methdologies of economics as practical applicabilities or accumulations of anomalies, there appear many problems with the mainstream methodologies.

For example, there are problems related to empirical hypotheses and data (Machlup, 1978). The first case is the empirical hypothesis problem or the distinction between theoretical laws and empirical laws when dealing with strictly empirical hypotheses. The second case is the limitations to the verification of empirical hypotheses when statistical and econometric analysis is applied for the purpose of verifying empirical hypotheses. The problem of uncertainty and asymmetric information, the aggregation problem in time-series data, etc., are other examples. Of course, more problems than discussed here are expected to be encountered in practice.

It would seem that these kinds of problems are quite directly connected with their methodological aspects, although this is not always the case for the problem of uncertainty and asymmetric information. Especially, methodological individualism has been regarded as a main source of these problems together with methodological monism, methodological falsificationism (or logical positivism), and methodological instrumentalism. The starting point of methodological individualism is that individual characteristics or dispositions can be aggregated into collective behaviors of decisions while "aims, methods, and theories are together in an inseparable whole" (Kuhn, 1970) in methodological holism.

Methodological individualism has played a critical role in economics, especially in constructing the foundation of the neoclassical economic paradigm, including rational choice theory and welfare economics, and has been advocated strongly by many economists in terms of its practicability and possible achievability. However, methodological individualism has many digressions and has been criticisized in many aspects, including methodological holism in particular. The first criticism comes from the general aspects of rational choice theory, which is concerned with finding the best means to given ends (Elster, 1989). That is, rational choice theory may not yield determinate predictions when there are several actions that are equally and optimally good and when there are no actions as good as any other. Also, people may fail to confirm to the predictions of rational choice theory since people can behave irrationally (Elster, 1989). Second, macro-level political phenomena cannot be easily explained by rational choice theory since macro-social phenomena are "valued ends" and micro-social phenomena are "factual states" (Luke, 1987). Third, the macro-social concepts are a priori excluded from the analysis in methodological individualism since macro-social processes and qualities are not reducible to individual facts but, to an important degree, are sui generis entities (Luke, 1987).

It seems that methodological individualism in rational choice theory and some other economics areas may not explain macro-social behavior or phenomena successfully because of these reasons. Finding a social norm such as altruism, duty, fairness, envy, etc., may be an alternative to the rational choice theory. However, what we need to do is specify a mechanism, e.g., natural selection, to explain norms of competition, by which the outcome of a social norm sustains the norm. On the other hand, we should keep in mind again that an important implication of methodological individualism may be "the fact that breaking with the individualist pattern can be worth the risks, in the more controversial cases of non-individualist social explanation" (Miller, 1987, p.118). Coleman (1990, pp.3-5) describes the points favoring methodological individualism (or the internal analysis of system behavior) in social science as follows:

1. When the systems are large in size and few in number, system-level (or macro-level) data may not be adequate to confirm theories since there can be too many alternative hypotheses which cannot be rejected by the data. Observations are very often made at a level below that of the system as a whole, and interventions should be implemented at these lower levels to be useful.

2. An explanation, based on actions and orientations of lower-level (or micro-level) units, can be more stable and general than an explanation which remains at the macro-level since the system's behavior results from the actions of its component parts.

3. The image of man demanded by a theory that begins at the level of social systems remains abstract in that a human being is just a socialized element of a social system. However, the internal analysis of system behavior or methodological individualism is grounded in a humanistically common image of man.

4. There exist several forms of interdependence of individual actions and they show the wide variety of ways in which the micro-to-macro transition occurs.

Methodological individualism may "encourage innocent explanations but forbid sinister explanations of the widespread existence of a disposition among the members of a social group" (Watkins, 1957, p.110). The existence of imperfect information may make it impossible for us to abandon methodological individualism since "there are really no a priori limits to what might influence an individual's choice" and methodological individualism "has been at the foundation of much scientific progress" (Levy, 1985, p.108). More importance may lie in developing methodological individualism in a way that allows the linkage of methodological individualism with other methodologies.

2.2 The Need for New Methodology

Societies, over time, become more and more dependent on knowledge of highly diversified and specialized kinds and as a result, individuals are more closely bound together and more independent as rational actors (Cavanaugh, 1987). A characteristic of modern society is that we have the increasing rationality in industrial society together with the increasing separation of home and work (while both these serve to deepen the alienation of labor, i.e., alienation from the means of production) (Worsely, 1970). Therefore, some may argue that methodological individualism can be justified in this respect. However, one of the main discoveries of modern sociology is that rationality is limited and appears only under certain conditions and society itself may be ultimately based on a non-rational foundation, not on reasoning or rational agreement (Collins, 1982).

Society may be based on trust through social contracts and solidarity may underlie a contractual society (Collins, 1982). Further, as we discussed earlier, the problems with empirical hypotheses and data make it more difficult to reduce the gaps between economic theory and practice. Therefore, accepting the methodologies, such as methodological individualism and methodological falsificationism, as a basis for professional inquiry may be justified, being a normative statement, in that it is almost impossible to find a universal law for social phenomena since there is such great complexity and variety in social phenomena. However, the role of methdology in economics should be reconsidered at this point. Machlup has stated that the reason we bother with methodology is that "the failure to make distinctions between statements of different order often has serious practical consequences" (1978, p.70). It may be doubted whether there really have been a substantial degree of serious practical consequences resulting from the use of alternative approaches since these approaches have not to date been thoroughly tested. Perhaps, within a restricted domain, it could be possible to apply an alternative economic methodology to the problem of different political and social systems (Blaug, 1980). Of course, the resulting pictures of different methodologies would be much different. For example, according to Lakatos (1978, p.92), "the reconstruction of scientific progress as proliferation of rival research programmes and progressive and degenerative problemshifts gives a picture of the scientific enterprise which is in many ways different from the picture provided by its reconstruction as a succession of bold theories and their dramatic overthrows". The latter view is Kuhn's. According to Lakatos, a series of theories is theoretically progressive or constitutes a theoretically progressive problemshift "if each new theory has some excess empirical content over its predecessor, that is, if it predicts some novel, hitherto unexpected fact." A theoretically progressive series of theories is empirically progressive "if some of this excess empirical content is also corroborated, that is, if each new theory leads us to the actual discovery of some new fact." Finally, a problemshift is progressive "if it is both theoretically and empirically progressive, and degenerating if it is not" (Lakatos, 1978, pp.33-34).

In the past, there had been inductivism and conventionalism as rival methodologies of science to the contemporary falsificationism. In inductivism (of the 19th century), only the propositions, which either describe hard facts or infallible inductive generalizations from them, can be accepted into the body of science (Lakatos, 1978). Conventionalism emphasizes the factual discoveries and within conventionalism, "all scientific theories and hypotheses are merely condensed descriptions of natural events, neither true nor false in themselves but simply conventions for storing empirical information, whose value is to be determined exclusively by the principles of economy of thought" (Blaug, 1980, p.6). Then, falsificationism arose as a logico-epistemological criticism of inductivism and of Duhemian conventionalism (Lakatos, 1978). This contemporary falsificationism was developed as alternative methodology to the received view and replaced the received view of the interwar period of 1920-50.

Falsificationism, though logically impeccable, has epistemological difficulties of its own in that it represents a conventionalism. Thus, we may need a research program with, according to Lakatos (1978), a conventionally accepted "hard core" and with a "positive heuristic" to appraise continuity of scientific growth, and we may need a methodology which offers a new rational reconstruction of science. Here, "hard core" of the research program is a characteristic which is tenaciously protected from refutation by a vast "protective belt" of auxiliary hypotheses, and "positive heuristic" is meant by a methodological rule telling us what paths of research to pursue.

As Max Weber (1949) indicated, it is believed that the concern of the social sciences about the qualitative aspects of phenomena and the problems of the social sciences is mandated by the value-relevance of the phenomena treated, i.e., social science concerns about value-added social phenomena. Therefore, methodological monism and individualism are not necessarily the best analytical tools with which to study collective social behaviors.

Beyond these considerations, one reason that such classical economists as Adam Smith and Karl Marx are still appraised is that they incorporated other social factors or forces with economic factors in consideration of broad, long-term economic and social movements. It follows that reconstructing all these different methodologies or views may produce more synthetic alternative methodologies, just as the methodological pluralists insist. Of course, methodological pluralism has not lacked for critics. For example, this school has been criticized insofar as it has no universally applicable method of choice (since it assumes that no single optimal methodology is discoverable), which can lead to methodological anarchism or dogmatism (Caldwell, 1982). Methodological pluralism, sometimes combined with (Kuhnian's) methodological holism, seems to be more sound insofar as there are no universal rules explaining all necessarily complicated and diversified social phenomena.

2.3 The Case for Survival Analysis

A resurgent, but classic, movement in advances of economics is understanding an economic system as a dynamic system. Within a dynamic economic system, all the social factors or forces are combined with economic factors in consideration of broad, long-term economic and social movements. For example, in an evolutionary (or adaptive) system, market firms are characterized by evolution by natural economic selection in which "traits of firms, including those traits underlying the ability to produce output and make profits, are transmitted through time" (Nelson and Winter, 1982, p.9). The routine behavioral patterns of firms are modeled as searches and the firms evolve over time through the joint action of search and selection, in which the condition of the industry in each period affects the condition in the following period.

According to Nelson and Winter (1982), evolutionary economics is based on a Lamarckian mechanism of externally directed hereditary changes. That is, inheritance of acquired characters and adaptive changes both characterize the evolution process. It has been known in genetics that "this mechanism is restricted in theory to the special case in which an environmental influence can modify the phenotype in a given direction, and at the same time change the heredity so that the altered phenotype is reproduced in subsequent generations" (Grant, 1963, pp.133-4). This concern seems to be not important in economics since environmental influences and individual agents' learning mechanism are major concerns in dynamic economic systems, and because we are dealing with organizations or human beings, whose successive decision making process eventually determines its failure (or loss of welfare) or success (or gain of welfare) in an economic system.

An economic organization consists of (rational) human beings, and a human being's perception, interpretation, and knowledge is influenced from a social as well as an individual process that depends on the nature of the collective (or social and individual) consciousness. A human's survival is affected by the social consciousness of the human's relationship to the environment (Norgaard, 1984). The application of the evolutionary concept, which was developed to explain the biological evolution, is an obvious and relevant analogy as we can see in examples such as bankruptcy and reorganization of resources into new or surviving firms (Day, 1975). To some extent, it is true that the concepts of sociobiology have opened perspectives about economics as a biological science, although the lack of a methodological framework raises the problems of practice as shown in the critiques of the traditional pattern modelling (Jones, 1989). Moreover, what principally distinguishes economics as a discipline from others is its approach, which is comprehensive and may be applicable to all kinds of human behavior, and sociological and psychological concepts and techniques can be provided for the methodologies of economics by the other social sciences(Becker, 1976). To represent the reality, "the concept of model validity should give way to the notion of building confidence on a model along several dimensions" (Radzicki, 1988, p.644). The descriptive richness of the system dynamics modelling could be obtained through the introduction of mathematical precision (Radzicki, 1988).

In these respects, survival analysis may be said to be a part of evolutionary economics which makes it possible to find state probabilities in evolutionary economics. However, survival analysis is different from evolutionary economics in that the lifetime, not the time unit considered in general dynamic system theory, enters into the model as a random variable for which inferences are made. A survival model alone is not a dyanamic model although it could easily be incorporated into a dynamic model.

2.4 Objectives of Thesis

The reality is that appropriate tools for the analyses of issues in fisheries management are hard to find. Even though there exist some applicable analytical tools, such as dynamic modeling, uncertainty can easily complicate the modeling effort. Much effort has been devoted to solve the uncertainty problems related to ecology and management. However, most approaches are based on advanced mathematical and statistical, analytical tools which are difficult to use, while at the same time adding much complexity to the analyses. Stochastic control program research is an example of this. Further, sometimes hidden facts, such as a chaotic pattern in the biological growth functions, are not addressed with appropriate explanations.

In addition, the adopted economic methodology may imply discrepancies between economic theory and practical management effects from the start. In most cases of fisheries models, more emphasis is given to biology, not the responses of fishery industry or fishermen. Individual rationality is assumed for empirical convenience without discussion of its consequences. These aspects should be considered for management purposes.

There exist discrepancies between economic theory and practicability of prevalent fisheries models. The sources, nature, and consequences of these discrepancies should be clarified for the purposes of fishery management. Economists should respond by exploring ways to empirically address these issues, with limited information and using relatively simple analytical procedures. In general, it is neither practical nor necessary to collect all the raw data available for a managed system as it is not possible to make a complete model of that system, and collecting all the raw data does not imply a complete understanding of a managed system (Walters, 1986). Recognizing difficulties associated with data availability and collection, one possible response would be to introduce probabilistic measures. Providing a partial answer to this challenge is the aim of this thesis, in which survival analysis is explored as an analytical tool to address the above issues related to fishery management.

The main objectives of this thesis are:

1) to explore the feasibility of survival analysis as a legitimate approach for solving issues in fishery management, especially the uncertainty problem of responses of fishermen to imposed regulations and economic and biological changes in

environments;

2) to discuss economic methodological issues in fishery management and to show methodological background of survival analysis in economics; and

3) to show how survival analysis can be applied to typical dynamic models for fishery and conventional fishery regulation methods.

More specifically, survival analysis is developed as an analytical tool to (a) address issues in fishery management and provide practical (empirical) tools for fishery managers to reduce the problems of uncertainty, and (b) clarify the impacts of fishery regulation and economic and biological changes on the fishermen's final decisions about entry and exit from the fishery.

Survival analysis makes it possible to (a) assess the roles of different types of regulatory tools in probabilistic terms, (b) incorporate alternative economic behavioral assumptions about fishermen, and (c) provide information from this survival analysis for fishery managers. Understanding the dynamic nature of fisheries models, in association with survival analysis, and incorporating this knowledge into the fisheries management practices is also an effort in this thesis.

Chapter 3

Concepts and Models in Survival Analysis

It was argued in Chapter II that survival analysis can be intended to address the issues of the evolution of social institutions and market competitions. In this Chapter, the statistical concepts and models in survival analysis are described to provide definitional aspects of survival analysis and a linkage between statistical concepts and empirical estimation. Then, survival analysis in economics is reviewed and a general model of survival analysis in economics is described. Thus, the main purposes of this chapter are to show 1) the basic definitions in survival analysis, 2) how the distribution models in survival analysis can be extended to regression models, 3) how the likelihood functions for the estimation are derived for different models, and 4) how a general model of survival analysis in economics could be developed. By doing so, we will be able to develop the models needed in the area of economics.

3.1 History of Survival Analysis

Survival analysis has played an important role in analyzing lifetime or survival time (or failure time) data in biology, biomedicine, engineering, and other disciplines. Lifetime refers to "the time to the occurrence of some event" (Lawless, 1982). Survival analysis is used to make statistical inferences about lifetime or failure time distributions for a population of interest. It can be used to investigate the lifetime or endurance of manufactured products, the time to learning of a skill by human beings or animals, the duration of human or animal diseases and the treatment effects for these diseases, etc.

Survival analysis originated from the works on mortality table centuries ago. The modern type of survival analysis started in engineering about 60 years ago (Miller, 1981). However, the recent increasing interests in survival analysis have been the results of the advances in statistical methods since 1970's. The parametric models had been the main models on survival analysis until Cox (1972) developed the nonparametric model.

3.2 Basic Concepts in Survival Analysis

Mathematically, lifetime is a positive-valued random variable. The basic concepts of lifetime distributions can be described in the following fashion:

Let T be a single nonnegative lifetime variable. The cumulative distribution function of T, F(t), can be written as

$$F(t) = \Pr [T \leq t] = \int_0^t f(u)\, du, \tag{3.1}$$

where f(t) is the probability density function of T and the pth quantile of $\Pr\,[T \le t_p] = p$ gives $t_p = F^{-1}(p)$. Then, the survivor function S(t), representing the probability of an individual surviving until time t, is defined as

$$S(t) = \Pr\,[T \ge t] \\ = 1 - F(t) \\ = \int_t^\infty f(u)\,du. \tag{3.2}$$

The hazard function, representing the instantaneous rate of death, or failure, at time t given that the individual survives until time t, is defined as

$$h(t) = \lim_{dt \to 0} \Pr[t \le T \le t+dt \mid T \ge t]/dt \\ = f(t)/S(t) \\ = f(t)/[1-F(t)]. \tag{3.3}$$

Thus, h(t)dt is the approximate probability of death in the interval [t,t+dt), given survival until time t. A useful re-expression of this is the cumulative hazard function H(t), defined as

$$H(t) = \int_0^t h(u)\,du\ . \tag{3.4}$$

3.3 Statistical Models in Survival Analysis

Parametric and nonparametric models are the two main types of distribution models in survival analysis. Typical examples of parametric distribution models are the exponential, Weibull, extreme value, and gamma distributions. Lawless (1982) suggests use of mathematical convenience and availability of statistical methods to choose a specific model when choice of a particular model is not obvious. For example, the Weibull distribution is often chosen by researchers because it is flexible in the sense that it belongs to the two-parameter family of distributions; its probability density function, survivor function, and hazard function have simple closed forms; and good statistical and numerical methods are available for this distribution.

In general, "there is no explicit theoretical reasoning indicating that a Weibull distribution should be used--it is just that a power transformation is a practical, convenient way of introducing some flexibility in the model" (Johnson and Kotz, 1970, p. 251). The Weibull distribution with scale parameter α and shape parameter β and its survivor function and hazard function are given as follows.

$$F(t) = 1-\exp[-(t/\alpha)^{\beta}] \tag{3.5}$$

$$f(t) = (1/\alpha)\beta(t/\alpha)^{\beta-1}\exp[-(t/\alpha)^{\beta}] \tag{3.6}$$

$$S(t) = \exp[-(t/\alpha)^{\beta}] \tag{3.7}$$

$$h(t) = (1/\alpha)\beta(t/\alpha)^{\beta-1} \tag{3.8}$$

(3.9) $E[t^r] = \alpha^r\Gamma(1+r/\beta)$, where $\Gamma(k)=\int_0^\infty u^{k-1}e^{-u}du$ and r indicates the r-th moment.

$$E[t] = \alpha\Gamma(1+1/\beta) \tag{3.10}$$

$$Var[t] = \alpha^2[\Gamma(1+2/\beta) - \Gamma(1+1/\beta)^2] \tag{3.11}$$

If there is a time t^* before which no deaths or failures can occur, then the three-parameter Weibull distribution, in which t^* is a threshold parameter, would be approriate

(Lawless, 1982).

Nonparametric models such as the Kaplan-Meier estimator are often used when an underlying distribution cannot be found.

One useful way to handle heterogeneity in a population or for observations which are not identically-and-independently distributed observations is the use of regression-type models. There are three major types of models for regression-type analysis of (censored) lifetime data. These are the parametric proportional hazard model, parametric accelerated lifetime model, and nonparametric proportional hazard model.

3.3.1 Parametric Model

3.3.1.1 Proportional Hazards Model

A family of proportional hazards models is a class of models with the property that different observations have hazard functions which are proportional to one another (Lawless, 1982). The standard form of hazard function of T, given the vector of explanatory variables x, can be written as

$$h(t|x) = h^*(t;v)g(x), \tag{3.12}$$

where v is the vector of model parameters. For the illustration, suppose that the shape parameter β in the Weibull distribution is held fixed, the scale parameter depends on x, i.e., $\alpha=\alpha(x)$, and $x=x_1$ and $x=x_2$ for two individuals are given. Then,

$$h(t|x_1)/h(t|x_2) = [\alpha(x_2)/\alpha(x_1)]^{\beta}, \tag{3.13}$$

which does not depend on t. Therefore, we can write $h(t|x)=h^*(t)g(x)$, and $h^*(t)$ can be thought of a baseline hazard function for an individual for whom $g(x)=1$. Also, if b is the vector of parameters for the characteristic (explanatory) variables in the regression and we can write $\log(\alpha_i)=x_i{}'b$, then

$$\begin{aligned} S(t_i) &= \exp\{-[t_i/\exp(x_i{}'b)]^{\beta}\} \\ &= \exp[-\exp(x_i{}'d)t_i^{\beta}], \text{ where } d=-\beta b, \end{aligned} \tag{3.14}$$

$$H(t_i) = \exp(x_i{}'d)t_i^{\beta} \text{ , and} \tag{3.15}$$

$$h(t_i) = \exp(x_i{}'d)\beta t_i^{\beta-1}. \tag{3.16}$$

The likelihood function for the proportional hazards model is written as

$$\begin{aligned} L(b) &= \Pi_{i=1}^{k} [f(t_i;x_i)^{\delta i}F(t_i;x_i)^{1-\delta i}] \\ &= \Pi_{i=1}^{k} \{h(t_i;x_i)^{\delta i}\mathrm{Exp}[-\textstyle\int_0^{ti} h(u;x_i)\ du]\}, \end{aligned} \tag{3.17}$$

where δ_i is the indicator variable for censoring of lifetime. Censoring occurs when exact lifetimes for a portion of the observations are known, but the lifetimes for the remainder are known only to exceed certain values (Lawless, 1982). There are three types of censoring; type I, type II, and random censoring. In type I censoring, the total number of samples is known, but some of the samples are not observed. Only a pre-determined number of observations is observed in type II censoring. If censoring times are random, then it is called random censoring. In general, censoring time and lifetime are assumed to be independent of each other. In the above maximum likelihood function, type I censoring is assumed. The likelihood function for random censoring can be of the same form as the one for type I censoring.

3.3.1.2 Accelerated Lifetime Model

While the analysis of survival data is specified via the hazard function in the proportional hazards model, another line of analysis can be initiated from the survival function in the accelerated lifetime (or scale parameter) model. For a simple description, suppose that there are two treatments represented by values 0 and 1 of the explanatory variable x and a constant μ such that the survivor function at x=1, $S_1(t)=S(t|x=1)$, is $S_1(t)=S_0(\mu t)$. Then,

(3.18) $f(t|x=1) = f_1(t) = \mu f_0(\mu t)$ and

(3.19) $h_1(t) = \mu h_0(\mu t)$.

The more general form is

(3.20) $S(t;x) = S_0(t\mu(x))$,

(3.21) $f(t;x) = f_0[t\mu(x)]\mu(x)$, and

(3.22) $h(t;x) = h_0[t\mu(x)]\mu(x)$,

where x is the vector now and the subscript 0 indicates a baseline. The last relationship $h(t;x)=h_0[t\mu(x)]\mu(x)$ implies that the covariate term $\mu(x)$ (or constant term μ) can accelerate or retard the time to failure according to the values of $\mu(x)$ by assuming that the survival time of an individual with covariate x, T_x, has the same distribution as $T_0\mu(x)$.

A typical representation of parametric accelerated lifetime model in terms of random variables can be given as follows (Cox and Oakes, 1984, p.65):

Suppose $T=T_0/\mu(x)$, where the subscript 0 indicates a baseline, x is the vector of explanatory variables, and $\mu(x)$ is a function such that T_0 has survivor function $S_0(t\mu(x))$. If $y_0=E[\log(T_0)]$, $\log(T)=y_0-\log(\mu(x))+e$, where e is a random variable with zero mean and distribution which does not depend on x. As it is not necessary to specify $\mu(x)$ further in problems with a limited number of distinct values of x, a natural candidate of parametric form for $\mu(x)$ can be $\mu(x;b)=\exp(x'b)$. Then,

(3.23) $\log(T) = y_0-x'b+e,$

which is a linear regression model. The covariate vector x acts additively on log(T) (or multiplicatively on T) (Kalbfleisch and Prentice, 1980).

Assuming the Weibull distribution of lifetime T and letting Y=log(T), the probability density fuction of Y is written as

(3.24) $f(y|x) = \beta \mathrm{Exp}\{[y-\log\alpha(x)]\beta-e^{[y-\log\alpha(x)]\beta}\},$

where $-\infty<y<\infty$. By transformation of variables,

(3.25) $y = \log\alpha(x)+(1/\beta)e,$

where e has a standard type I extreme value distribution with the probability density function Exp[e-Exp(e)]. If the error term e in this parametric accelerated model is distributed by normal, logistic, and logarithm of gamma variates, then the log-normal, the log-logistic, and the generalized gamma regression models are obtained respectively (Prentice and Kalbfleisch, 1979). Again, the Weibull distribution is the only distribution which belongs to both the proportional hazard model and accelerated lifetime model since log(T) is linear in x. That is, the Weibull log-linear regression models are the only log-linear models which coincide with proportional hazards models.

If our attention is on a particular time t_0, failure or survival by time t_0 can be treated as a binary response in the linear logistic or log logistic accelerated model. This model can be used to test of goodness of fit (Cox and Oake, 1984). For example, consider a linear logistic model in which

(3.26) $$\log\{S(t_0;x)/[1-S(t_0;x]\} = x'd+\alpha(t_0) ,$$

where $\alpha(t_0)$ refers to the baseline x=0 indicating failure. x=1 represents survival at time t_0. Supposing that d is independent of t, $\alpha(t)=-\beta\log(t/\alpha)$, and $d=-\beta b$, then

(3.27) $$S(t;x) = 1/\{1+[(t/\alpha)\exp(x'b)]\}^{\beta}$$

with its baseline survivor function $1/[1+(t/\alpha)^{\beta}]$ which is the log logistic distribution.

3.3.1.3 Time-Dependent Covariate

When the covariate vector is allowed to vary with time, i.e., $x=x(t)$, there are two types of time-dependent covariates (Kalbfleisch and Prentice, 1980). One type is the external covariate whose time path X_i is determined in advance for each individual under study. Here, X_i represents the whole covariate process to the termination of testing and $X_i(t)$ the covariate path up to time t, $\{x_i(\tau):0<\tau<t\}$. The ancillary covariate, which is "the output of a stochastic process that is external to the individual under study" and whose "marginal probability distribution of X_i, $i=1,\dots,n$ does not involve the parameters of the failure time model" (Kalbfleisch and Prentice, 1980, p.123), is an example of external covariate. In this case, ancillary covariates play the role of ancillary statistics for the failure time model. The ancillary statistic is the statistic whose distribution does not depend on the values of the parameters.

The other type of covariate is the internal covariate which is observed only when the individual survives and is not censored. Internal covariates are generated through a stochastic process by the individual under study.

The hazard function for external covariates with regression parmeter vector θ is defined as

$$(3.28)\qquad h(t;X,\theta) = \lim_{dt\to 0} \Pr[t\le T\le t+dt|X,\theta,T\ge t]/dt,$$

and the survivor function is

$$(3.29)\qquad S(t;X,\theta) = \Pr\,[T\ge t|X,\theta].$$

The usual relationships between survivor and hazard functions hold.

The hazard function for internal covariates is defined by

(3.30) $$h(t;X(t),\theta) = \lim_{dt \to 0} \Pr[t \le T \le t+dt \mid X(t),\theta,T \ge t]/dt,$$

and the survivor function $S(t;X(t),\theta) = \Pr\,[T \ge t \mid X(t),\theta] = 1$ provided the individual survives with x(t). Consequently, the hazard function for internal covariates is not related to a survivor function. Therefore, when the covariate vector x is allowed to vary with time as an external covariate or an internal covarite, the covariate vector x in the hazard function and likelihood function can be replaced with x(t) without any changes in the proportional hazards model. However, the replacement of x with x(t) in the accelerated model is not straightforward. It may be too complicated to be useful though the Weibull model can be generalized in terms of x(t) due to its proportional hazards interpretation (Prentice and Kalbfleisch, 1979).

Inferences about both proportional hazards and accelerated lifetime models with time-dependent covariates x(t) can be based on the same likelihood function given previously, but "the likelihood then has only a partial rather than a conditional likelihood interpretation" (Prentice and Kalbfleisch, 1979, p.34).

3.3.2 Nonparametric Model

The nonparametric model is commonly used when there is no censoring problem and the individuals' lifetime data do not depend on an underlying distribution. When dealing with censored, ungrouped data and estimating survivor function, the Kaplan-Meier estimator (or product-limit estimator) can be obtained for one-sample case. Cox's distribution-free model is useful to study grouped data or data with more than 2-sample cases and can be regarded as an extension of the Kaplan-Meier estimation.

3.3.2.1 The Product Limit Estimator of Survivor Function

Suppose that the interval $[0,t]$ is divided into k fixed number of subintervals. Let d_i indicate the number of individual failures at the subinterval $[t_{i-1},t_i]$, n_i the number of individuals at risk at the beginning of this interval, and w_i the number of individuals censored in the subinterval $[t_{i-1},t_i]$. Then,

$$n_i = n_{i-1}-(d_i+w_i) \tag{3.31}$$

and the empirical survivor function $S(t)$ is obtained as

$$\Pi_{i:ti<t}(1-d_i/n_i). \tag{3.32}$$

There is some concern about whether the observations censored in an interval should be included in the denominator n_i. However, if the sample size is large and the intervals are short, this concern is not important (Lawless, 1982). The variance of $S(t)$ is approximately

$$S(t)^2 \Sigma_{i:ti<t}[d_i/n_i(n_i-d_i)]. \tag{3.33}$$

3.3.2.2 The Distribution-Free Proportional Hazards Model

When our concern is comparing two lifetime distributions, one approach is first assuming that the proportional hazards models hold, and then obtaining two separate Kaplan-Meier estimators and plotting them against each other to see whether the logarithms of two survivor functions differ by a constant independent of time t. However, if our primary concern is either to test for a treatment effect or to compare two survivor functions to see whether they are about the same population, a regression model can be more helpful since the power of the test may be improved (Pierce, 1989).

For the illustration of distribution-free proportional hazards model, let's consider the comparison of two lifetime distributions with survivor functions $S_1(t)$ for the first sample and $S_2(t)$ for the second sample and hazard functions $h(t)$ for the first sample and $h(t)e^b$ for the second sample (Cox, 1975; Pierce, 1989). $h(t)$ is a completely unspecified hazard function and b is a coefficient vector for type-specifying covariables x. Here, observations from these two distributions are treated as resulting from a single population and a type-specifying covariate variable, which takes on the value 0 or 1 according to whether an observation comes from the first or second distribution, is defined. The more general form of $h(t)e^{b}$ is $h(t)e^{x'b}$. For the inference purpose, the tested hypothesis can be written as $H_0:S_1(t)=S_2(t)$ or $H_0:b=0$. Further, after dividing the time scale into narrow intervals, the following notation is used:

n_{k1}= the number at risk at the beginning of the k^{th} interval of first sample
n_{k2}= the number at risk at the beginning of the k^{th} interval of second sample
$n_{k.}= n_{k1}+n_{k2}$
d_{k1}= the number of deaths in the k^{th} interval of first sample
d_{k2}= the number of deaths in the k^{th} interval of second sample
$d_{k.}= d_{k1}+d_{k2}$
h_k= the approximate value of h(t) on the k^{th} interval
l_k= the length of the k^{th} interval,

where n_{ki} are decreased by both the number of deaths and the numbers censored as time progresses.

Assuming that the hazard functions do not change greatly over an interval, d_{ki}'s are approximately distributed by Poisson with mean values of $n_{k1}h_kl_k$ and $n_{k2}h_ke^{b}l_k$ respectively. In fact, d_{ki} can have more precision by binomial distribution, which leads us to use a hypergeometric distribution for the inference about b (Pierce, 1989). The inference from an interval about b is made by conditioning on the sum $d_{k.}$, i.e., (3.34) $d_{k1} \sim \text{Binomial}[d_{k.}, p_k=n_{k1}/(n_{k1}+n_{k2}e^b)]$.

Further assuming that the binomial observations from different intervals are independent between them, the likelihood function for b, L(b;x), becomes

(3.35) $L(b;x) = \Pi_k[n_{k1}/(n_{k1}+e^b n_{k2})]^{dk1}[n_{k2}e^b/(n_{k1}+e^b n_{k2})]^{dk2}$

in the absence of knowledge of the baseline hazard function h(t). As the intervals are narrowed enough to isolate individual deaths in each interval and d_{k2} is either 1 or 0 (assuming no ties), L(b) can be written as

(3.36) $L(b) = \Pi_k\ e^{bdk2}/[(n_{k1}+e^b n_{k2})^{dk.}]$,

where the nuisance terms ${n_{k1}}^{dk1}$ and ${n_{k2}}^{dk2}$ have been dropped from the initial likelihood function since the same inferences can be maintained. This likelihood function can be regarded as the so-called partial likelihood function for the two-sample case. More generally, if x_i is defined as a covariable vector of any type (or as an indicator vector of the different samples), and letting $t_{(1)}<t_{(2)}<.....<t_{(k)}$ be the ordered response (death) time which is narrow enough to isolate individual failures and assuming no ties in response times, this gives Cox's (general) partial likelihood function (Cox, 1975).

The general partial likelihood function L(b) can be written as

(3.37) $L(b) = \Pi_{i=1}^{k}\ \exp(x_{(i)}, b)/\Sigma_{j\epsilon Ri}\exp(x_j{}'b)$,

where $R_i=R(t_{(i)})$ is the set of individuals at risk just prior to the time $t_{(i)}$, and $x_{(i)}$ is the regression vector associated with the individual observed to die at $t_{(i)}$ or the covariate vector for the individual with response at time $t_{(i)}$. As we can see, this L(b) is formed by taking the product of all such factors as $\exp(x_j'b)/\Sigma_{l\epsilon R(t)}\exp(x_l'b)$ over the k observed lifetimes. $\exp(x_j'b)/\Sigma_{l\epsilon R(t)}\exp(x_l'b)$ is the probability that a death is of individual j, given R_i and that a death occurs at t_i. If censored observations, which are assumed to be distinct from any lifetimes, are involved, then R_i is the set of individuals who have not yet failed or been censored by the time i (Cox, 1975). This partial likelihood gives consistent estimates (Cox, 1975).

When time intervals are not narrow enough to isolate individual failures and a small number of ties exist, the likelihood function can be written as

$$(3.38) \qquad L(b) = \Pi_{i=1}^{k} \ \{\exp(S_i'b)/[\Sigma_{j\epsilon R_i}\exp(x_j'b)]^{d_i}\},$$

where S_i is the sum of the regression vectors x for d_i individuals and d_i is the number of lifetimes equal to $t_{(i)}$ (Lawless, 1982; Cox, 1972). If all d_i=1, then this general partial likelihood function is the same as the one with isolated failures and no ties.

If there are many ties in the sample, then a discrete model, based on grouped observations from the continuous model, can be considered. In this case, the sample consists of multinomial observations and adjustments for ties can be studied (Lawless, 1982). Writing D_i as the set of individuals who die at $t_{(i)}$, the likelihood function is modified as

(3.39) $L(b) = \Pi_{i=1}^{k} \{\exp(S_i'b)/[\Sigma_{\mathrm{all}\ Dj}\exp(S_j'b)]^{di}\}$,

where the summation in the denominator is over all possible sets of D_j drawn from R_i, and $S_j=\Sigma_{l\epsilon Dj}x_l$ is the sum of the regression vectors for individuals in D_j (Cox, 1972; Cox, 1975). A reasonable test of no treatment effect or b=0 for these multinomial observations can be done through using the approximate normal deviate

(3.40) $z=\Sigma_k\{[d_{k1}-d_{k.}(n_{k1}/n_{k.})]/\sqrt{\Sigma_k d_{k.}(n_{k1}/n_{k.})(n_{k2}/n_{k.})}\}$.

Another way is using a score test as can be seen in the Mantel-Haenszel test (Lawless, 1982; Mantel and Haenszel, 1959: Pierce, 1989). The log-rank test (or exponential ordered scores test) and a generalization of the Wilcoxon and Kruskal-Wallis tests are two other distribution-free tests for the equality of two or more lifetime distributions (Lawless, 1982).

The profile likelihood function for b is essentially the same as the partial likelihood function if the time intervals are narrow since the nuisance parameters h_1, h_2, ...,h_k in the partial likelihood function are eliminated by conditioning on the sums $d_{k.}$'s in each interval. The profile likelihood function is defined as

(3.41) $\mathrm{Max}_d\ L(b,d;x)$,

where d is the vector of nuisance parameters in the regression model. Formulating some kind of regression-type model for the parameters h_1, h_2, ..., rather than allowing them to be totally free, is an alternative method to handle nuisance parameters in inferences (Pierce, 1989; Lawless, 1982; Cox, 1975). The partial likelihood also has been justified as a marginal likelihood by Kalbfleisch and Prentice (1973, 1980).

Cox's distribution-free proportional hazards model can be extended to incorporate the random time-dependent covariates, i.e., x(t), into the model for certain purposes. Cox and Oakes(1984) call this covariate an evolutionary covariate, and the issues related to this dynamic covariate is well addressed in Chapter 8 of their book. The efficiency of b estimation depends on whether the censoring is related to the values of regression variables. Also, the relative efficiency of the partial likelihood estimator depends on the degree of variation in the expected values of the covariate vector x (Prentice and Kalbfleisch, 1979). Here, the expected values of covariate vector x means the expected values obtained by using the conditional distributions across the failure times $t_{(i)}$ for i=1,...,k such that the ith individual with covariate $x_{(i)}$ fails given that an individual is known to have failed among the risk set $R(t_{(i)})$. The partial likelihood function for the lifetime distribution with x(t) is modified to

$$(3.42) \qquad L(b) = \Pi_{i=1}^{k} \ \{\exp[(x_i(t_{(i)})'b)]/\Sigma_{j\epsilon Ri}\exp[(x_j(t_{(j)})'b)]\},$$

but the conditions for the corresponding asymptotic likelihood theory to apply are difficult to find and even less clear than in the fixed covariate case (Prentice and Kalbfleisch, 1979).

The modeling procedure described here is appropriate when the lifetime distribution is unimodal or its hazard function is monotone. Therefore, when the hazard function is U shaped or when the lifetime distribution is multimodal, the application of mixture models is useful for both parametric and nonparametric regression models (Lawless, 1982). "Discrete mixture models arise when individuals in a population are each one of k distinct types, with a proportion p_i of the population being of the ith type; the p_i's satisfy $0<p_i<1$ and $\Sigma p_i=1$" (Lawless, p.27, 1982). That is, the mixture models are considered when the heterogeneity of samples is obvious. An individual randomly selected from this population then has survivor function

$$S(t)=p_1S_1(t)+.....+p_kS_k(t). \tag{3.43}$$

Cox's distribution-free method can be used to address the heterogeneity problems of samples by making heterogeneity-specifying type variables and modifying the followed partial likelihood. For example, when the baseline hazards differ among strata or subsets in the population, the partial likelihood function is modified to make products over strata of the likelihood function. Similar applications can be shown in the regression analysis with multiple failures types, in the sense that an individual experiences several failures over time. Supposing that each failure is one of m distinct types or causes denoted by $J \epsilon \{1,2,...,m\}$, the hazard function with covariate function X(t) from cause j at time t is modified to

(3.44) $\quad h_j[t,X(t)] = \lim_{dt \to 0} \Pr[t \leq T \leq t+dt, J=j \mid T \geq t, X(t)]/dt$

for all (t,j). Thus, the maximum likelihood function is written by

(3.45) $\Pi_{j=1}^{m} \Pi_{i=1}^{kj} \quad \{\exp[(x_i(t_{ji})'b_j)]/\Sigma_{l \epsilon R(tji)} \exp[(x_l(t_{ji})'b_j)]\}$,

where $t_{j1}, t_{j2}, ...$ represent the incidence times for disease or cause or type j, b_j is the regression coefficient for type j, k_j is the time interval variable k for type j, and R(t) refers only to the set of individuals matched at time t (Prentice and Kalbfleisch, 1979, p.34-37).

When it is assumed that the latent type-dependent failure times $T_1,...,T_m$ exist, and $T=\min(T_1,...,T_m)$ and $J=(j \mid T_j \leq T_k$ for all k), "it has been known that data of the type (T,J) do not permit one to identify the joint or marginal distributions for $T_1,...,T_m$, nor to test independence of latent failure times, without introducing additional untestable assumptions such as a parametric model for the joint distributions of $T_1,...,T_m$" (Prentice and Kalbfleisch, 1979, p.34). This is analogous to the identification problems in the mixture models and this is why some econometricians introduce parametric models for the joint distributions of heterogeneous lifetime variables in the mixture model studies, e.g., for the area of unemployment duration data studies such as Heckman and Singer (1984c) and Elbers and Ridder (1982).

In general, the estimation of mixture models and followed inferences are very complicated since it involves multiparameters. However, Heckman and Singer(1984c), Atkinson and Tschirhart(1986), and others, have shown the empirical applications of mixture models when a Weibull distribution for duration times is mixed.

3.4 Survival Analysis in Economics

The statistical concepts and models in survival analysis have been discussed so far. Now, the question is whether we could apply the concepts in survival analysis to economic matters. Surprisingly, the idea of using survival concepts had been explored by economists some 30 years ago. Therefore, the empirical and theoretical works related to survival analysis in economics are reviewed in this section. We start this review with the development of survival analysis in traditional economics.

3.4.1 Development of Survival Analysis in Traditional Economics

The current types of survival analysis had not been well-known in economics until theoretical advances in statistics in the 1970's were applied to economic issues.

Development of economic survival analysis has been remarkable especially in the area of unemployment duration data analysis in the late 1970's and 1980's. Since then, the impacts of methodological advances in survival analysis on economic applications have been immense. An early application of survival analysis in economics, before the theoretical advances in survival analysis, was Stigler's (1958) study of cost structure and economies of scale. Several U.S. industries including steel, automobiles,and petroleum refining over several decades were studied for firms and plants to reveal optimum size in terms of private costs. Stigler found that most cost curves were usually dish-shaped with small minimum efficient scale.

After Stigler's work, many works such as Saving (1961) and Weiss (1964) have been done to offer evidence on the reliability of the survival analysis as a tool for industry analysis. These works show that economies of scale are realized as the firm expands from very small size to some identifiable minimal optimal scale, unit costs tend to remain constant at the optimal level as the firm grows, and most of the scale economies observed are economies of the large-scale plant (Bain, 1969). However, this approach has been criticized in several aspects. Critics argue, for example, that it cannot evaluate firm-level economies, that it does not clarify the shape of the cost curve, and that it focuses on changes in the size-distribution rather than the distribution itself (Shepherd, 1985). These criticisms arise mainly from two sources. First, many economists have tried to connect the survivor principle to a limited body of economic theory, such as the theory of perfect competition. The second reason is that convenient statistical methods were lacking for the regression-type model of survival analysis before the 1980's. The drawbacks of survival analysis in economics can be relaxed by introducing the regression-type survival model and relaxing some assumptions about the industry structure.

3.4.2 Development of Survival Analysis in Organizational Sociology

Another main area of studying survival analysis before the 1980's was 'organizational sociology'. In this area, a general framework for the study of organizational mortality has been developed through the traditions of business policy and organizational sociology. Carroll(1983) reviewed 32 empirical studies of failure and mortality published in the business policy and economic literature before 1983. According to his paper, research methodologies ranged from detailed case studies to statistical analyses of populations. The most common findings from these studies are:

1) Organizations are most likely to fail in the first few years of operation. (The same finding may not be expected in

other industries. For example, the fishery industry has the nature of common property and regulation. This may produce different findings.)

2) In many cases, the causes of mortality are organizational factors such as managerial incompetence and lack of experience.

3) Most of these studies concern density or size of populations of both people and organizations.

Carroll argues that not all findings reported from these studies are consistent though. The effect of business cycles on failure rates were not resolved, the relationship between organizational size and the rate of death involved discrepancies among studies, and there were inconsistent findings about the relative failure rates of different types of organizations. He also states that "inconsistences in the findings of these studies should not be surprising since much of this research suffers from serious methodological problems" (Carroll, 1983, p.310). Most importantly, censored samples were not addressed legitimately, different models were not comparable, and it was difficult to test hypotheses in these studies. To avoid these problems, Carroll developed three models of organizational mortality in his paper without considering covariates, i.e., non-regression- type models were studied. These three models are the constant rate model, Gompertz hazard model, and the model of Makeham's Law which is an extension of the Gompertz model. Then, 52 different data sets were used to examine the plausibility of these proposed models.

The Gompertz distribution, which was developed in 1825 to study human mortality, has a hazard function which can be written as

$$h(t) = \exp(\alpha+\tau t), \tag{3.46}$$

where α is the parameter for a constant and τ is the coefficient for lifetime. The Gompertz distribution is still very often used in biology to study animal mortality. Carroll found in this study that Makeham's Law is the best-fitting model for organizational mortality, although its estimation requires data with low levels of censoring.

Another interesting work in this area is the work of Delacroix, Swaminathan, and Solt's (1989). In this study, the relationship between density and the failure rate of organizations, i.e., of California wineries, is studied through the Gompertz distribution in which the hazard (or failure) rate h(t) is expressed as a regression-type model

$$h(t) = \exp[x_i'(t)b]\exp[\tau t], \tag{3.47}$$

where x_i is a vector of covariates for individual weineries for each year, b is a vector of regression coefficients, and τ is the coefficient for organizational age. The covariates for population density is the number of wineries in existence at the end of the previous year or at the beginning of the current year, and this density variable is used in both its linear and its quadratic terms. It was found in this work that a model focusing on prior foundings and prior failings gives a superior account of the failure rate in the California wine industry. Similar studies have been done by Hannan and Freeman (1986, 1988). These works found curvilinear relationships between density and commercial competition with changing U-pattern of signs from negative to positive in the populations of American labor unions, newspapers, and semi-conductor firms. That is, they found that at low levels of density, each increment in density lowers the probability of failure while at high levels of density, each increment in density raises the probability of failure (Hannan and Freeman, 1988).

3.4.3 Development of Unemployment Duration Data Analysis

It is believed that the real advances of applications of survival analysis in economics came through the works in unemployment duration data analysis, including job search theory, which started at the end of 1970's. Examples are the works of Salant (1977) and Lancaster (1979).

In his 1977 paper, Salant studied the average length of time people spend looking for work as an important index of economic welfare by showing how unemployment duration data can be used to improve our understanding of the labor market. Unemployment duration spells were treated as a random variable, and instantaneous escape rate from unemployment was represented as a failure rate or hazard rate. The analytical tool was a mathematical model incorporating renewal theory, and the main issue was in finding the values of mean and variances of unemployment duration, estimating the parameters of time distributions for different sets of sample workers, and interpreting the estimation outcomes. Here, an individual was assumed to have a constant escape rate, and the exponential distribution was assumed for the density of completed spell lengths of unemployment. The exponential distribution does not reflect any duration dependence of hazard rate since its hazard function is constant.

Salant's study was based on the non-regression type model, but Lancaster (1979) used Cox's (1972) proportional hazards model, assuming the constant baseline hazard function across the individuals, to study the variation between unemployed job seekers in the time length of unemployment duration in terms of search theories. Further, a simulation study was done to see whether the parameters of time distribution could be estimated practically with good precision. It was found that a large number of data are required for the useful precision as well as fairly strong assumptions about the functional form of survivor function and about the form of the error distribution in the regression model. Also, Lancaster argues that the uncorrected heterogeneity of individuals results in biased coefficients, and in particular can result in negative duration dependence in models with no duration dependence of baseline hazard function at the individual level (Atkinson and Tschirhart, 1986; Heckman and Signer, 1984b). The estimated falling hazard rate represents, at least in part, the mere effect of unrecognized heterogeneity of the sample individuals or omitted regressors. Therefore an idea of mixture model was suggested since "if we are to obtain estimates of the time variation of the hazard in which we can place any confidence, we ought to attempt to allow for error in our specification of the systematic sources of variation of the hazard function due to the omission of relevant regressors" (Lancaster, 1979, p.948). It was concluded that "the study of duration of unemployment data is probably not going to be a very helpful way of testing those predictions of search theory which concerns themselves with the way in which individuals vary their reservation wage as time passes" while "it is possible to make useful estimates of the effects of regressors on the expected duration of unemployment of individuals and that such estimates are rather insensitive to the precise form assumed for the duration distribution" (Lancaster, 1979, pp.955-6). Unfortunately, the maximum likelihood function given by Lancaster can not cope with censored observations and tied observations.

While the models of Salant (1977) and Lancaster (1979) are based on the parametric models, the use of Cox's distribution-free proportional hazard model has been started since the 1980's although it involves some difficulties with censored data. The main emphasis given by economists has been to the so-called finite mixture models due to the lack of observability of economic duration data (Heckman and Singer, 1984b).

Heckman and Singer (1984a) used the finite mixture models approach, as Lancaster (1979) suggested, to minimize the impact of distributional assumptions of duration time and study the heterogeneous components in samples of duration data. The idea of mixture likelihoods used in this study was initially suggested by Lindsay (1983a, 1983b), and the relationship between, for example, the mixture density $f_Q(x)$ corresponding to mixing distribution Q is represented as $f_Q(x)=\int f_\theta(x)dQ(\theta)$, where $\{f_\theta:\theta\epsilon\Omega\}$ is a parametric family of densities with respect to some sigma-finite measure (Lindsay, 1983a).

Main conclusions in the study by Heckman and Signer (1984a) were that:

1) parameter estimates obtained from econometric models for unemployment duration data are sensitive to assumed functional forms for the distribution of unobserved variables in parametric models, and this kind of practice can over-parameterizes econometric duration models;
2) a consistent nonparametric maximum likelihood estimator for the structural parameters and the distribution function

of unoberved variables in general proportional hazards models with censoring and time varying variables can be found if there is information about the functional form of a duration model conditional on values of unobserved variables or empirical distribution of durations; and
3) the nonparametric maximum likelihood estimator, obtained from finite mixture of Weibull distribution of duration time, estimates the structural parameters rather well, but does not produce reliable estimates of the underlying mixing distribution.

Also, this nonparametric maximum likelihood estimator is more consistent with the theory than estimators obtained from mixture densities of Weibull distribution having normal, gamma, and multinomial distributions as mixing distributions respectively. For the estimation of nonparametric finite mixture of Weibull distributions, the EM (Expectation-Maximization) algorithm was used. The EM algorithm was developed by Dempster, Laird, and Rubin (1977) to compute maximum likelihood estimates from incomplete data such as grouped, censored or truncated data, finite mixture models, variance component model, etc. In the case of censored data, the EM algorithm replaces censored samples t_i with $E[T_i | T_i \geq t_i]$.

In a companion paper, Heckman and Signer (1984b) also argued that the non-parametric model such as Kaplan-Meier estimation might not be successful in econometric applications since 1) "the available samples are small especially after cross-classification by regressor variables," and 2) "empirical modesty leads most analysts to admit that some determinants of any duration decision may be omitted from the data sets at their disposal" (1984b, p.77). Further, they studied the multiple unemployment spells based on the single spell duration models. Multiple spell models were treated in terms of stochastic process, in which time invariant regressors x(t)=x were assumed. Similar studies, based on job search theory, have been done by Kiefer and Neumann (1981) and Lancaster and Chesher (1983).

Parametric and nonparametric survival models which have been used in economic applications so far have been mentioned. However, there is an important aspect of using duration data model, that of 'identifiability' of mixture models. (Similar works have been done for the identifiability of multiple failures or multivariate failure time model (see Prentice and Kalbfleisch, 1979, p.34)). The issue of identifiability concerns whether the distribution of specification error term for unobserved heterogeneity and the observed heterogeneity function (or the function for covariates) are identified, given the duration distribution, and whether it is possible to distinguish between time dependence and unobserved heterogeneity. Elbers and Ridder (1982) argued in their study of identifiability of the proportional hazards model that time dependence (or baseline hazard function) and unobserved heterogeneity can be distinguished under some conditions at least in the context of the proportional hazards model. Hekmann and Singer (1984c) also have shown the identifiability conditions for the nonparametric estimation procedure. They argue that "an essential ingredient of any nonparametric estimation strategy is knowledge of conditions under which the model is identified" (1984c, p.231).

Heckman and Singer (1984a, 1984b) mainly advocated the non-parametric approach for the heterogeneous observations. However, many economists worked to develop the parametric mixture models for the heterogeneity of samples. Examples are the works by Butler and Worrall (1985), and Butler and McDonald (1986). Butler and Worrall (1985) used Cox's proportional hazards model to estimate hazard rates for a variable that "both determines whether one leaves Workers' Compensation as well as the length of time one stays on Workers' Compensation" (p.716). Both Weibull distribution model and Singh-Maddala (or Burr (1942)'s type 12) distribution model were used to study the relative performance. Here, the use of the Burr-12 distribution was to allow for 'random effects' type of heterogeneity across samples, and Burr-12 distribution is obtained when the scale parameter in Weibull distribution is assumed to be distributed as a gamma function. Singh and Maddala later derived the same distribution through both a discussion of failure rates and models of decay. The Singh-Maddala distribution function has a closed form which greatly facilitates estimation and anlaysis of results (McDonald, 1984). Butler and Worrall (1985) found in their study, for the incentive response exhibited by workers with claims for indemnity benefits arising from lower-back injuries, that the expected length of stay on Workers' Compensation is significantly affected by changes in benefits, wages, and other major parameters of the Workers' Compensation process, including the representation of the claimant by a lawyer.

In a study similar to that of Butler and Worrall (1985), Butler and McDonald (1986) studied the hazard rates for completed spells of unemployment implied by the conditional distribution and unconditional distribution, i.e., the Singh-Maddala model and Weibull model respectively, while generalizing Salant's (1977) model for the data from the Bureau of Labor Statistics. One interesting result was that once heterogeneity is controlled across spells, the hazard rates are still an increasing function of time on a spell, which is of course known as duration dependence (or baseline hazard) in duration data analysis. Atkinson and Tschirhart (1986) also have studied the mixture models as Heckman and Singer suggested in their papers. The mixture models of Singh-Maddala distribution, exponential distribution and Weibull distribution were adopted to explain the length of participation in a risky career such as the National Football League. Only single spell models were considered, and Cox's distribution-free proportional hazards model, which is not comparable to these mixture models, was also estimated. They found that the Burr-12 continuous mixture model was superior to Heckman and Singer's model of nonparametric finite mixture of Weibull distributions in their data from the National Football League.

Earlier, the studies of identifiability conditions in nonparametric duration data analysis were briefly mentioned. However, these identifiability conditions do not have a significant meaning if we can find ways of avoiding the parameterization of the baseline hazard function. This is why we are much interested in Cox's partial likelihood approach although observability problems may exist as Heckmann and Singer (1984b) pointed out. The possibility of lost relative efficiency is another main concern in applications of partial likelihood approach having time-dependent covariates (Lawless, 1982). One of the first attempts to utilize Cox's partial likelihood approach in economics (or distribution-free proportional hazards model) was by Fenn (1981). Fenn used Cox's distribution-free proportional hazards model with tied observations to study duration data about sickness duration, residual disability and their relationship with income replacement. However, Fenn's model was based on single spell models which Cox's model was intended to handle, and ignored the dynamic aspects such as lagged-duration dependence and occurrence dependence in multiple unemployment spells. Therefore, Trivedi and Alexander (1989) adopted Prentice's, et al. (1981) multivariate failure time model to to study the lagged-duration dependence and occurrence dependence in reemployment probability and multiple unemployment spells. In that multivariate failure time model, a partial likelihood function for the regression coefficients of individuals experiencing multiple failures is derived by relating the hazard or intensity function to covariates and to preceding failure time history (Prentice, et al, 1981).

For example, when the time scale for the arbitrary baseline hazard function is the time t, from the beginning of the study, a partial likelihood for the multivariate failure time data or multiple failures data can be written as

(3.48) $L(b) = \prod_{s\geq 1}\prod_{i=1}^{d_s} [\exp\{z_{si}(t_{si})'b_s\}/\Sigma_{l\in R(t_{si},s)}\exp\{z_l(t_{si})'b_s\}]$.

In this likelihood function, i indicates a subject under consideration. $s=s\{N(t),Z(t),t\}$ is the stratification variable which may change as a function of time for a given subject. $N(t)=\{n(u):u\leq t\}$ is the variable for the number of failure on a study subject prior to time u, and $Z(t)=\{z(t):u\leq t\}$ is the covariate process up to time t. $z(u)=\{z_1(u),....,z_p(u)\}$ denotes a vector of covariates, for a study subject, available at time u≥0. t_{si} is the time at which subject i fails in stratum s, b_s is a column vector of stratum-specific regression coefficients, $t_{s1}<....<t_{sd_s}$ denote the ordered, assumed distinct, failure times in stratum s, and $z_{si}(t_{si})$ denotes subject i's covariate vector at t_{si}. R(t,s) is the set of subjects at risk in stratum s just prior to time t.

Trivedi and Alexander (1989) argue that the weakness of partial likelihood approach is that it neglects unobserved heterogeneity across observations. However, it may not be a major source of distortion since the stratification of observations by the number of spells may lead to greater homogeneity. The neglect of unobserved heterogeneity is particularly serious if the object is inference about the baseline hazard.

3.4.4 Other Applications of Survival Analysis in Economics

Solon (1985) investigated whether introduction of unemployment insurance benefits taxation in 1979 had had the predicted effect of reducing unemployment duration. That is, the unemployment duration of claimants before benefits were taxed was compared with the duration of those who claimed benefits after the tax change. In this study, unemployment duration was distributed by Weibull and the effect of benefit taxation on compensated duration was estimated by computing the sample mean of the estimate of expected unemployment duration. Zuehlke (1987) adopted a Weibull hazard model to study the relationship between probability of sale and market duration in housing markets. Also, Norton and Norton, Jr. (1986) studied the validity of the economies of scale in the newspaper industry, and its approach was the survivor method in the traditional sense in which newspaper enterprises in a market were classified into size categories and market shares of the respective size classes over time were measured. In particular, the logit model was used to estimate the coefficients of covariates, where firms were categorized as gaining market share (in this case, dependent variable equals 1) or not gaining market share (dependent variable equals 0).

On the other hand, Dupont (1983) developed a method to estimate the size of a heavily exploited animal population from catch data and relative-harvest-effort data. It is based on a competing-risk (or birth and death process) model for natural and catch mortality that is similar to Cox's (1972) distributional-free proportional hazards model. In this model, the initial cohort sizes are estimated as parameters with parameters for hazard rates and covariate functions to avoid the problem of modelling the birth rate of the population. Frank (1988) has developed a model of the evolution of an industry whose concern is more with the individual firm. It is based on the model of the risk-neutral entrepreneur maximizing the expected utility. The study suggests that the time profile of failure depends critically on initial sunk costs. That is, the duration of the lag before a firm exits is positively related to sunk entry costs.

Many studies on organization mortality and unemployment duration data analysis before 1980's showed evidence of negative duration dependence. The applications of survival analysis have been significantly increased in economics since 1980's due to advances in statistical methods, and the studies on duration dependence were still a main part. The main development of theory and practice in the application of survival analysis to economic models have come from the unemployment duration data analysis, and methodologies have been developed mainly to consider heterogeneity of samples in unemployment data or to address multiple spells data, as an effort to identify the sources of duration dependence in the models and to develop the more appropriate models for economic events such as unemployment. However, so-called finite mixture models to deal with heterogeneity of samples and multiple spells are relatively difficult to practice while the partial likelihood approach, which can be extended to address the issues of heterogeneity and multiple spells successfully if unobserved heterogeneity is not a major concern, is relatively easy to use. Therefore, judgement about benefit and loss resulting from choosing a specific model would be an important factor for the success of application of survival analysis in economics.

3.5 Concluding Comments

There have not been any attempts to generalize survival analysis in economics. Survival analysis has been used for different purposes and different models. Therefore, it may not be necessary to develop a general model of survival analysis in economics. However, it seems that the models of survival analysis in economics can be developed by following two different directions in general.

First, the idea of evolutionary economics for market competition can be developed by the statistical concepts of survival model since the survivals of individual firms or agents are the subjects of studies. Survival analyses in the traditional economics, unemployment duration data analysis, and organizational mortality analysis belong to this category. Second, survival model in economics can be developed by incorporating the definitions of survival rate or hazard rate into dynamic economic models.

It is obvious for the first case that the ideas of distribution and regression models in statistical survival analysis can be directly reduced to the general model of survival analysis in economics. Estimation of survival model would be the main objective of analysis here. The second case is an extension of the first case. There can be many ways to develop the second type of models since the survivor function or hazard function can be defined for the various situations in economics. For example, the survival rate can represent the probability that a event, i.e., yes or no in a decision process, would happen. Alternatively, the hazard rate can represent the probability that a firm exceeds the fixed level of pollution allowed.

On the other hand, there have not been any theoretical criteria developed yet to decide whether a parametric model or nonparametric model should be chosen for a specific given lifetime data set. It is believed that there would be some loss of efficiency in using the nonparametric model when the data appear to come from a parametric model such as the Weibull model (Lawless, 1982). In general, it is recommended to use the nonparametric model first. Then, the appropriateness of a parametric model can be judged by plotting the relationships between survival times and survival rates. Concerning the applications of survival analysis to economics, any parametric or nonparametric model can be utilized in the area of economics. However, there have not been enough accumulation of empirical works to help the model selection process. Therefore, the correct understanding of the basic concepts and models on survival analysis would be critical in developing survival analysis in economics.

Chapter 4

Fishery Management and Survival Analysis

In general, the purpose of fishery management is "to insure that the correct amount of fish is being caught at the proper size, at the proper time, and at the lowest possible cost" (Anderson, 1986, p.192). The main objectives of fishery management have been recognized as efficiency, equity, and biological conservation along with the political support of the majority of fishermen involved. There exist many types of regulatory tools which can be used alone or together to satisfy the management objectives. No one regulatory tool can satisfy all of those objectives simultaneously. The correct choice of a regulatory tool or a combination of some regulatory tools depends on the biological, economic and institutional peculiarities of the particular fishery involved (Anderson, 1986).

According to Anderson (1986, pp.243-248), the adequate process of developing fisheries management policy can be summarized in the following steps:

1. Determine the current state of the fishery since the stock, fleet, and harvest will very likely be suboptimal in size and combinations if the fishery is not regulated.
2. Select appropriate objectives as a guide to developing a management program.

3. Select an appropriate regulation package to best achieve the stated objectives.
4. Monitor the fishery under regulation.
5. Finally, periodically reevaluate the fishery and objectives of management.

The various objectives of fishery management would be achieved if this kind of optimal process of developing fishery management policies could be developed. However, the reality involves versatile complexties which result from the dynamics of population biology, fishery industry, and management policies.

This chapter discusses various types of dynamics in fishery management. Then, a framework for survival analysis in fishery management is presented.

4.1 Dynamics and Uncertainty in Fishery Management

4.1.1 Dynamic Modeling in Fishery Management

In the dynamic modeling of fisheries, most issues concentrate upon the existence of steady-state equilibria for the stock and stability of those equilibria, and regulation policies to maintain the social optimal level of stocks. In addition, property rights for open-access fishery and the difference between economic and biological overfishing have been major issues in this approach. As discussed earlier, the results of this kind of modeling have not been very successful.

The uncertainty problem in dynamic modeling is another major issue. According to Walters (1986), it is usual to distinguish between three types of uncertainty about natural systems. First, certain inputs or disturbances that occur rather regularly or frequently over time will generate unpredictable and uncontrollable changes. Second, there is statistical or parametric uncertainty about forms and parameter values of various functional responces, such as production rates as a function of stock size. Third, there is always basic structural uncertainty about even what variables to consider or how to bound the problem. Stochastic modeling will produce better results than deterministic modeling in modeling fisheries, insofar as the natural rate of growth of the stock is not deterministic. Also, much of dynamic modeling work has been based on the assumption of a fixed and exogenous price for the harvested resource, typically resulting in 'bang-bang' solutions for the harvesting policy (Pindyck, 1984). For exmaple, Pindyck (1984) gave an example of stochastic modeling for renewable resources in his paper. When the market has well-defined property rights, and prices are determined endogenously, Pindyck's stochastic model showed that stochastic fluctuations in the stock would increase harvesting costs over time and that at any stock level, these effects would reduce rent and increase the rate of harvest. His model also showed that an increase in the variance of stock fluctuations would reduce the expected growth rate of the stock, and would increase rent and reduce the harvesting rate. As a result, the overall effect of an increase in variance may be to decrease the harvesting rate, increase it, or leave it unchanged (Pindyck, 1984, p.194).

Obviously, the solutions of Pindyck's stochastic modeling are different from the traditional bang-bang solutions of deterministic modeling as discussed in Clark (1985). Therefore, the dynamic modeling approach to fisheries management should be enhanced by looking at some important aspects such as the uncertainty problem and the discrepancy between theoretical developments and persistence of suboptimal regulations.

Conflicts among different management objectives and the time frame of fishery management are also main sources of difficulties arising in fishery management (Anderson, 1986). The success of dynamic modeling approach in fishery management is very likely to depend on those.

4.1.2 Uncertainty in Dynamic System

Walters' first type of uncertainty in modeling natural systems is unpredictability or uncontrollability of various types of changes in the systems. The second type of uncertainty is statistical or parametric uncertainty about forms and parameter values of various functional responses.

While survival analysis may be developed to address this first type of uncertainty, dynamic programming techniques have not been very succesful in dealing with the second type of uncertainty.

A typical problem in applying theories of dynamic system to reality has been that long term prediction may be almost impossible even if a simple model with exact parameter values is given since there can exist a butterfly effect. That is, small changes in environmentals can lead the system to an entirely different pattern in which prediction deteriorates badly due to the existence of the hidden fatcs such as chaotic pattern of system (Gleick, 1987). Further, the stochastic description of the dynamic system has been another important issue since reality is more likely to be random, and this has not been successful in providing the correct descriptions of nature due to mathematical complexity.

The recent development in the fractal geometry and accompanied development in computer algorithms show that prediction can be improved significantly if a pattern in the pattern is to be found and all the dynamic systems have some kind of universality which can be analyzed under the fractal dimension (Gleick, 1987). The chaotic pattern, in which the system does not settle into any finite periodic cycle and which was thought to be impossible to analyze in the past, may be systematically and mathematically studied (Barnsley, 1988; Thompson and Stewart, 1986).

On the other hand, the detailed information about a dynamic system may not be directly related to issues of renewable resources management and economics since most observed parameter values in the biological growth models do not exceed the values which cause unpredictable chaotic patterns in a system. Also, even if the functional relations for a system are known, errors in measurement and computing would still make predictions unreliable (Kelsey, 1988). The recent developments in chaos theory clarifies more details on this issue (Barnsley, 1988; May, 1987; Peitgen and Saupe, 1988; Thompson and Stewart, 1986).

4.1.3 Concluding Comments

It is not exepcted that survival analysis can handle all the problems of dynamics and uncertainty in fishery management. However, survival analysis would be able to reduce the problems of uncertainty of behavioral responses of fishermen and to clarify the impacts of fishery regulation and economic and biological changes on the fishermen's final decisions about entry and exit from the fishery. The assumptions about market structure and bilateral behavioral responses of the regulatory authority and individual fishermen could be relaxed for analytical purposes.

4.2 Framework for Survival Analysis in Fishery Management

Chapter III stated that there can be two directions for the development of survival model in economics. This also holds for the case of fishery management. That is, the first standard approach for the survival analysis in fishery management is the direct linkage of statistical survival concepts to individual fishing firms' or fishermen's survivals. The second approach is the extension of the defintions of the survival rate or hazard rate to the typical dynamic profit or utility maximization model.

In this section, the second approach is discussed first to show the general description about how we make the various survival regression models for fishery management. Also, it is shown that the concepts of the survivor function and hazard function can be introduced into the dynamic fishery model, mainly the optimal control model.

4.2.1 Extension of Survival Analysis to Dynamic Fishery Model

A particular feature of the definitions of the survival rate or hazard rate is that they can be incorporated into the optimal control problem for fishery managment since the definitions of survival rate and failure (or hazard) rate provide a differential equation (system), i.e., $[dF(t)/dt] = h(t)[1-F(t)]$. On the other hand, optimal control theory has been very influential in the management of renewable resources such as fisheries in that it can incorporate biological and economic aspects into an Hamiltonian system which provides precise optimal solutions within the range of given constraints. In this section, a few applications of the survival technique to optimal control problems are discussed. These discussions will help us understand some implications of survival model in dynamic fishery models.

4.2.1.1 Examples of Application of Survival Model to Dynamic Fishery Model

There are many ways in which survival analysis can be applied to fishery regulations and other economic theories. For example, if fishermen can be categorized into a few groups having different bargaining power, then an aspect of wealth redistribution by political process can be described. The conventional utility or profit maximization models based on the control theory approach can be extended to incorporate each fisherman's survival rate. Also, the simple principal-agent model can be modified to address the uncertainty problem in terms of survival rate. Assumption about competitive market structure is not needed in regression-type survival analysis.

In the following examples, the planning time period is assumed to be infinite. The main reasons for the assumption of infinite time horizon are that it is difficult to specify the terminal values of state variables fish stock x(t) and survival rate S(t), and the process of fish growth and survival rate have no expected terminal dates. Another economic rationale for the assumption of infinite time horizon is that "what happens in the very distant future has almost no influence on the optimal solution for the period in which one is interested" (Seierstad and Sydsæter, 1987, p.231). In general, the conditions to obtain optimal control solutions for the case of infinite time horizon are almost the same as the conditions for the case of finite time horizon. However, the finite time horizon transversality condition "can not carry over to the infinite horizon case without imposing restrictions on the functions involved in general" (Seierstad and Sydsæter, 1987, p.231).

Further, there is the problem of choice of optimality criterion when the objective function in a control problem does not converge for all admissible pairs of state and control variables. There are several optimal criteria available, and Seierstad and Sydsæter (1987) provides a good discussion of this topic.

Example 1: A Model for Regulatory Authority and Sole-owner

Suppose that there exist a sole-ownership fishery whose goal is to maximize the profit from the fishery. Let x(t) be the level of fish population at time t, k(t) a time variable for catch ($0 \leq k(t) \leq k_{max}$), u(t) another control variable for the authority's regulation effort ($0 \leq u(t) \leq 1$), $c(x,u)$ the function of unit cost per fish satisfying $(\partial c/\partial x)>0$, $(\partial^2 c/\partial x^2)\leq 0$, $(\partial c/\partial u)>0$, and $(\partial^2 c/\partial u^2)\geq 0$, w the vector of states of world or the vector of socio-economic and biological variables, and $x \epsilon w$. The states of world are expressed through explanatory variables in the regression analysis and time-dependent variables such as price and interest rate would belong to w. $S(t,q;w)$ is the survival rate at time t, q is the vector of parameters of distribution, and censoring is not assumed. $G(x)$ is the biological growth fuction. Here, the growth function $G(x)$ is assumed not to cause any chaotic pattern for simplicity. The individual firm's probability of exit at any time, given survival to that time, depends on the regulation effort $u(t)$ of authority and a natural failure (hazard) rate $h(t)$ (Kamien and Schwartz, 1981, p.175-78).

If the sole-owner of fishery maximizes his or her own profits with survival rate $S(t,q:w)$, under the assumption that the unit cost c does not depend on the authority's regulatory effort u for simplicity, the mathematical expression is written as

$$(4.1) \qquad \text{Max.}_{k(t)} \quad \int_0^\infty [p-c(x)]k(t)S(t,q;w)e^{-rt}\,dt \geq \prod_0 ,$$

where $\prod_0$ is the reservation profit level or individual rationality constraint. The first order condition for this maximization problem is

(4.2) $$\int_0^\infty (p-c)S(t,q;w)e^{-rt}\,dt = 0.$$

Now, the regulatory authority tries to maximize the net monetary social outcome function $b(k,w)-y(u)$, where $b(k,w)$ is the monetary outcome function satisfying $(\partial b/\partial k)>0$, $(\partial^2 b/\partial k^2)\leq 0$, $(\partial b/\partial x)>0$, $(\partial^2 b/\partial x^2)\leq 0$, $x\epsilon w$, and y is the monetary management cost function of regulation effort u satisfying $(\partial y/\partial u)>0$ and $(\partial^2 y/\partial u^2)\geq 0$. Then, the mathematical representation is

(4.3) $$\begin{aligned} &\mathrm{Max.}_{u(t),k(t)} \int_0^\infty [b(k,w)-y]S(t,q;w)e^{-rt}\,dt \\ &\quad \text{s.t.} \int_0^\infty (p-c)S(t)e^{-rt}\,dt = 0 \\ &\qquad dx/dt = G(x) - k(t) \\ &\qquad dS/dt = -h(t)S(t)u(t) \\ &\qquad 0 \leq k \leq k_{\max} \\ &\qquad 0 \leq u \leq 1. \end{aligned}$$

The solution of this problem may be regarded as co-ordinated by the authoruty and the sole-owner because the decisions for $u(t)$ and $k(t)$ are made simultaneously. The Hamiltonian is written as

(4.4) $$\begin{aligned} H = \{[b(k,w)-y]+\mu[p-c(x)]\}S(t)e^{-rt} + \tau[G(x)-k(t)] \\ -\delta h(t)S(t)u(t)+ \alpha_1 k + \alpha_2(k_{\max}-k) + \alpha_3 u + \alpha_4(1-u), \end{aligned}$$

where α's, δ, and τ are costate variables for restrictions and μ is a costate variable for the restriction of individual firm's profit maximization behavior. The solution to this optimization problem can be obtained from the maximum principle. The necessary conditions are:

(4.5) $(\partial H/\partial k) = b_k' S(t)e^{-rt} - \tau + \alpha_1 - \alpha_2 = 0$

(4.6) $(\partial H/\partial u) = -y_u' S(t)e^{-rt} - \delta h(t)S(t) + \alpha_3 - \alpha_4 = 0$

(4.7) $\alpha_1 \geq 0$ or $\alpha_1 k=0$, $\alpha_2 \geq 0$ or $\alpha_2(k_{max}-k)=0$,

$\alpha_3 \geq 0$ or $\alpha_3 u=0$, $\alpha_4 \geq 0$ or $\alpha_4(1-u)=0$

(4.8) $\dot{\tau} = -(\partial H/\partial x) ==>$

$-\dot{\tau} = \{[b(k,w)-y]+\mu[p-c(x)]\}S_x'(t)e^{-rt} +$

$(b_x'-\mu c_x')S(t)e^{-rt} + \tau G_x'(x) - \delta h(t)S_x'(t)u(t)$

(4.9) $\dot{\delta} = -(\partial H/\partial S) ==>$

$-\dot{\delta} = \{[b(k,w)-y]+\mu[p-c(x)]\}e-rt - \delta h(t)u(t)$

From the necessary conditions,

(4.10) if $\tau > b_k' S(t)e^{-rt}$, $\alpha_1-\alpha_2 < 0$ then $\alpha_1=0$, $\alpha_2=1$, and $k^*=k_{max}$;

(4.11) if $\tau < b_k' S(t)e^{-rt}$, $\alpha_1-\alpha_2 > 0$ then $\alpha_1=1$, $\alpha 2=0$, and $k^*=0$;

(4.12) if $\tau = b_k' S(t)e^{-rt}$, $\alpha_1 = \alpha_2 = 0$ then

$\dot{\tau} = (b_{kk}''\dot{k}+b_{kx}''\dot{x})S(t)e^{-rt} - rb_k' S(t)e^{-rt} + b_k' S_t'(t)e^{-rt}$;

(4.13) if $-y_u' S(t)e^{-rt} - \delta h(t)S(t) > 0$, i.e., $\delta < [-y_u' e^{-rt}]/h(t)$,

$\alpha_3-\alpha_4 < 0$ then $\alpha_3=0$, $\alpha_4=1$, and $u^*=1$;

(4.14) if $\delta > [-y_u' e-rt]/h(t)$, $\alpha_3-\alpha_4 > 0$ then $\alpha_3=1$, $\alpha_4=0$, and $u^*=0$;

(4.15) if $\delta = [-y_u' e-rt]/h(t)$, $\alpha 3 = \alpha_4 = 0$ then

$\dot{\delta} = -[y_{uu}''\dot{u}/h(t)]e^{-rt} + [y_u'\dot{h}(t)/h(t)^2]e^{-rt} +$

$r[y_u'/h(t)]e^{-rt}$.

The three necessary conditions for τ and δ respectively give 9 cases to be considered in order to find the control solutions. The most interesting case is when $\tau = b_k' S(t) e^{-rt}$ in equation (4.12) and $\delta = -[y_u' e^{-rt}]/h(t)$ in equation (4.15). In this case, the relationship between optimal catch k^* and optimal stock level x^* can be obtained. First, the equations for μ can be derived from the conditions of (4.12) and (4.15) respectively. Then, those two equations can be equated as an identity equation. The identity equation is derived as

$$\begin{aligned} (4.16)\quad & \{-b_k' S(t)/[c_x' S(t) - (p-c(x)) S_x'(t)] + y_u'/[h(t)(p-c(x))]\} r \\ \equiv\ & -[(b_{kk}'' \dot{k} + b_{kx}'' \dot{x} + b_k' G_x') S(t) + b_k' S_t'(t) + (b-y-y_u' u) S_x'(t)]/[c_x' S(t) - \\ & (p-c(x)) S_x'(t)] \\ & + \{y_{uu}'' \dot{u} - y_u' [(\dot{h}(t)/h(t)) + u] - h(y)(b-y)\}/[h(t)(p-c(x))]. \end{aligned}$$

Now, assuming that the lifetime data has a Weibull distribution and the location parameter α depends on the vetor of state of nature w, we can write $h(t|w) = (\beta/\alpha(x))[t/\alpha(x)]^{\beta-1}$, where β is the scale parameter. If another assumption such that $\alpha(x) = b_0 + b_1 x$ is made for simplicity, $S_x'(t)$ is written as

$$\begin{aligned} (4.17)\qquad S_x'(t) &= \{\exp[-(t/(b_0+b_1x))^{\beta}]\}\beta[t/(b_0+b_1x)]^{\beta-1} t b_1 \\ &= S(t) h(t) t b_1 (b_0+b_1x). \end{aligned}$$

More generally,

$$(4.18)\qquad S_x'(t) = S(t) h(t) t \alpha(x) \alpha_x'(x).$$

Therefore,

$$h(t) = S_x'(t)/[S(t)h(t)t\alpha(x)\alpha_x'(x)] \text{ or} \tag{4.19}$$

$$S_x'(t)/S(t) = h(t)t\alpha(x)\alpha_x'(x). \tag{4.20}$$

Finally, two relationships can be derived from the above identity equation:

1) from the l.h.s.,

$$\{[p-c(x)]S_x'(t)\}/S(t)] = c_x'(x)/\{1+b_k'/[y_u't\alpha(x)\alpha_x'(x)]\}; \tag{4.21}$$

2) from the r.h.s.,

$$\begin{aligned}&[b(k,x)-y(u)]\{1+b_k'/[y_u't\alpha(x)\alpha_x'(x)]\}[S_x'(t)\}/S(t)] = \\ &\quad b_k'[h(t)-(\dot{h}(t)/h(t))-G_x'-u(t)] + y_u'uht\alpha(x)\alpha_x'(x) + \\ &\quad b_k'y_{uu}''\dot{u}/y_u' - (b_{kk}''\dot{k}+b_{kx}''\dot{x}).\end{aligned} \tag{4.22}$$

The control solution is obtained interactively from these two equations (4.21) and (4.22). The first equation (4.21) is the solution for the individual's profit maximizing behavior, and the second equation (4.22) is the solution for the authority's social payoff maximizing problem. These equations show that survival analysis can reflect uncertainty through the hazard rate and survival rate.

The term $b_k'/[y_u't\alpha(x)\alpha_x'(x)]$ represents the expression for the impact of individual's profit maximizing behavior on the authority's social payoff maximizing behavior, and the whole l.h.s. term of the second equation represents a kind of expected net payoff of regulatory authority. The term $b_k'[h(t)-(\dot{h}(t)/h(t))-G_x'-u(t)]$ on the r.h.s. of the second equation represents the expected return from regulating the catches, $y'_u uht\alpha(x)\alpha'_x(x)$ the expected cost of regulation efforts, $b'_k y''_{uu}\dot{u}/y'_u$ the effect of individual's profit maximizing behavior on the regulation cost, and $-(b''_{kk}\dot{k}+b''_{kx}\dot{x})$ the second-order impact of time on the payoff function b(k,x).

This example can be extended to a principal-agents model. First, the sole-owner has the following individual rationality constraint:

$$(4.23) \quad \int_0^\infty [p-c(x)]k(t)S(t,q;w)e^{-rt}\,dt + \int_0^\infty m(t)[1-S(t,q;w)]e^{-rt}\,dt \geq \int_0^\infty m(t)e^{-rt}\,dt,$$

where m(t) is the profit of the sole-owner when he engages in the other business. This constraint is reduced to

$$(4.24) \quad \int_0^\infty \{[p-c(x)]k(t)-m(t)]\}S(t,q;w)e^{-rt}\,dt \geq 0.$$

The sole-owner's profit maximization becomes

$$(4.25) \quad \begin{aligned} \text{Max.}_{k(t)} \quad & \int_0^\infty (p-c)k(t)S(t,q;w)e^{-rt}\,dt \\ \text{s.t.} \quad & \int_0^\infty [(p-c)k(t)-m(t)]S(t)e^{-rt}\,dt \geq 0 \\ & dx/dt = G(x) - k(t) \\ & 0 \leq k \leq k_{max} \end{aligned}$$

The Hamiltonian is

(4.26) $$H = [p-c(x)]k(t)S(t) + \mu\{[p-c(x)]k(t)-m(t)\}S(t)e^{-rt} + \tau[G(x)-k(t)]$$

By the Maximum Principle, the following solutions can be obtained:

1) when $\mu>0$, i.e., $\int_0^\infty [(p-c)k(t)-m(t)]S(t)e^{-rt}\,dt=0$.

This is a trivial case of $p-c(x)=m(t)$ since $S(t)\geq 0$. This solution follows when the individual rationality constraint is not considered. A closed form solution can be obtained.

2) when $\mu=0$, i.e., $\int_0^\infty [(p-c)k(t)-m(t)]S(t)e^{-rt}\,dt>0$.

An equilibrium solution at $d\tau/dt=0$ and $dx/dt=0$ is expressed as

(4.27) $$G_x'(x) + [\dot{S}(t)+G(x)S_x'(x)]/S(t) = r - [\dot{p}(t)-c_x'(t)G(x)]/[p-c(x)].)$$

Also, a bang-bang solution, $k^*(t)$ and $x^*(t)$, occurs for the sole owner. Then, the regulatory authority maximizes the net monetary social outcome function $b(k,w)-y(u)$. The regulatory authority's maximization problem is represented as

(4.28) $$\text{Max.}_{u(t)} \int_0^\infty [b(k^*,w)-y]S(t,q;w)e^{-rt}\,dt$$
$$\text{s.t. } dS/dt = -h(t)S(t)u(t)$$
$$0 \leq u \leq 1.$$

In this problem, $k^*(t)$ and $x^*(t)$ are treated as exogenous variables given by the sole-owner when an alternative decision for engaging in the other business exists. The Hamiltonian is

$$H = [b(k^*,w)-y(u)]S(t)e^{-rt} - \delta h(t)S(t)u(t). \tag{4.29}$$

The control solution for the above problem has been given by Kamien and Schwartz (1981, pp.175-178). Therefore, the two-step procedure can be used for the control solution of this principal-agents model.

Example 2: Fishing Permits Buyback Program

Another interesting application of survival analysis can be found in the fishing permits buyback program. The buyback program can be practiced through an auction market in which individual fishermen offer their sealed bid-prices and permits are sold at the lowest offer prices until the total fund available for the buyback program is freed.

Assuming that the auction market is opened up on a particular time t_0, the survivor function at t_0 is written as $S(t_0;z)$, where the covariable vector z includes the variable x of offer prices. Sales of permits are treated as binary responses, i.e., y=0 when the permit is not sold and y=1 when the permit is sold. Then, $S(t_0;z)$ can represent the probability that the permit is sold at time t_0 and $1-S(t_0;z)$ is the probability that the permit is not sold at time t_0.

The linear logistic or log logistic accelerated model can be used to obtain a measure of willingness-to-sell(WTS). WTS is obtained by the same manner as the willingness-to-pay measure is found in the discrete choice model of the contingent valuation method for environmental amenities (Mitchell and Carson, 1989). First, the logit ratio under a Weibull distribution of lifetime is written as

$$\log\{S(t_0;z)/[1-S(t_0;z]\} = -z'\beta\alpha-\beta\log(t/\alpha) \quad , \tag{4.30}$$

where α is the scale parameter, β is the shape parameter, and $S(t;x) = 1/\{1+[(t/\alpha)\exp(x'b)]^{\beta}\}$ with its baseline survivor function $1/[1+(t/\alpha)^{\beta}]$. Then, the expected WTS is calculated as

$$E[X] = \int_0^{x^*} xf(x)\ dx = \int_0^{x^*} F(x)\ dx = \int_0^{x^*} S(t_0;z)\ dx, \tag{4.31}$$

where x^* is the maximum bid-price.

Example 3: Fishery Overexploitation Problem

In control problems for fisheries management, it is common that the optimal level of catches involves the ex ante decision on the level of maximum allowable catch, designated as k_{max} in Example 1. The maximum allowable catch is usually determined based on the previous history of catches and population size (or data on catch per unit of effort) and some expected environmental and biological changes. However, actual level of maximum allowable catch may not be known to fisheries managers due to the unexpected environmental and biological changes. Assuming that the main goal of fisheries managers' is to determine the appropriate level of maximum allowable catch which maximizes the welfare of fishermen, the following analysis, which is based on Kamien and Schwartz's (1971) work, can be given. Survival rate does not represent the probability of 'stay in the fishery industry' in this application. It is just the statistical concept of cumulative probability of a event.

The economy is the same as in Example 1, but there can be many (or an infinite number of) fishermen. Alternatively, it can be assumed that the maximum allowable catch is exhausted by a representative fisherman due to, for example, excessive foreign demand on the target fishery offering a higher price than the domestic price. In this present case, the latter is assumed for convenience and a new concept, <u>ex post</u> optimal catch level, is introduced.

The <u>ex post</u> optimal catch level is the analytical optimal catch level after all events related to the model are realized, which may or may not be obtained in reality. Also, it is assumed that the <u>ex post</u> optimal catch of the target fishery by a representative fisherman can exceed the predetermined level of maximum allowable catch although the actually realized catch level does not exceed the predetermined level of maximum allowable catch.. Then, the probability of actual overexploitation by a representative fisherman or the probability that the <u>ex post</u> optimal catch k(t), which is not realized, exceeds k_{max} by time t is represented by $F(t)$ with $F(0)=0$. $F(t)$ is a cumulative distribution function and $1-F(t)$ corresponds to the survival rate in the previous application. The conditional probability of overexploitation that the <u>ex post</u> optimal catch exceeds k_{max} at time t, when the <u>ex post</u> optimal catch has not yet exceeded the kmax, is written as $F'(t)/[1-F(t)]$. Further, this conditional probability can be written as a function of <u>ex post</u> optimal catch level $k(t)$, which becomes a hazard function $h(k(t))$. Therefore, we have the following relationship:

$$F'(t)/[1-F(t)] = h(k(t)) \geq 0 \; ; \tag{4.32}$$
$$h(k=0) = 0 \; ; \; (\partial h/\partial k) \geq 0 \; ; \; (\partial^2 h/\partial k^2) \geq 0 \; ; \; k \geq 0.$$

The representative fisherman maximizes profit over different periods: the first period in which the ex post optimal catch does not exceed the pre-determined maximum allowable catch, and the second period in which the ex post optimal catch exceeds the pre-determined level of maximum allowable catch but the realized catch is within the pre-determined level of maximum allowable catch. In the first period, the profit at time t is $\pi_1(k_1(t))$ which is a strictly concave function of k. If the unit production cost is constant as c and the price is fixed, then

$$[p(t)-c(t)]k_1(t) = \pi_1(k_1(t)). \tag{4.33}$$

For the second period, the expected profit at time t is

$\pi_2(k_2(t))$ which satisfies $0 \le \pi_2(k_2(t)) < \pi_1(k_1(t))$ (see Kamien and Schwartz, 1971). The mathematical formulation is as follows.

$$(4.34) \qquad \text{Max.}_{k1(t)} \int_0^\infty \{\pi_1(k_1)[1-F(t)] + \pi_2(k_2)F(t)\}e^{-rt}\,dt$$
$$\text{s.t. } dF/dt = [1-F(t)]h(k_1(t))$$
$$F(0) = 0$$

This problem provides a unique solution such that $\pi_2 < \pi_1$. Discussion about this solution is given in Kamien and Schwartz (1971, pp.445-453).

4.2.1.2 Comments on Dynamic Fishery Model with Survival Model

Examples of the applications of survival technique in the optimal control approach for fishery models have been discussed so far, but not the qualitative properties of the models. By qualitative properties are meant the slope directions of resource supply function and factor demand function, symmetric negative semidefinitness of the Hessian matrix for the maximization problem with constraints, etc. (Caputo, 1989, 1990). It is interesting to consider whether the introduction of the survival functions as a state equation in the optimal control model would change the qualitative properties of the fishery models.

A possible approach to answer this question, especially with two or more state variables for which mathematics or phase diagram technique are difficult, is the dynamic primal-dual method developed by Caputo (1990). It is based on Silberberg's (1974) primal-dual method for dynamic optimization with constraints. Caputo's approach can involve the nonautonomous control problems, but requires that the number of constraints be less than the number of control (or decision) variables so that the optimal solution may depend on the choice of at least one control variable. It also requires that at least one control variable appears in every nondifferential constraint (Caputo, 1990, p.658). Caputo (1990) argues that "behavior which may appear to be inconsistent with static economic theory may in fact be quite consistent with the implications of dynamic economic theory" (p.678).

One of the initial works for the problem of comparative dynamics (or sensitivity analysis) was done by Oniki (1973) to analyze the effect of a parameter on the optimal solution or the dependence of a plan on exogeneous factors. His paper concerned the autonomous control problems with a parameter, and the necessary conditions of the Maximum principle were utilized to show how the comparative dynamics can be applied to economic problems. In Epstein (1978), a control variable was constrained in that the derivatives of the optimal plans, with respect to a parameter, were evaluated at a specified value of that parameter. Then, the Le Chatelier principle was applied to the necessary conditions of the Maximum principle to show that the solutions of a constrained and unconstrained optimal control problem depend on a vector of exogeneous parameters and to compare the responses of each solution to changes in parameters (Epstein, 1978). The assumption that optimal controls are smooth functions of the state and costate variables was adopted to utilize the Le Chatelier principle. Also, a similar approach to Caputo's, for the autonomous control problems, was used by Epstein (1982). That is, the comparative dynamics in the adjustment-cost model of the firm was studied through the concept of a Morishima matrix. It was argued that a comparable set of equations, which can play a basic role in deriving the qualitative comparative dynamics results given nonstatic expectations, may be derived from the Hamilton-Jacobi equation for the nonautonomous problems.

Caputo's primal-dual method, which appears more elegant and easier to apply than Epsteins's, can be directly applied to the previous models to see whether or how the introduction of a survival fuction as a state equation changes the qualitative characteristics of the typical fishery models as compared to one without survival function. In the previous examples with two state equations for fish growth and survival functions, the definition of survival rate produces a nonautonomous control problem and then the restriction that the number of constraints is less than the number of control variables is not satisfied. Therefore, the optimal solution may not depend on the choice of at least one control variable. It is expected that, as we can see in the solutions for the given applications, the introduction of a survival function as a state equation would change the qualitative properties of the model since the solutions involve the survival rate or hazard rate in themselves.

For example, for the illustration of the application of dynamic primal-dual method to the previous applications, consider the first application again, but this time for simplicity only the individual's profit maximizing model without the constraints on the control variables. It is assumed that the initial value of fish stock is known and equal to x_0. The Hamiltonian is written as

$$H = [p-c(x,u)]k(t)S(t)e^{-rt} + \tau[G(x)-k(t)] + \mu\{-h(t)[1-F(t)]u(t)\}. \tag{4.35}$$

Now, we can compare this Hamiltonian to the one without any survival function. When the survival function is not involved, the cumulative discounted supply function of resource (fish), which is the partial derivative of the optimal value function with respect to the market price of the fish $\partial H/\partial p|_{\text{optimal path}}$ and the result of the dynamic envelope theorem (Caputo, 1990), does not involve any probabilistic terms. That is, the Hamiltonian appears as

$$H = [p-c(x,u)]k(t)e^{-rt} + \tau[G(x)-k(t)]. \tag{4.36}$$

However, when the survival function is introduced as a state equation, $\partial H/\partial p|_{\text{optimal path}}$ shows that the cumulative function is weighted by the optimal survival rate.

The same procedure can also be applied to the principal-agent models of the second and third applications to see whether there is any qualitative difference between the first simple profit maximization model and the principal-agent model of the second and third kinds. A much more detailed analysis on this subject would be required to enrich the applications of survival techniques to the optimal control problems for the fishery.

4.2.2 Standard Approach

The survival rate, which can be estimated from a regression-type model, can represent the probability of surviving in the fishery industry. Survival in an industry is the consequence of maintaining normal profit under economic and biological environmental changes and authority's regulatory effort. That is, the estimated survival rate can be interpreted as the empirical (or posterior) probability of the event 'stay in industry' and the hazard rate as the instantaneous probability of the event 'exit from industry'. All of the factors affecting this survival rate such as fish stock level, cost variable, and regulatory activity are expressed as explanatory variables in the regression analysis. The regulatory tools are interpreted as treatments which are specified as covariables in the survival function. Some may argue that some firms or fishing families last for several generations. However, this is not difficult to handle in survival analysis since those can be treated as censored, and another characteristic variable explaining the reason for longer existence can be introduced.

4.2.2.1 Data Requirement

If survival analysis is used just for the estimation of survival rates through parametric or nonparametric models, data of individual fishing firms, some of which may be averaged on individual levels, are needed on vessel sizes and other capacity limits, fish stock level (or fish landing sizes or catch per unit effort), fish prices, and capital costs. The existence of alternative species that can substitute for the target fishery and detailed information about regulation, in addition to the lifetime data of individual firms, are also required.

When the purpose of analysis is to compare two different time periods or samples, two sets of data are required. The required data for analyzing the whole fisheries industry in an economy would be much larger than that for a single fishery. Details on data requirement for each case can be described as follows.

1) It is often difficult to obtain data on fish population. Further, even if possible to obtain, they should be for the individual fishing firm base as cross-sectional

data are used to estimate survival rates. Then, some data which reflect the size of fish population and have the nature of cross-section data are required. An appropriate candidate is the individual firm's catch per unit effort (CPUE). When k indicates the level of catch, the firm's CPUE can be expressed as (k/E) from the relationship k=qEx by assuming the catchability coefficient q=1 to normalize units of fishing effort E. Therefore, the fish population variable x can be replaced with a proxy variable (h/E) in the estimated regression model and time-averaged (h/E) can be used. An alternative variable is the variable for individual firm's averaged fish landing sizes. CPUE or fish landing sizes could be treated as time-dependent covariables if there are significant changes in the given periods.

2) Information about fleet sizes of individual fishing firms are needed, such as tonnages of fishing fleets. Individual firm's fleet sizes may need to be averaged over time if there were some changes on fleet sizes as a result of expansion or reduction of investment. The anlyses based on individual fishing boats are also possible. In a case that a firm owns several fishing boats, a covariable specifying their ownership can be made.

3) Data on availability of alternative species when a target species can not be harvested, due to regulation or other reasons, are required. The number of alternative species for individual firms can be used for this as a

covarible.

4) Detailed information is required about fishery regulation such as when the regulation started, what kinds of regulation tools have been used, and how the regulation has been implemented. In a simple case, a type-specifying variable for whether a firm is affected or not by regulation can be used in an analysis using just one regression model. However, it is very difficult to incorporate regulation information into a regression model since regulation is not in general imposed at the beginning of the concerned time period. That is, the imposition of regulation at a certain time point in a concerned time period raises some statistical difficulties in estimation. This is one reason for comparing two survival rates with and without regulation, to study regulation impacts on individual firms.

5) Time-dependent economic covariables such as interest rate and price can be introduced into the model to assess their impacts on the survival of individual firms or fishing boats. As discussed in Chapter III, there are two types of time-dependent covariables --- external and internal time-dependent covariables. External time-dependent covariables are the main type of time-dependent covariables in economic applications of survival analysis. Interest rate and price would belong to this category.

6) Finally, lifetime data on individual fishing firms are required.

All of these data are selected to reflect the biological and economic environments which influence the survivals of individual fishing firms or boats.

4.2.2.2 Estimation

The estimation of survival models can be done using standard techniques of maximum likelihood estimation. If a Weibull distribution is chosen for a model, given a unimodal lifetime distribution and one sample, the constancy of shape parameter, assumed for mathematical convenience, can handle some problems successfully. The (profile) likelihood function can be used to obtain the confidence intervals of parameters. For example, the likelihood ratio method provides 1-α level confidence set of parameter β as

$$(4.37) \qquad 2[l(\hat{\beta}, \hat{v};x) - l(\beta_0, \hat{v}_0;x)] < z^2{}_{\alpha/2} ,$$

where $\hat{\beta}$ and $\hat{v}$ are the maximum likelihood estimate (MLE)'s of β and v when the tested hypothesis $\beta=\beta_0$ is not imposed, $\hat{v}_0$ is the MLE of v with the constraint $\beta=\beta_0$, $l(\cdot)$ is the log likelihood function, $l(\beta_0, \hat{v}_0;x)$ is the profile likelihood function of β, and v is a vector of nuisance parameters whose dimension can be greater than 1.

The standard statistical inference procedure can be maintained through this (profile) likelihood function. Bootstrapping is an alternative method to find standard errors and confidence intervals. The bootstrap for censored data is essentially the same as for uncensored data (Efron, 1981; Wahrendorf, Becher, and Brown, 1987).

4.2.2.3 Development of Covariables for Analysis of Fishery Regulation

When concerned with management issues such as the impact of certain regulations on the fishery industry, the data set just described is not enough to address those issues. The problem becomes more complicated when only one sample is available due to the overlap of a few regulations or the discrete and repeated regulations in a time period investigated. Also, we may be interested in developing a one sample model which can analyze the regulatory impacts.

If there are two samples of different time spells with and without regulations, the survival technique provides the tool necessary to compare two samples. When only one sample is available, it appears that emphasis should be given to the development of appropriate covariables to reflect the regulatory impacts, economic and biological changes, the past lifetime lengths of individual fishing firms or boats, etc., although these covariables also can be used for two sample cases.

There appears to be several candidate variables for achieving those objectives. First, the data of exact time at which individual firms entered the fishery industry can be a possible covariable. By including the variable for these exact times, their effect on the survival rates, which may be a consequence of the changing economic and environmental situations, can be analyzed. In general, different firms enter into an industry at different times. Therefore, if a survival study is performed for certain time period, these random entries would create random censoring time problems. Also, if the data of entry times for some firms are not available, it would cause a double censoring problem. One way to reduce the difficulty caused by random censoring time and double censoring is by making a few assumptions such as 1) our interest is in a certain time period and the survival analysis starts at the beginning of this time period, 2) few firms may enter the fishery industry under regulation or due to some other factors, and 3) even if some firms enter the fishery industry, the impact on the industry is insignificant. By making these assumptions, random censoring and double censoring problems can be remedied.

Second, the variable for the time length, over which individual fishing firms or boats experience the fishery regulations, can be used. This variable seems to be particularily helpful when individuals experience the repeated regulations at different times.

Third, the variable for the time length of existence in the fishery before a certain regulation is imposed can be made. This variable is intended to reflect the impact of past experience in the fishing industry on survival rates under regulations.

Finally, time-dependent economic covariables such as price and capital cost should be utilized for economic analyses. For example, the variable of capital cost must be included in the model if a regulatory tool is to prevent new entries into the fishery by raising capital costs. In addition to these variables, more covariables for the anaysis of fishery regulations are expected to be found.

4.3 Conclusion

Two ways of utilizing survival analysis in fishery management have been discussed so far. The drawbacks of survival analysis in economics can be resolved by introducing a regression-type survival model and relaxing some of the assumptions about industry structure. For example, heterogeneity of fishermen can be reflected in explanatory variables in regression models. The number of covariables are not limited, as long as the necessary computational facilities are available. However, the combination of some types of regulation tools may lead to multicollinearity problems in regression-type models, and additional difficulties in choosing appropriate covariables. The size of fishing fleet (or capacity level), fish stock level (or catch per unit effort), capital cost, fish prices, availability of alternative species, regulations, etc., could be possible covariables. Either a single species or an entire fishery industry can be analyzed for a single time spell or multiple spells. This approach may require less information about a fisherman's cost or behavior; at least, it can provide guidelines about how important cost information is. That is, the estimated parameters provide information about necessary characteristics of a particular data set. One of the findings of classical survival analysis for the competitive industry in the long run was that detailed information about production cost may not be required since instead of cost levels, the industry's production capacity levels could be used to obtain the survival rates (Stigler, 1968). Without the assumption of competitive structure, the regression-type model of survival analysis might require data about production cost or capacity level. As mentioned earlier, its analytical tool, i.e., regression, is relatively easy to perform in practice.

Another interesting merit comes from handling technical changes in fishery industry. All of the technological changes are accompanied by various negative and positive externalities, and these externalities affect individual survival. For example, a development of new, efficient fishing gear may increase the hazard rate of an individual fishing boat due to overfishing by new technology and the resulting reduced profit in the long run. Whether the technological change is capital-saving or labor-saving may be an important question in analyzing individual firms' survivals. The diffusion rate of technological change can influence their social and economic outcomes, and selection and adaptation to or modification of technological changes are required to make a new technology function in a new environment (Rosenberg, 1976). In general, it is very difficult to distinguish the contribution of technical change from other changes in human behavior, motivation, social organization, and other less obvious technological forces (Rosenberg, 1982). Also, there is the problem of time lag between the invention itself and the innovation process. However, in fisheries, technical changes appear as new gear types, processing facilities, fish school-detecting radar or machines, etc. which can allow researchers to make some covariates for those changes, and the time lag between invention and innovation is not that long compared to lifetimes. Also, when there is a newly developed fishing technology, two time periods with and without the new technology can be compared.

On the other hand, survival anaysis can be complicated if attention is paid to multi-parameter family of distributions. Having more parameters in the models is not the best way of analysis. Also, prediction is limited when the uncertainties related to environmental and biological changes heavily influence the survival rate. The biological uncertainties are disregarded in survival analysis since only the present and past levels of fish stock are required.

Chapter 5

A Case Study

One of the main objectives of this thesis as introduced in Chapter II is to provide an empirical tool to reduce the uncertainty in economic models and assess the impacts of fishery regulation in probabilistic terms. The empirical estimation of the survival model is discussed in this chapter. It is shown that estimation and inference in survival models is not different from those in the typical regression models. Survival analysis is applied to the Icelandic trawl fishery. Emphasis is on showing how the survival model can be used to analyze a fishery industry and regulations in it.

5.1 Icelandic Trawl Fishery

The fishery industry is the most important industry in Iceland, resulting in 78.1% of total export-value in 1987 (Arnarson, 1990). Several fisheries regulations have been imposed by the Icelandic government in the past, including season closures for 1977-83 and individual transferable quotas (ITQ) from 1984. It is said that the regulations did not have significant impacts on the trawl fishery industry before 1977, while the marine jurisdiction expansions in 1956, 1972, and 1974 may have (Arnarson, 1990). However, the intention here is to study the Icelandic trawl fishery and regulation impacts in it by the survival technique to the extent possible to show the applicability of survival analysis.

The main target species of trawling boats are cod, saith, redfish, and Greenland halibut. There were only side trawlers before the 1970's, which were generally above 500 tons in size. Stern trawlers were introduced in the 1970's, and only stern trawlers were left in operation after 1977.

In general, stern trawlers are categorized into two types in size: large ones, those bigger than 500 tons and medium-size ones, those between 300 and 500 tons. Also, stern trawlers consist of two types of trawlers according to processing abilities. One is a factory trawler which is used primarily for direct export of the caught fishes. The other is a fresh fish trawler which first sends the caught fishes to the freezing plants onshore before exporting. As is common in most fisheries, there is a geographic distinction of catch due to ocean current movement and its accompanied fish migration in the Icelandic trawl fishery. Also, different trawlers' origins require different levels of fishing effort.

The analysis is performed separately for the large stern trawlers and medium-size trawlers. The sampling unit is the individual trawl boat, not the companies owning those boats. The data for the medium-size trawlers are available only after 1974.

5.2 Model Specification

Cox's nonparametric regression model and a Weibull regression model are estimated. A Weibull regression model has the same specification as given in Chapter III, but the nonparametric model is estimated through the partial likelihood function. The estimated hazard function in Cox's model is written as

$$\lambda(t,x) = \lambda_0 e^{xb}, \tag{5.1}$$

where λ_0 represents the baseline hazard, x the vector of covariables, and b the parameters for x. The estimation of a Weibull regression model is intended to compare its results with nonparametric results. In general, if plotting of log[-log(estimated $S(t)=\hat{S}(t)$)] versus log(t) from the given data set shows a linear relationship, then a Weibull model is an appropriate parametric model for the data.

Three characteristic variables are chosen a priori for the estimation. The first one is the one to show the impact of averaged catch per unit effort (ACPUE) on survival rates. The second one is the variable of years at which individual fishing boats enter into the fishing industry. This variable is designed to identify the effect of different entering times on survival rates. In general, it is expected that the landing sizes, the sizes of fish population or the CPUE play an important role in maintaining the fishing operation. However, it is very difficult to introduce a time-dependent covariate which reflects the size of fish population (or

CPUE) and the aspects of changing economic and biological environments. The averaged CPUE or landing sizes are not appropriate for this purpose since they are fixed time-independent variables. A possibility is using the time of entry into the fishing industry as an external covariate as Crowley and Hu (1977) and Kalbfleisch and Prentice (1980) have shown. Then, the effect of time of entry into the fishing industry on the survival rate, which may be a consequence of the changing economic and environmental situations, can be analyzed. The third one is the indicator variable for the different boats' origins which reflects the geographic distinction.

Interest rate and price of fish and fish products, as external time-dependent economic covariables in the model, are also introduced later to identify their impacts on survivals of individual trawlers.

The catch per unit effort is obtained by dividing total catch by fishing operation days. The ACPUE would be more appropriate if changes in CPUE are stable. Otherwise, it may be treated as an external time-dependent covariate. The variable to represent different ownerships by different companies is also a candidate covariable since individual companies are different in business operation. This variable is dismissed in the following applications since it is not possible to identify all ownerships in the given data sets. The sizes of individual boats are not considered because boat sizes are not much different among large or medium-size trawlers. It is expected that the survival rates vary among different sizes and the optimal size of trawl boats may be found.

5.3 Estimation Procedure

The nonparametric model developed by Cox and a Weibull regression model are fitted for two data sets. The statistical software used is 'PEANUTS', developed by D. Preston and D. Pierce (1990), to fit proportional hazards models to ungrouped, censored survival data using Cox's partial likelihood methods. A GAUSS program (Version 2), which was developed by D. Pierce for his 1989 class, is used to estimate the Weibull regression model. All data used are listed in the Appendix.

When covariables are involved in the nonparametric model, there are are two ways to estimate the parameters vector b and baseline survivor function $S_0(t)$. The first is to maximize the likelihood function for the observations simultaneously with respect to b and $S_0(t)$. The second is based on Cox's approach. We estimate b from the partial likelihood function first and then estimate $S_0(t)$ by assuming that b is equal to the MLE $\hat{b}$ obtained from the partial likelihood function. The PEANUTS program utilizes the second approach and more specifically it uses Breslow's estimate (Lawless, 1982). The estimated baseline cumulative hazard rate $\hat{H}_0(t)$ (= $-\ln S_0(t)$) is written as

(5.2) $$\Sigma_{i:ti<t}[d_i/\Sigma_{l\epsilon Ri(t)}\exp(x_l{}'b)],$$

where d_i indicates the number of failures at t_i and R_i the risk set at t_i. This estimate is called the empirical cumulative hazard function in the nonparametric model. Finally the empirical survivor function is obtained by $\hat{S}_0(t)^{\exp(x\hat{b})}$ (Lawless, 1982).

The assumption of proportional hazards can be checked for two sample problem if another data set is available. When there is just one sample, the assumption of proportional hazards can be tested if there is a (defined) time-dependent covariable. The likelihood method gives the value of normal deviate z which is calculated by square-rooting $2[l(\hat{\beta},\hat{v};x)-l(\beta_0,\hat{v}_0;x)]$.

When defined or ancillary time-dependent covariables are involved in the estimation, Cox's nonparametric method, i.e., the partial likelihood approach, is still valid under the assumption that the hazard at time t depends only on the current values of time-dependent covariables (Kalbfleisch and Prentice, 1980). However, Cox's method does not provide efficient estimators when there are time-dependent covariables, especially internal time-dependent covariables, and random censorship since the partial likelihood does not consider the complete history of individuals, i.e., the distribution of values of time-dependent covariables changes over time. For the correct likelihood of individual survival, the contributions of the time processes of time-dependent variables and censoring must be incorporated into the likelihood. That is, the conditional probabilities of the covariate information at time t, on the whole history of individuals and failures before time t, and the conditional probabilities of censoring, on individual histories, failures, and the covariate information before time t, should be calculated for the correct likelihood (Kalbfleisch and Prentice, 1980, Ch.5). This would require rather complicated calculations, and we use Cox's partial likelihood approach at the cost of loss of efficiency in estimators. Kalbfleisch and Prentice (1980) argue that "a characterization of situations in which the partial likelihood has reasonable efficiency properties is necessary before the routine use of this partial likelihood can be advocated" (p.141). It seems that further research is required in order to have more efficient estimators when time-dependent covariables are involved. Cox's partial likelihood method is still used for time-dependent covariables in this thesis.

5.4 Estimation Results

Estimations are performed first for large stern trawlers and medium-size trawlers separately without considering any external time-dependent covariables. Then, the estimations of models including external time-dependent covariables are pursued.

5.4.1 The Case of Large Stern Trawlers

The nonparametric model is estimated by using PEANUTS. There are 28 observations from the years 1972 to 1989, and with 8 of them censored. Three covariables of entering year, ACPUE, and different regions were used to fit the model. There are two indicator variables specifying regions, the south-west and north-west. In the estimation procedure, the indicator variable for the north-west region is dropped to avoid the singularity of matrix.

The estimation results show that two parameter estimates for entering year and averaged catch per unit effort are significant, but the parameter estimate of the variable for the south-west region is not significant. Table 1 is the summary of this data set, and Table 2 shows survival probabilities, hazard rates and cumulative hazard rates. Table 2 is based on the Kaplan-Meier (or product limit) estimation which does not consider the covariables. Figure 1 shows the plot of survivor function versus time, and Table 3 summarizes the parameters estimates. The variable name YR indicates the variable for the entering years in Table 3, and SW represents the variable for the south-west region.

As we can see in Table 3, the averaged catch per unit effort has a negative relationship with hazard rates, which is expected. The size of this estimate is relatively high. The more interesting result is the significance of the estimated parameter for entering year. As mentioned earlier,

TABLE 1 Data Summary for the Large Stern Trawlers

Stratum	Time	Events	Count
1	17.00	1	3
1	15.00	1	8
1	14.00	1	9
1	13.00	1	10
1	12.00	1	11
1	11.00	1	13
1	9.00	1	14
1	7.00	1	15
1	5.00	3	19
1	4.00	1	20
1	3.00	3	23
1	2.00	2	25
1	1.00	3	28

TABLE 2 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Large Stern Trawlers in the Period of 1972-89

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	3	28	.1071	.1071	.8929
2.00	2	25	.0800	.1871	.8214
3.00	3	23	.1304	.3176	.7143
4.00	1	20	.0500	.3676	.6786
5.00	3	19	.1579	.5255	.5714
7.00	1	15	.0667	.5921	.5333
9.00	1	14	.0714	.6636	.4952
11.00	1	13	.0769	.7405	.4571
12.00	1	11	.0909	.8314	.4156
13.00	1	10	.1000	.9314	.3740
14.00	1	9	.1111	1.043	.3325
15.00	1	8	.1250	1.168	.2909
17.00	1	3	.3333	1.501	.1939

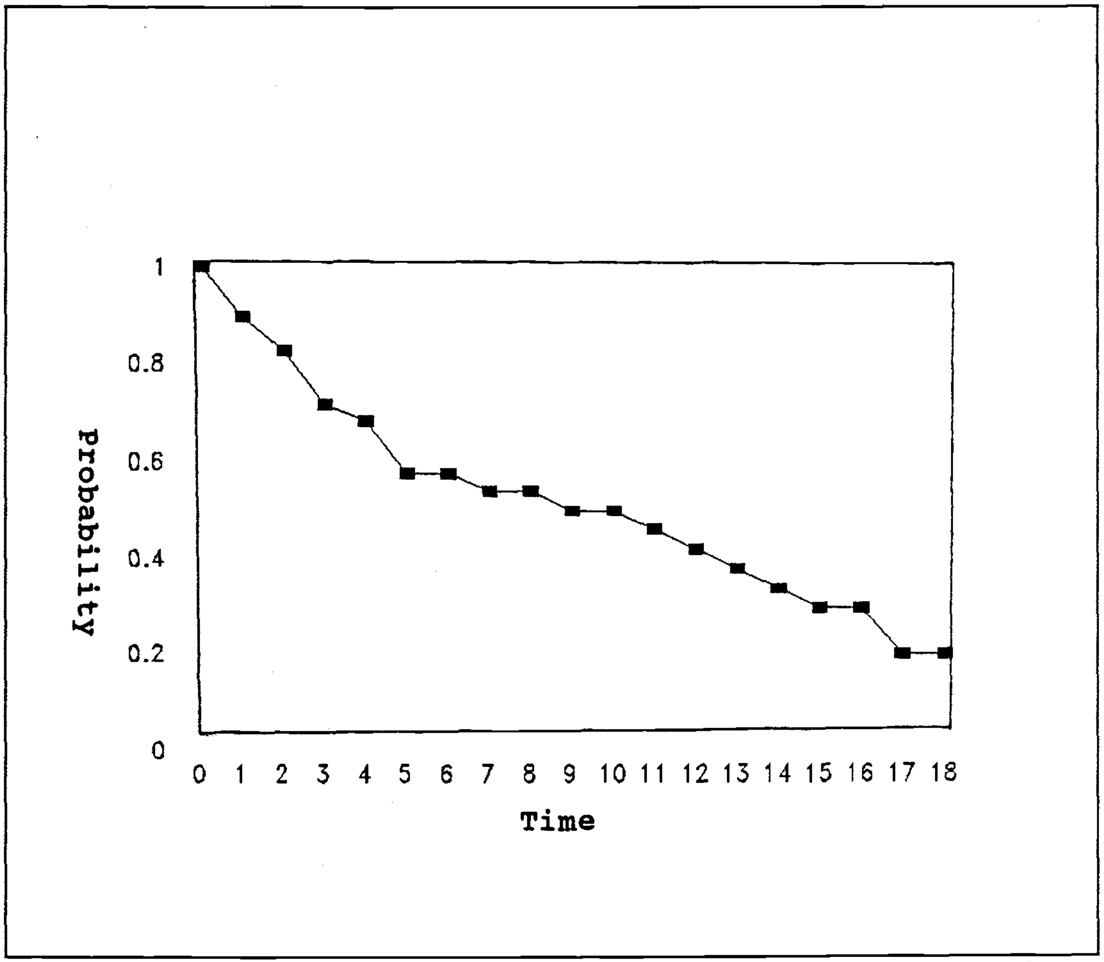

FIGURE 1 Estimated Survival Curve for Large Stern Trawlers

TABLE 3 Parameter Estimates Summary Table for the Large Stern Trawlers

Name of Variable	Estimate	Std.Err.
1 YR	.1909	.0662
2 ACPUE..........	-.3337	.1299
3 SW	.3116	.5813

Deviance = 93.4562
Number of risk sets = 13

TABLE 4 Weibull Model Estimates for the Large Stern Trawlers

parameter	d-hat	std err	t-values
shape(ß)	1.74143	0.320930	5.4262
intercept	-2.16256	1.816368	-1.1906
entering yr	0.21897	0.063791	3.4327
ave cpue	-0.34205	0.127481	-2.6832
SW region	0.26596	0.575525	0.4621

the reason for introducing the variable of entering year is that it may reflect the changing economic and biological situations. The significance of this estimate may imply that survival rates of Icelandic large stern trawlers fishery depend on such changes significantly. There is no conclusive information available about whether a positive or negative relationship between survival rate and time of entry is expected. However, its positive sign in the estimation implies that survival ability of individual trawlers durimg the first few years of operation is decreasing over time. This dependence on time of entry may be more fully explained if some measures of general condition of individual trawler at different times are available. For example, time-dependent covariables for changing capital cost and tax rules in Iceland can be utilized for this purpose. Plotting log[-log(estimated $S(t)=\hat{S}(t)$)] versus log(t) gives another interesting result, i.e., that of a rough linear relationship. Therefore, the Weibull model is estimated to compare its results with nonparametric results. Table 4 shows the parameter estimates for the Weibull model.

In Table 4, d-hat corresponds to the estimates of b for the nonparametric model. (As discussed earlier in Chapter III, d is actually $-\beta*b$, where β is the shape parameter of Weibull distribution and b is the parameter vector of the covariables for the survivor function in the proportional hazards model.) As can be seen in Table 3 and Table 4, the magnitudes of parameter estimates in both parametric and nonparametric models are slightly different, and the estimates of the coefficient for the south-west region specifying variable are not significant in both cases. Again, the similarities of estimates between these models may be confirmed by the fact that the plot of log[-log(estimated $S(t)=\hat{S}(t))$] versus log(t) shows a linear relationship.

Consider the issue of regulation impact. It was stated that there have been season closure and individual transferable quota (ITQ) system in the Icelandic trawl fishery. The given data set is not appropriate to analyze the impact of season closure since the period 1977-83 under season closure cut the period of 1972-89 into three periods of 1972-76, 1977-83, 1984-89 and these period are not long enough to compare. Also, all the trawlers may have not been affected by season closures. Therefore, only the case of the ITQ system is analyzed. There are two time periods of the years 1972-83 and 1984-89. The first period is before the ITQ was imposed and the latter is after the ITQ was imposed. The first period has 24 observations and the second 20 observations. Many of the observations from the second period are continuations from the first period, and these are assumed to start their lifetime in 1984. These two data sets are not directly comparable because the second data set comes from the shorter time spell of 6 years while the first set comes from the longer one of 12 years. However, the nonparametric estimation results show some interesting points. Table 5 shows the estimated hazard rates and cumulative hazard rates with survival rates for the first data set. Table 6 shows those for the second set when the covariables are not introduced for both sets yet. Figure 2 is the estimated survival curves for the first and second data sets. Table 7 is the summary of parameter estimates for the first data set and Table 8 is for the second data set.

Only the parmeter estimate of averaged CPUE is significant in the first period while the parameter estimates for the entering year and averaged CPUE are significant with reduced credibility in the second period. The magnitude of the estimate for the averaged CPUE in Table 7 is much higher than that in Table 8. It seems that the averaged CPUE plays a more influential role in affecting the survival rates in the first period than in the second period. The reduced credibility of parameter estimates from the second period may be due to the fact that the second period has a shorter time spell than the first one. Also, when comparing Table 5 and 6, the hazard rates in the second data set, which is for the period after the ITQ system is imposed, are higher than the first data set although it has a shorter time period. There may be a few reasons for these findings. The first reason can be the effect of regulation, which results in higher hazard rates and less influential roles of other covariables. The second may be changes in interest rate and tax rules in

TABLE 5 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Large Stern Trawlers before the ITQ Is Imposed

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	1	24	.0417	.0417	.9583
2.00	2	22	.0909	.1326	.8712
3.00	2	20	.1000	.2326	.7841
4.00	1	17	.0588	.2914	.7380
5.00	1	15	.0667	.3581	.6888
9.00	1	13	.0769	.4350	.6358

TABLE 6 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Large Stern Trawlers after the ITQ Is Imposed

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	5	20	.2500	.2500	.7500
2.00	1	15	.0667	.3167	.7000
3.00	1	14	.0714	.3881	.6500
4.00	4	13	.3077	.6958	.4500
5.00	1	9	.1111	.8069	.4000

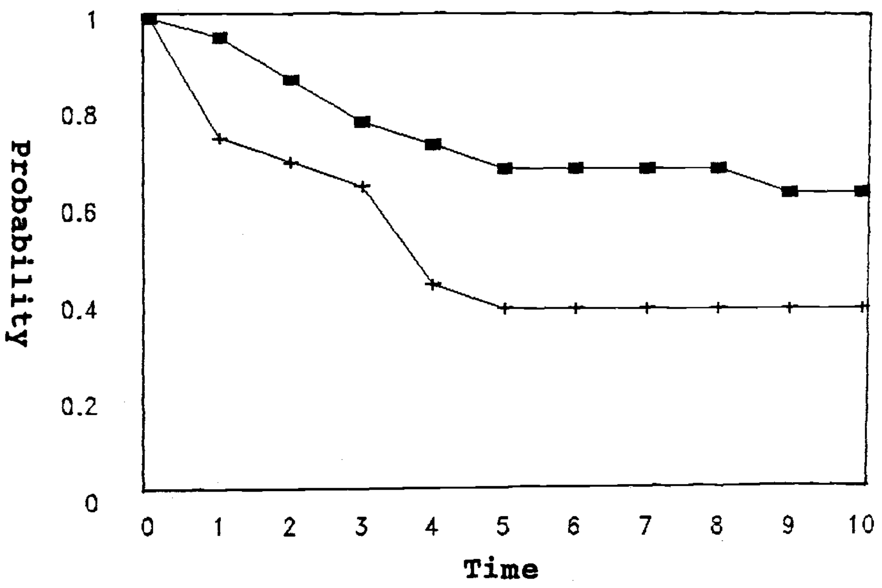

FIGURE 2 Estimated Survival Curves for Large Stern Trawlers before and after the ITQ Is Imposed (-■- :1972-83, -+- :1984-89)

TABLE 7 Parameter Estimates Summary Table for the Large Stern Trawlers before the ITQ Is Imposed

Name of Variable	Estimate	Std.Err.
1 YR	-.0327	.1444
2 ACPUE............	-.5286	.2111
3 SW	-.3549	.8949

Deviance = 37.1603
Number of risk sets = 6

TABLE 8 Parameter Estimates Summary Table for the Large Stern Trawlers after the ITQ Is Imposed

Name of Variable	Estimate	Std.Err.
1 YR	.6484	.3122
2 ACPUE............	-.3275	.1712
3 SW	-.1023	.8882

Deviance = 58.1933
Number of risk sets = 5

TABLE 9 Parameter Estimates Summary Table for the Large Stern Trawlers after the ITQ Is Imposed with EXPYR variable

Name of Variable	Estimate	Std.Err.
1 YR	.4792	.4061
2 ACPUE............	-.3453	.1694
3 SW	-.1794	.9076
4 EXPYR	-.0535	.0838

Deviance = 57.7971
Number of risk sets = 5

1980's which resulted in high capital costs and reduced profits. The third may be the existence of the duration dependence. Therefore, the variable for the time length of existence in the fishery before the ITQ is imposed is introduced into the estimation to identify whether higher hazard rates are due to the duration dependence. If there does not exist a duration dependence, then the parameter estimate for this new variable would be insignificant or its magnitude would be very small. Table 9 is the summary of parameter estimates for the new estimation. EXPYR in Table 9 represents the variable for the time length of existence in the fishery industry before the ITQ system is imposed.

As expected, Table 9 shows that the parameter estimate, of the time length of existence in the fishery before the ITQ system is imposed, is very small and not significant. Also, the likelihood test, for adding a new variable of the time length of existence in the fishery gives the value of the normal deviate as .6294. Therefore, the regulation may be the main source of higher hazard rates and less influential roles of introduced covariables.

5.4.2 The Case of Medium-Sized Trawlers

The data for the medium-sized trawlers have 119 observations starting from 1975 and many of them are tied observations. Again, the nonparametric model is first estimated and its results show no new qualitative findings.

TABLE 10 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Medium-Sized Trawlers over the Period 1975-89

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	6	119	.5042E-01	.0504	.9496
2.00	10	110	.9091E-01	.1413	.8633
3.00	5	98	.5102E-01	.1923	.8192
4.00	3	92	.3261E-01	.2250	.7925
5.00	5	88	.5682E-01	.2818	.7475
6.00	6	79	.7595E-01	.3577	.6907
7.00	2	72	.2778E-01	.3855	.6715
8.00	4	68	.5882E-01	.4443	.6320
9.00	4	63	.6349E-01	.5078	.5919
10.00	3	56	.5357E-01	.5614	.5602
11.00	1	49	.2041E-01	.5818	.5487
12.00	1	45	.2222E-01	.6040	.5366
13.00	1	41	.2439E-01	.6284	.5235
14.00	3	32	.9375E-01	.7222	.4744

TABLE 11 Parameter Estimates Summary Table for the Medium-Sized Trawlers

Name of Variable	Estimate	Std.Err.
1 YR	.1384	.0411
2 ACPUE	-.4410	.0722
3 R1	-.6657	.9167
4 R2	.0069	.7500
5 R4	-.5853	.8690
6 R5	-.5722	.7842
7 R6	-.4752	.8767
8 R7	-.8245	.8095

Deviance = 411.919
Number of risk sets = 14

TABLE 12 Weibull Model Estimates for the Medium-Sized Trawlers

parameter	d-hat	std err	t-values
shape(ß)	1.72917	0.19949	8.6679
interecpt	-1.14304	1.12499	-1.0160
year	0.18086	0.04227	4.2791
ave cpu	-0.49063	0.07376	-6.6514
south	-0.75749	0.91468	-0.8281
south-west	-0.07263	0.75241	-0.0965
west	-0.60210	0.86697	-0.6945
north-west	-0.67585	0.78356	-0.8625
north-east	-0.55541	0.87697	-0.6333
east	-0.96672	0.80889	-1.1951

TABLE 13 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Medium-Sized Trawlers over the Period 1975-83

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	3	102	.0294	.0294	.9706
2.00	10	96	.1042	.1336	.8695
3.00	3	82	.0366	.1702	.8377
4.00	1	72	.0139	.1841	.8260
5.00	3	67	.0448	.2288	.7891
6.00	4	59	.0690	.2978	.7346
8.00	1	37	.0270	.3248	.7148

TABLE 14 Parameter Estimates Summary Table for the Medium-Sized Trawlers over the Period 1975-83

Name of Variable	Estimate	Std.Err.
1 YR	.0727	.0917
2 ACPUE	-.6473	.1163
3 R1	-1.575	1.445
4 R2	-.7632	1.096
5 R4	-.6043	1.205
6 R5	-.9758	1.112
7 R6	-1.022	1.264
8 R7	-.9073	1.149

Deviance = 170.386
Number of risk sets = 7

TABLE 15 Hazard Rates, Cumulative Hazard Rates, and Survival Rates for the Medium-Sized Trawlers over the Period 1984-89

Time	Evnts	Count	Hazard	Cum Haz	Surv
1.00	10	94	.1064	.1064	.8936
2.00	3	82	.0366	.1430	.8609
3.00	3	78	.0385	.1814	.8278
4.00	9	75	.1200	.3014	.7285
5.00	6	65	.0923	.3937	.6612

TABLE 16 Parameter Estimates Summary Table for the Medium-Sized Trawlers over the Period 1984-89

Name of Variable	Estimate	Std.Err.
1 YR	-.0192	.2011
2 ACPUE	-.3283	.0999
3 EXPYR	-.1292	.0657
4 R1	-.2018	1.226
5 R2	.3357	1.042
6 R4	-1.415	1.417
7 R5	-.0126	1.081
8 R6	-.1436	1.229
9 R7	-1.138	1.162

Deviance = 239.668
Number of Risk Sets = 5

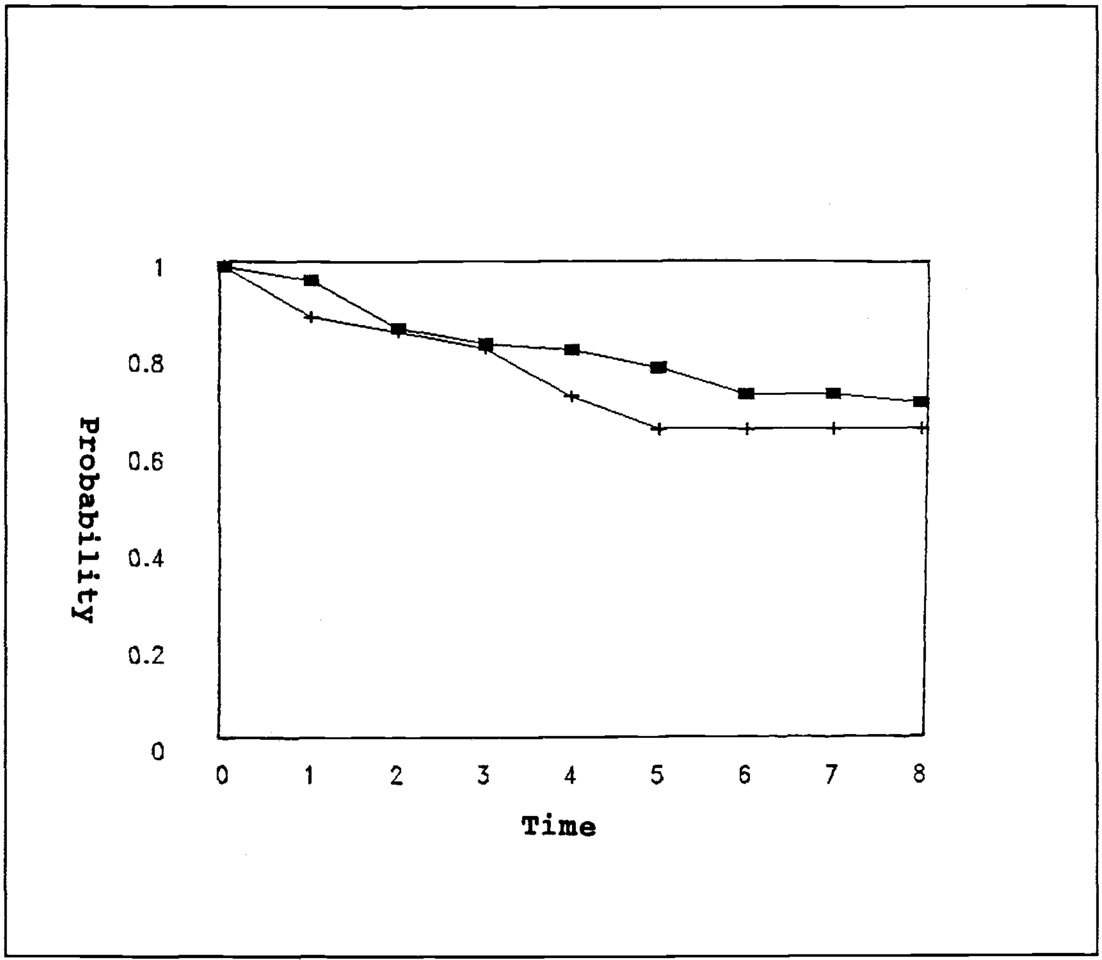

FIGURE 3 Estimated Survival Curves for Medium-Size Trawlers before and after the ITQ Is Imposed (-■- :1974-83, -+- :1984-89)

Table 10 shows the data set and Table 11 the Kaplan-Meier (or product limit) estimates of survival rates. Table 12 shows the summary of parameter estimates.

As we can see in Table 10, there is no significant duration dependence, i.e., the positive relationship between hazard rates and survival time, in this data set. Also, there exist many tied observations. Other models such as the grouped data model or parametric model may fit the model better. Cox's nonparametric model may not be appropriate since the discrete nature of the lifetimes should be explicitly recognized (Lawless, 1982). Therefore, the Weibull regression model is estimated. The estimation results from the Weibull regression model are shown in Table 12.

As in the case of nonparametric model, none of the parameter estimates for region-specifying variables are significant and the parameter estimates for entering-year variable and averaged catch per unit effort variable have the same signs and about the same magnitudes as those for the nonparametric model. Therefore, it seems that the nonparametric model performs relatively well even under many tied observations in the present case. In both cases of large stern and medium size trawlers, direct comparison of estimation results is not possible since they are different in the time lengths of investigated periods. However, the parameter estimates for the variables of entering year and averaged CPUE also have the same signs and are not significantly different from each other. There may exist the similar survival patterns in both types of trawlers although more data may be required to confirm this statement.

The analysis for the impact of the ITQ system is given by the same method given for the large stern trawlers. There are 102 observation for the period of 1975-83 and 94 observations for the period of 1984-89. Tables 13 shows the survival rates and hazard rates for the data set of 1975-83 and Table 14 is its summary of parameters estimates. Table 15 is for the survival rates and hazard rates for the second period of 1984-89 and Table 16 is the summary of parameter estimates when the variable for the time length of existence in the trawl fishery industry is introduced. The results are very similar to the case of large stern trawlers. Figure 3 shows the estimated survival curves befor and after the ITQ is imposed.

The likelihood ratio tests for the appropriateness of adding new indicator variables of different regions to the nonparametric model, which are not reported here, show that there is evidence for regional distinction in the medium-sized trawlers, but no evidence for this in the large stern trawlers. Therefore, the estimation, with dropping out the covariable for specifying different regions, was performed to check again whether there was any significant geographic distinction aross regions. Seven different regions are

TABLE 17 Parameter Estimates Summary Table for the Medium-Sized Trawlers in Different Regions

Regions	Variable	Estimate	Std.Err.
1. Mid-West, South-West, South	YR	.1094	.0619
	ACPUE	-.4329	.0918
2. North-West, North-East	YR	.2840	.0871
	ACPUE	-.3330	.1541
3. West	YR	.0576	.2182
	ACPUE	-.7650	.3257
4. East	YR	.0491	.1131
	ACPUE	-.5181	.2220

reduced to 4 regions this time to consider geographic similarities among some regions. The mid-west, south-west, and south regions are combined into one region, and the north-west and north-east regions into another region. Table 17 shows its estimation results based on Cox's nonparametric model. An interesting result is that only the estimate for the entering year in the north-west and north-east region is significant. It may be due to many exits of trawlers which entered the industry recently in that region. The magnitudes of the estimates for ACPUE in the west and east regions are higher than those in the other regions.

5.4.3 Estimation Results for Time-Dependent Economic Variables

Estimation results when time-dependent economic variables are not included in the model have been shown so far. In this section, the estimation results are discussed when time-dependent economic variables, interest rate and price of fish and fish products, are introduced to identify their impacts on survivals of individual trawlers.

Most of the real interest rates used here have negative values due to high inflation in Iceland. The prices of fish and fish products were based on export prices in terms of the Icelandic monetary unit, kronur, since the domestic prices were not available. They were obtained first by weighting the prices for frozen fish, salted fish, iced fish, and fish

TABLE 18 Parameter Estimates Summary Table with Interest Rate and Price for the Large Stern Trawlers

Name of Variable	Estimate	Std.Err.
1 YR	.1962	.0728
2 ACPUE..........	-.2985	.1429
3 R	-.6221	1.5450
4 PRICE	.9176	.4910

Deviance = 87.206
Number of risk sets = 13

TABLE 19 Parameter Estimates Summary Table with Interest Rate and Price for the Large Stern Trawlers in South-West Region

Name of Variable	Estimate	Std.Err.
1 YR	.2218	.0808
2 ACPUE..........	-.1812	.1776
3 R	.0853	1.8240
4 PRICE	1.2410	.6095

Deviance = 58.950
Number of risk sets = 12

TABLE 20 Parameter Estimates Summary Table with Interest Rate and Price for the Medium-Sized Trawlers

Name of Variable	Estimate	Std.Err.
1 YR	.1675	.0490
2 ACPUE	-.3037	.0838
3 R	-.3544	1.1750
4 PRICE	.6835	.3390

Deviance = 401.840
Number of risk sets = 14

TABLE 21 Parameter Estimates Summary Table with Interest Rate and Price for the Medium-Sized Trawlers in Different Regions

Regions	Variable	Estimate	Std.Err.
1. Mid-West, South-West, South (50 observations)	YR	.1227	.0791
	ACPUE	-.3869	.1040
	R	-3.0620	1.4930
	PRICE	.4277	.3961
2. North-West, North-East (31 observations)	YR	.3935	.1234
	ACPUE	-.1129	.1523
	R	.8598	2.1170
	PRICE	1.3840	.7112
3. West (17 observations)	YR	----	----
	ACPUE	----	----
	R	----	----
	PRICE	----	----
4. East (21 observations)	YR	.0483	.2059
	ACPUE	.3948	.5521
	R	5.6860	4.6540
	PRICE	4.6500	1.9210

meal and oil in terms of their quantities, and then by deflating those weighted prices by inflation rates. Building cost index data,from the quarterly publication Economic Statistics by the Central Bank of Iceland, were used to find inflation rates. The data on export prices were available from OECD Surveys, Iceland by OECD.

As discussed briefly in the previous section for the estimation results for the case of medium-sized trawlers, 7 regions in Iceland are combined into 4 regions to identify geographical distinction in medium-sized trawlers. There are only two origins for large stern trawlers, the south-west and north-west, and the estimation for the north-west is not performed due to the lack of degrees of freedom. Also, the estimation results, for identifying the regulatory impacts by looking at two different time periods with and without the ITQ system, are not reported. Too many censored observations and the resulting large number of same values for the time-dependent covariables, interest rate and price, seem to produce highly biased estimators. Table 18 shows the parameter estimates for large stern trawlers, while Table 19 shows those for large stern trawlers in the south-west region. There were 21 observations available for the south-west region. An (R) indicates interest rate.

When comparing the estimation results for large stern trawlers to those without economic variables, interest rate and price, there are no significant changes in signs and magnitudes of parameter estimates for entering year and ACPUE (Tables 3, 18 and 19). The estimate for the price variable is significant and has a positive sign while the estimate for interest rate is not significant. This is also true for the case of medium-sized trawlers (Tables 11 and 20). The positive relationship between hazard or exit rates and price may be explained by saying that high prices of fish may result in more intensified competition in fishing operation and its resulting high exit rates in the trawl industry due to decreased profits. Alternatively, high fish prices may be the result of overfishing. On the other hand, low prices of fish may be the result of oversupply of fish and fish products, which in turn may reduce profit per unit fish but increase total profit due to increased catches. These arguments are tentative; there is no obvious information available at this stage to identify the reasons for the positive relationship between price and exit rate in the Icelandic trawl fishery. Insignificance of the estimate for interest rate may be unique to the Icelandic trawl fishery, given the poor performance of the Iceland econmy over the past 20 years.

The estimation for the medium-sized trawlers in different regions (Table 21) show some interesting findings. First, the estimates for entering year, ACPUE, and interest rate are significant in the region of mid-west, south-west and south while the estimate for price variable is not. For the region of north-west and north-east, the estimates for entering year and price are significant, and only the estimate for the price variable is significant in the region of east. The estimation was not possible for the region of west due to too many censored observations in 1989. There may be an interaction effect between price and CPUE which may not be easily identified or explained. It seems that the survival patterns of medium-sized trawlers are different across regions.

5.5 Discussion

The empirical application of the survival technique to the Icelandic trawl fishery may have weaknesses in that the time spells compared have the large difference in time lengths. In addition, some data about ownership and target species are not available, and there is a lack of information about the details of the fishery regulations. However, the given study suggests some interesting points which may be specific in the Icelandic trawl fishery.

First, many previous studies on organizational mortality and unemployment duration data have shown negative duration dependence on their data sets. This finding led many economists to develop more advanced models for heterogeneity of samples. However, there seems to be no evidence of this in this study.

Second, it seems that the catch per unit effort or its analogous variables and regulation (the ITQ in this case) are the main factors determining the survival rates in this industry. Further, there seems to be no room for introducing a variable representing technical change into the model since the hazard rates for the more recent period with regulation are higher than those for the previous period without regulation.

Third, the magnitudes of parameter estimates in both parametric and nonparametric models are not significantly different. Both parametric and nonparametric models seem to be reasonable for the given data sets.

Fourth, it was not possible to estimate Cox's nonparametric model in some cases due to the incomplete nature of data. Parametric models such as polynomial model are recommended for the incomplete data sets.

Fifth, there may exist similar survival patterns in both large stern and medium-sized trawlers in terms of signs and magnitudes of the parameter estimates for explanatory variables. The impact of the ITQ system seems to be more severe on large stern trawlers, showing higher hazard rates. The survival patterns for medium-sized trawlers, however, may change across regions in that the estimates for the introduced covariables differ in signs and magnitudes.

Finally, there exists a positive relationship between fish price and exit rate in the Icelandic trawl fishery, and the reasons for this need to be clarified by further research. Insignificance of the estimate for interest rate may be due to high inflation rates in Iceland economy.

Chapter 6

Evaluation of Survival Analysis in Fishery Management

Survival analysis has been explored as a new methodology to overcome weaknesses of the mainstream economic methodologies, and as an analytical and empirical tool to address the issues in fishery management. More specfically, it has been shown that survival analysis can be applied to fishery management in two ways. First, it can study the idea of market competition by utilizing the statistical concepts of the survival model. Second, it can help us develop the dynamic models for fishery management in a way which incorporates the mathematical definitions of the survival model into a dynamic system model. There are several ways to develop the second kind of models.

In this chapter, survival analysis in fishery management is evaluated in terms of theoretical and empirical contents.

6.1 Theoretical Aspect

While neoclassical economics can still offer relatively good approximations of reality in many cases, a main objective of this thesis is to link the ideas of methodological reconstruction concept to survival analysis in economics. More specifically, the linkages between design of regulation, enforcement, and behavioral response by those regulated are explored in terms of the terminology used in statistical survival analysis.

Survival analysis is basically intended to address the issues of the evolution of social institutions and market competition. Also, survival analysis can be developed to incorporate the survivor function into the dynamic model since the definitions of survivor function and hazard rate provide a state equation for a dynamic system. In doing this, an analogy or reduction of economic competition to evolutionary biology is given. This analogy still can mislead us since the biological theory of evolution by natural selection rests on two mechanisms. First, the biological theory of evolution by natural selection requires a mechanism in which all variety - raw material for selection - is generated by a steady stream of random changes or mutations in the genes, and it requires a mechanism in which the few useful mutations are selected and retained. Also, there has been little success so far in explaining human behavior since people do not behave in the usual way that most animals do (Elster, 1989). Fortunately, this weakness is not of much concern in survival analysis due to its natural definitional aspects. Firms are regarded as analogous to organisms, competing for survival in the (competitive) market and economic competition is viewed as a selection process. "A firm is characterized by a set of routines, just as an organism is by its genes" (Elster, 1989, p.79). Technical change, whose process is not continuous, is also a routine affecting the survivals of individual firms. On the other hand, selection processes may not provide the best alternative in the feasible set since they "are restricted to the alternatives that are thrown up by chance" (Elster, 1989, p.72). Also, in economic competition, much faster changes in the economic environments, than in decision-making processes for bankruptcy, expansion, etc., may not produce an optimal adaptation to changing environments. Then, some explanatory power in complex, rapidly evolving economics may be lost (Elster, 1989).

6.2 Empirical Aspect

Survival analysis can be a powerful empirical tool to address the issues in fishery management. The estimation procedure is relatively simple. There are versatile distribution and regression models to be used. Unfortunately the collection of lifetime data in fishery management has not been done much.

Survival analysis for fishery management at this stage may have weakness in incorporating fishery regulation into one simple model. The development of an efficient estimation technique to include the whole history of time-dependent covariables has not been satisfactory. However, the findings given in the case study show the usefulness of survival analysis for fishery management. Therefore, more efforts on developing the more extensive models and estimation techniques will enhance the applicability of survival analysis in resource economics.

Chapter 7

Summary, Conclusions, and Suggestions for Future Research

The main objective of this thesis was to develop a theoretical and empirical framework to address issues in fishery management, and to suggest some ways to apply this framework to actual data through empirical probabilities of economic events. Thus, so-called survival analysis was suggested as a new methodology to overcome the persistent discrepancies between economic theory and practice. Methodologically, survival analysis is adopted on the basis of rational reconstruction since mainstream economic methodology has its own limitations in confirming the theory and is sometimes a major source of discrepancy. Survival analysis provides another way to examine the industry through defining survival rates as posterior probabilities of consequences of firms' efforts to survive in the industry under changing environments. This approach can be applied to all industries in total.

In the past, survival analysis in economics was limited due to a lack of advances in statistical methods. Recent developments in statistical methods have made it possible to apply survival analysis to industry analysis. Survival analysis can be used to estimate the survival function or hazard function easily. Also, it can be easily incorporated into dynamic fishery models since the definition of survival function provides a state equation in the dynamic system or control problem.

This study suggests some insights about how to analyze certain properties of an industry and its components with fewer information-acquiring costs and relatively easy regression technique. The applications of survival analysis to economic theory are largely open and more research on this area will make the applied economics richer. For example, it can be applied to the problems of price movement on the competitive market, market competition, nonrenewable resource harvesting, pollution control, unemployment or failure data analysis. Especially, in the application to fishery management, survival analysis will serve as an empirical tool to identify the impacts of regulation on fishermen's activities. Further, it will provide fishery managers with guidelines to design new policies through the applications of survival analysis shown in the previous section.

Survival analysis can be a legitimate approach to address the uncertainty issues in fishery management and other areas of resource economics. However, there exist limitations of this approach in applying it to, say, fishery management. First, few efforts have been devoted to collecting lifetime data in the fishery industry. Second, the application of survival technique to optimal control models for the fishery easily complicates the problems when the number of state and control (or decision) variables increases. Sometimes, it would not be possible to find optimal solutions and do analysis of comparative dynamics. Also, in some areas such as dealing with heterogeneity of samples and multiple spells of individual sample, the survival technique is somewhat difficult to practice due to its complexity. It is important to find ways to reduce complexity in the modeling process. Third, for the success of the application of survival analysis in economics, the choice of a specific model is an important factor and there have been too few applications to help in this model selection process. Therefore, more model development and empirical applications would be required to show the appropriateness of the application of survival analysis to resource economics. Fourth, Cox's partial likelihood approach still can be used for time-dependent covariables, but there is a loss of efficiency in estimation. More advanced estimation techniques need to be developed for time-dependent covariables given that many economic variables involve a time dimension. Finally, the simple nonlinear models may not have simple properties. Therefore, when the application of survival technique to optimal control problem is given, more attention to the assumptions of mathematical functions and boundary conditions is required not to have any unexpected pattern on the mathematical model. Also, the more detailed analysis of comparative dynamics on this application would be an interesting research topic since properties of the fishery model may be changed by the introduction of a survival function.

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APPENDIX

APPENDIX

THE DATA

DATA I (Large Stern Trawlers);

lifetime, failed/censored, entring year, averaged CPUE, interest rate at time t, price at time t, south-west, north-west.

1	1	80	5.0	-.141	3.50	1	0
1	1	87	8.9	.173	3.84	1	0
1	1	87	14.1	.173	3.84	1	0
2	1	82	8.9	-.587	5.63	1	0
3	1	85	9.6	.173	3.84	1	0
3	1	77	11.0	-.030	3.66	1	0
3	1	74	7.9	.105	4.36	1	0
4	1	74	9.3	0	3.92	1	0
5	0	85	12.3	.095	3.15	1	0
5	1	80	11.4	-.045	3.79	1	0
7	1	81	7.3	.173	3.84	1	0
9	1	74	9.5	-.041	4.74	1	0
11	0	79	11.6	.095	3.15	1	0
11	1	74	12.5	-.045	3.79	1	0
12	1	73	11.6	-.045	3.79	1	0
13	1	73	11.3	-.007	3.18	1	0
15	1	73	11.6	.173	3.84	1	0
16	0	74	10.0	.095	3.15	1	0
17	1	72	9.6	-.142	3.04	1	0
17	0	73	11.6	.095	3.15	1	0
18	0	72	11.0	.095	3.15	1	0
2	1	74	7.3	-.318	3.05	0	1
5	1	83	12.7	.173	3.84	0	1
5	1	82	8.4	-.042	3.50	0	1
14	1	74	11.2	.173	3.84	0	1
15	0	75	12.4	.095	3.15	0	1
15	0	75	13.3	.095	3.15	0	1
16	0	74	12.6	.095	3.15	0	1

DATA II (Large Stern Trawlers before 1984);

lifetime, failed/censored, entring year, averaged CPUE, interest rate at time t, price at time t, south- west, north-west.

1	1	80	5.0	-.141	3.50	1	0
2	1	82	8.9	-.587	5.63	1	0
3	1	74	7.9	.105	4.36	1	0
3	1	77	11.0	-.030	3.66	1	0
3	0	81	6.5	-.587	5.63	1	0
4	1	74	7.3	0	3.92	1	0
4	0	80	5.0	-.587	5.63	1	0
5	0	79	10.9	-.587	5.63	1	0
9	1	74	9.5	-.041	4.74	1	0
10	0	74	12.8	-.587	5.63	1	0
10	0	74	10.4	-.587	5.63	1	0
11	0	73	12.0	-.587	5.63	1	0
11	0	73	11.9	-.587	5.63	1	0
11	0	73	12.7	-.587	5.63	1	0
11	0	73	12.4	-.587	5.63	1	0
12	0	72	9.3	-.587	5.63	1	0
12	0	72	11.3	-.587	5.63	1	0
1	0	83	6.9	-.587	5.63	0	1
2	1	74	7.3	-.318	3.05	0	1
5	1	72	8.4	.105	4.36	0	1
9	0	75	11.5	-.587	5.63	0	1
9	0	75	13.4	-.587	5.63	0	1
10	0	74	11.7	-.587	5.63	0	1
10	0	74	12.5	-.587	5.63	0	1

DATA III (Large Stern Trawlers since 1984);

lifetime, failed/censored, entring year, years of experience before the ITQ, averaged CPUE, interest rate at time t, price at time t, south-west, north-west.

1	1	87	0	14.1	.173	3.84	1	0
1	1	87	0	8.9	.173	3.84	1	0
1	1	84	11	6.7	-.045	3.79	1	0
1	1	84	10	9.0	-.045	3.79	1	0
1	1	84	4	11.2	-.045	3.79	1	0
2	1	84	11	8.2	-.007	3.18	1	0
3	1	85	0	12.3	.173	3.84	1	0
4	1	84	11	9.3	.173	3.84	1	0
4	1	84	3	7.9	.173	3.84	1	0
5	0	85	0	12.3	.095	3.15	1	0
5	1	84	12	10.2	-.142	3.04	1	0
6	0	84	11	9.6	.095	3.15	1	0
6	0	84	12	10.5	.095	3.15	1	0
6	0	84	10	12.7	.095	3.15	1	0
6	0	84	5	12.2	.095	3.15	1	0
4	1	84	1	14.2	.173	3.84	0	1
4	1	84	10	9.9	.173	3.84	0	1
6	0	84	10	12.9	.095	3.15	0	1
6	0	84	9	13.8	.095	3.15	0	1
6	0	84	9	13.3	.095	3.15	0	1

DATA IV (Medium-Size Trawlers);

lifetime, failed/censored, entering year, averaged CPUE, interest rate at time t, price at time t, south, south-west, middle-west, west, north-west, north-east, east.

2	1	77	4.0	-.115	3.91	1	0	0	0	0	0	0
7	0	83	9.8	.095	3.15	1	0	0	0	0	0	0
8	1	77	8.4	-.045	3.79	1	0	0	0	0	0	0
11	0	79	9.4	.095	3.15	1	0	0	0	0	0	0
11	0	79	13.8	.095	3.15	1	0	0	0	0	0	0
13	1	75	9.0	.173	3.84	1	0	0	0	0	0	0
13	0	77	9.3	.095	3.15	1	0	0	0	0	0	0
13	0	77	10.1	.095	3.15	1	0	0	0	0	0	0
15	0	75	9.5	.095	3.15	1	0	0	0	0	0	0
1	1	85	10.4	-.007	3.18	0	1	0	0	0	0	0
1	1	75	3.3	-.318	3.05	0	1	0	0	0	0	0
1	0	89	8.5	.095	3.15	0	1	0	0	0	0	0
1	1	75	6.7	-.318	3.05	0	1	0	0	0	0	0
2	1	80	4.5	-.106	3.83	0	1	0	0	0	0	0
2	0	88	5.0	.095	3.15	0	1	0	0	0	0	0
2	1	82	7.2	-.587	5.63	0	1	0	0	0	0	0
2	1	76	7.6	0	3.92	0	1	0	0	0	0	0
2	1	82	8.4	-.587	5.63	0	1	0	0	0	0	0
3	1	82	6.9	-.045	3.79	0	1	0	0	0	0	0
4	1	85	9.9	-.142	3.04	0	1	0	0	0	0	0
4	1	81	7.4	-.045	3.79	0	1	0	0	0	0	0
4	0	86	15.7	.095	3.15	0	1	0	0	0	0	0
5	0	85	11.3	.095	3.15	0	1	0	0	0	0	0
5	1	75	4.9	-.030	3.66	0	1	0	0	0	0	0
5	1	75	9.5	-.030	3.66	0	1	0	0	0	0	0
6	1	75	8.7	-.141	3.50	0	1	0	0	0	0	0
7	1	81	7.8	.173	3.84	0	1	0	0	0	0	0
7	1	78	11.2	-.045	3.79	0	1	0	0	0	0	0
9	0	81	9.7	.095	3.15	0	1	0	0	0	0	0
9	1	76	9.0	-.045	3.79	0	1	0	0	0	0	0
9	1	77	10.3	-.007	3.18	0	1	0	0	0	0	0
9	0	81	16.9	.095	3.15	0	1	0	0	0	0	0
10	0	80	12.1	.095	3.15	0	1	0	0	0	0	0
10	1	79	10.7	-.142	3.04	0	1	0	0	0	0	0
10	1	78	9.2	.173	3.84	0	1	0	0	0	0	0
10	0	80	12.7	.095	3.15	0	1	0	0	0	0	0
10	1	75	9.0	-.045	3.79	0	1	0	0	0	0	0
11	1	78	6.3	-.142	3.04	0	1	0	0	0	0	0
12	0	78	11.5	.095	3.15	0	1	0	0	0	0	0
12	0	78	11.3	.095	3.15	0	1	0	0	0	0	0
12	1	75	5.5	-.042	3.50	0	1	0	0	0	0	0
13	0	77	10.2	.095	3.15	0	1	0	0	0	0	0
14	0	76	9.2	.095	3.15	0	1	0	0	0	0	0
14	1	75	9.1	-.142	3.04	0	1	0	0	0	0	0
15	0	75	12.9	.095	3.15	0	1	0	0	0	0	0

15	0	75	10.6	.095	3.15	0	1	0	0	0	0	0
5	1	81	10.3	-.007	3.18	0	0	1	0	0	0	0
6	1	77	8.0	-.041	4.74	0	0	1	0	0	0	0
10	0	80	10.0	.095	3.15	0	0	1	0	0	0	0
15	0	75	10.5	.095	3.15	0	0	1	0	0	0	0
2	1	82	4.0	-.587	5.63	0	0	0	1	0	0	0
3	1	78	8.5	-.141	3.50	0	0	0	1	0	0	0
3	1	75	6.3	0	3.92	0	0	0	1	0	0	0
6	0	84	9.1	.095	3.15	0	0	0	1	0	0	0
7	0	83	12.0	.095	3.15	0	0	0	1	0	0	0
10	0	80	11.1	.095	3.15	0	0	0	1	0	0	0
11	0	79	12.0	.095	3.15	0	0	0	1	0	0	0
12	0	78	8.7	.095	3.15	0	0	0	1	0	0	0
13	0	77	11.2	.095	3.15	0	0	0	1	0	0	0
14	1	75	12.6	-.142	3.04	0	0	0	1	0	0	0
14	0	76	12.7	.095	3.15	0	0	0	1	0	0	0
15	0	75	13.2	.095	3.15	0	0	0	1	0	0	0
15	0	75	12.1	.095	3.15	0	0	0	1	0	0	0
15	0	75	10.2	.095	3.15	0	0	0	1	0	0	0
15	0	75	12.2	.095	3.15	0	0	0	1	0	0	0
15	0	75	11.6	.095	3.15	0	0	0	1	0	0	0
15	0	75	15.2	.095	3.15	0	0	0	1	0	0	0
1	0	89	8.8	.095	3.15	0	0	0	0	1	0	0
1	1	87	15.0	.173	3.84	0	0	0	0	1	0	0
1	1	88	5.9	-.142	3.04	0	0	0	0	1	0	0
2	0	88	9.3	.095	3.15	0	0	0	0	1	0	0
2	1	82	5.2	-.587	5.63	0	0	0	0	1	0	0
3	1	85	4.8	.173	3.84	0	0	0	0	1	0	0
3	0	87	6.5	.095	3.15	0	0	0	0	1	0	0
4	1	80	5.7	-.587	5.63	0	0	0	0	1	0	0
5	1	75	7.0	-.030	3.66	0	0	0	0	1	0	0
5	0	85	9.7	.095	3.15	0	0	0	0	1	0	0
6	1	78	6.9	-.587	5.63	0	0	0	0	1	0	0
6	1	82	12.7	.173	3.84	0	0	0	0	1	0	0
6	1	77	8.8	-.041	4.74	0	0	0	0	1	0	0
9	1	79	7.4	.173	3.84	0	0	0	0	1	0	0
13	0	77	10.3	.095	3.15	0	0	0	0	1	0	0
14	1	75	7.9	-.142	3.04	0	0	0	0	1	0	0
15	0	75	9.0	.095	3.15	0	0	0	0	1	0	0
15	0	75	12.3	.095	3.15	0	0	0	0	1	0	0
15	0	75	9.3	.095	3.15	0	0	0	0	1	0	0
15	0	75	8.6	.095	3.15	0	0	0	0	1	0	0
15	0	75	8.1	.095	3.15	0	0	0	0	1	0	0
15	0	75	8.4	.095	3.15	0	0	0	0	1	0	0
15	0	75	9.6	.095	3.15	0	0	0	0	1	0	0
3	1	76	6.0	-.115	3.91	0	0	0	0	0	1	0
6	1	82	10.2	.173	3.84	0	0	0	0	0	1	0
8	1	76	6.0	-.587	5.63	0	0	0	0	0	1	0
9	1	79	11.5	.173	3.84	0	0	0	0	0	1	0
9	0	81	10.5	.095	3.15	0	0	0	0	0	1	0
15	0	75	8.1	.095	3.15	0	0	0	0	0	1	0
15	0	75	10.2	.095	3.15	0	0	0	0	0	1	0

```
15 0 75  8.4   .095 3.15 0 0 0 0 0 1 0
 1 1 83  6.6 -.587 5.63 0 0 0 0 0 0 1
 1 0 89  9.8   .095 3.15 0 0 0 0 0 0 1
 2 1 82  3.7 -.587 5.63 0 0 0 0 0 0 1
 2 1 75  6.2   .105 4.36 0 0 0 0 0 0 1
 2 1 75  6.9   .105 4.36 0 0 0 0 0 0 1
 5 1 83 10.2   .173 3.84 0 0 0 0 0 0 1
 5 0 85  6.8   .095 3.15 0 0 0 0 0 0 1
 5 0 85  9.0   .095 3.15 0 0 0 0 0 0 1
 8 1 77  8.8 -.045 3.79 0 0 0 0 0 0 1
 8 0 82  8.7   .095 3.15 0 0 0 0 0 0 1
 8 1 81  9.1 -.142 3.04 0 0 0 0 0 0 1
13 0 77  9.3   .095 3.15 0 0 0 0 0 0 1
13 0 77 10.1   .095 3.15 0 0 0 0 0 0 1
13 0 77  9.5   .095 3.15 0 0 0 0 0 0 1
15 0 75  8.9   .095 3.15 0 0 0 0 0 0 1
15 0 75  9.1   .095 3.15 0 0 0 0 0 0 1
15 0 75  9.1   .095 3.15 0 0 0 0 0 0 1
15 0 75  9.8   .095 3.15 0 0 0 0 0 0 1
15 0 75  9.9   .095 3.15 0 0 0 0 0 0 1
15 0 75  8.8   .095 3.15 0 0 0 0 0 0 1
15 0 75  9.5   .095 3.15 0 0 0 0 0 0 1
```

DATA V (Medium-Size Trawlers before 1984);

lifetime, failed/censored, entering year, averaged CPUE, interest rate at time t, price at time t, south, south-west, middle-west, west, north-west, north-east, east.

1	0	83	7.0	-.045	3.79	1	0	0	0	0	0	0
2	1	77	4.0	-.115	3.91	1	0	0	0	0	0	0
5	0	79	9.4	-.045	3.79	1	0	0	0	0	0	0
5	0	79	12.5	-.045	3.79	1	0	0	0	0	0	0
7	0	77	9.0	-.045	3.79	1	0	0	0	0	0	0
7	0	77	9.4	-.045	3.79	1	0	0	0	0	0	0
7	0	77	8.5	-.045	3.79	1	0	0	0	0	0	0
9	0	75	8.9	-.045	3.79	1	0	0	0	0	0	0
9	0	75	8.5	-.045	3.79	1	0	0	0	0	0	0
1	1	75	6.7	-.318	3.05	0	1	0	0	0	0	0
1	1	75	3.3	-.318	3.05	0	1	0	0	0	0	0
2	1	76	7.6	0	3.92	0	1	0	0	0	0	0
2	1	80	4.5	-.106	3.83	0	1	0	0	0	0	0
2	1	82	7.2	-.587	5.63	0	1	0	0	0	0	0
2	0	82	6.9	-.587	5.63	0	1	0	0	0	0	0
2	1	82	8.4	-.587	5.63	0	1	0	0	0	0	0
3	0	81	7.2	-.587	5.63	0	1	0	0	0	0	0
3	0	81	9.6	-.587	5.63	0	1	0	0	0	0	0
3	0	81	16.8	-.587	5.63	0	1	0	0	0	0	0
3	0	81	6.5	-.587	5.63	0	1	0	0	0	0	0
4	0	80	13.2	-.587	5.63	0	1	0	0	0	0	0
4	0	80	13.7	-.587	5.63	0	1	0	0	0	0	0
5	1	75	9.5	-.030	3.66	0	1	0	0	0	0	0
5	1	75	4.9	-.030	3.66	0	1	0	0	0	0	0
5	0	79	10.0	-.587	5.63	0	1	0	0	0	0	0
6	1	75	8.7	-.141	3.50	0	1	0	0	0	0	0
6	0	78	5.7	-.587	5.63	0	1	0	0	0	0	0
6	0	78	10.6	-.587	5.63	0	1	0	0	0	0	0
6	0	78	11.8	-.587	5.63	0	1	0	0	0	0	0
6	0	78	11.5	-.587	5.63	0	1	0	0	0	0	0
6	0	78	11.6	-.587	5.63	0	1	0	0	0	0	0
7	0	77	10.2	-.587	5.63	0	1	0	0	0	0	0
7	0	77	11.1	-.587	5.63	0	1	0	0	0	0	0
8	0	76	10.0	-.587	5.63	0	1	0	0	0	0	0
8	0	76	10.0	-.587	5.63	0	1	0	0	0	0	0
9	0	75	8.8	-.587	5.63	0	1	0	0	0	0	0
9	0	75	9.1	-.587	5.63	0	1	0	0	0	0	0
9	0	75	5.2	-.587	5.63	0	1	0	0	0	0	0
9	0	75	12.3	-.587	5.63	0	1	0	0	0	0	0
9	0	75	10.4	-.587	5.63	0	1	0	0	0	0	0
3	0	81	10.5	-.587	5.63	0	0	1	0	0	0	0
4	0	80	11.2	-.587	5.63	0	0	1	0	0	0	0
6	1	77	8.0	-.041	4.74	0	0	1	0	0	0	0
9	0	75	10.1	-.587	5.63	0	0	1	0	0	0	0
1	0	83	11.7	-.587	5.63	0	0	0	1	0	0	0
2	1	82	4.0	-.587	5.63	0	0	0	1	0	0	0

```
3 1 78  8.5 -.141 3.50 0 0 0 1 0 0 0
3 1 75  6.3  0    3.92 0 0 0 1 0 0 0
4 0 80 10.5 -.587 5.63 0 0 0 1 0 0 0
5 0 79 12.4 -.587 5.63 0 0 0 1 0 0 0
6 0 78  8.8 -.587 5.63 0 0 0 1 0 0 0
7 0 77 11.7 -.587 5.63 0 0 0 1 0 0 0
8 0 76 12.8 -.587 5.63 0 0 0 1 0 0 0
9 0 75 10.3 -.587 5.63 0 0 0 1 0 0 0
9 0 75 12.3 -.587 5.63 0 0 0 1 0 0 0
9 0 75 11.5 -.587 5.63 0 0 0 1 0 0 0
9 0 75 14.6 -.587 5.63 0 0 0 1 0 0 0
9 0 75 12.6 -.587 5.63 0 0 0 1 0 0 0
9 0 75 12.8 -.587 5.63 0 0 0 1 0 0 0
9 0 75 12.5 -.587 5.63 0 0 0 1 0 0 0
2 1 82  5.2 -.587 5.63 0 0 0 0 1 0 0
2 0 82 11.0 -.587 5.63 0 0 0 0 1 0 0
4 1 80  5.7 -.587 5.63 0 0 0 0 1 0 0
5 0 79  6.6 -.587 5.63 0 0 0 0 1 0 0
5 1 75  7.0 -.030 3.66 0 0 0 0 1 0 0
6 1 78  6.9 -.587 5.63 0 0 0 0 1 0 0
6 1 77  8.8 -.041 4.74 0 0 0 0 1 0 0
7 0 77 10.2 -.587 5.63 0 0 0 0 1 0 0
9 0 75 11.0 -.587 5.63 0 0 0 0 1 0 0
9 0 75  9.1 -.587 5.63 0 0 0 0 1 0 0
9 0 75  7.1 -.587 5.63 0 0 0 0 1 0 0
9 0 75  8.1 -.587 5.63 0 0 0 0 1 0 0
9 0 75  7.5 -.587 5.63 0 0 0 0 1 0 0
9 0 75  8.0 -.587 5.63 0 0 0 0 1 0 0
9 0 75  9.3 -.587 5.63 0 0 0 0 1 0 0
9 0 75  8.0 -.587 5.63 0 0 0 0 1 0 0
2 0 82  9.3 -.587 5.63 0 0 0 0 0 1 0
3 0 81 10.2 -.587 5.63 0 0 0 0 0 1 0
3 1 76  5.2 -.115 3.91 0 0 0 0 0 1 0
5 0 79 12.0 -.587 5.63 0 0 0 0 0 1 0
8 1 76  6.0 -.587 5.63 0 0 0 0 0 1 0
9 0 75  9.3 -.587 5.63 0 0 0 0 0 1 0
9 0 75 10.5 -.587 5.63 0 0 0 0 0 1 0
9 0 75  8.3 -.587 5.63 0 0 0 0 0 1 0
1 0 83  7.9 -.587 5.63 0 0 0 0 0 0 1
1 1 83  6.6 -.587 5.63 0 0 0 0 0 0 1
2 0 82  8.8 -.587 5.63 0 0 0 0 0 0 1
2 1 82  3.7 -.587 5.63 0 0 0 0 0 0 1
2 1 75  6.2  .105 4.36 0 0 0 0 0 0 1
2 1 75  6.9  .105 4.36 0 0 0 0 0 0 1
3 0 81  9.1 -.587 5.63 0 0 0 0 0 0 1
7 0 77  9.2 -.587 5.63 0 0 0 0 0 0 1
7 0 77  9.1 -.587 5.63 0 0 0 0 0 0 1
7 0 77 10.2 -.587 5.63 0 0 0 0 0 0 1
7 0 77 10.4 -.587 5.63 0 0 0 0 0 0 1
9 0 75  8.5 -.587 5.63 0 0 0 0 0 0 1
9 0 75  7.5 -.587 5.63 0 0 0 0 0 0 1
9 0 75  8.7 -.587 5.63 0 0 0 0 0 0 1
```

```
9 0 75  9.3 -.587 5.63 0 0 0 0 0 0 1
9 0 75  9.9 -.587 5.63 0 0 0 0 0 0 1
9 0 75  8.2 -.587 5.63 0 0 0 0 0 0 1
9 0 75  9.3 -.587 5.63 0 0 0 0 0 0 1
```

DATA VI (Medium-Size Trawlers since 1984);

lifetime, failed/censored, entering year, averaged CPUE, years of stay in operation before 1984, interest rate at time t, price at time t, south, south-west, middle-west, west, north-west, north-east, east.

1	1	84	10.2	7	-.045	3.79	1	0	0	0	0	0	0
4	1	84	9.2	9	.173	3.84	1	0	0	0	0	0	0
6	0	84	9.7	7	.095	3.15	1	0	0	0	0	0	0
6	0	84	10.8	7	.095	3.15	1	0	0	0	0	0	0
6	0	84	14.9	5	.095	3.15	1	0	0	0	0	0	0
6	0	84	10.3	1	.095	3.15	1	0	0	0	0	0	0
6	0	84	11.1	9	.095	3.15	1	0	0	0	0	0	0
6	0	84	9.5	5	.095	3.15	1	0	0	0	0	0	0
1	1	84	7.9	3	-.045	3.79	0	1	0	0	0	0	0
1	1	84	8.4	9	-.045	3.79	0	1	0	0	0	0	0
1	1	84	8.1	8	-.045	3.79	0	1	0	0	0	0	0
1	1	89	8.5	0	.095	3.15	0	1	0	0	0	0	0
1	1	85	10.4	0	-.007	3.18	0	1	0	0	0	0	0
1	1	84	7.0	2	-.045	3.79	0	1	0	0	0	0	0
2	0	88	5.0	0	.095	3.15	0	1	0	0	0	0	0
2	1	84	7.6	7	-.007	3.18	0	1	0	0	0	0	0
3	1	84	6.2	9	-.042	3.50	0	1	0	0	0	0	0
4	1	85	9.9	0	-.142	3.04	0	1	0	0	0	0	0
4	1	84	7.0	6	.173	3.84	0	1	0	0	0	0	0
4	1	84	8.9	3	.173	3.84	0	1	0	0	0	0	0
4	0	86	15.7	0	.095	3.15	0	1	0	0	0	0	0
5	0	85	11.3	0	.095	3.15	0	1	0	0	0	0	0
5	1	84	9.7	9	-.142	3.04	0	1	0	0	0	0	0
5	1	84	11.3	5	-.142	3.04	0	1	0	0	0	0	0
5	1	84	7.1	6	-.142	3.04	0	1	0	0	0	0	0
6	0	84	11.4	4	.095	3.15	0	1	0	0	0	0	0
6	0	84	9.7	3	.095	3.15	0	1	0	0	0	0	0
6	0	84	10.2	7	.095	3.15	0	1	0	0	0	0	0
6	0	84	8.2	8	.095	3.15	0	1	0	0	0	0	0
6	0	84	11.2	6	.095	3.15	0	1	0	0	0	0	0
6	0	84	11.2	6	.095	3.15	0	1	0	0	0	0	0
6	0	84	11.1	6	.095	3.15	0	1	0	0	0	0	0
6	0	84	12.0	4	.095	3.15	0	1	0	0	0	0	0
6	0	84	17.0	3	.095	3.15	0	1	0	0	0	0	0
6	0	84	13.7	9	.095	3.15	0	1	0	0	0	0	0
6	0	84	11.0	9	.095	3.15	0	1	0	0	0	0	0
2	1	84	10.0	3	-.007	3.18	0	0	1	0	0	0	0
6	0	84	11.1	9	.095	3.15	0	0	1	0	0	0	0
6	0	84	9.2	4	.095	3.15	0	0	1	0	0	0	0
5	1	84	12.7	9	-.142	3.04	0	0	0	1	0	0	0
6	0	84	9.1	0	.095	3.15	0	0	0	1	0	0	0
6	0	84	11.8	5	.095	3.15	0	0	0	1	0	0	0
6	0	84	11.5	4	.095	3.15	0	0	0	1	0	0	0
6	0	84	10.1	9	.095	3.15	0	0	0	1	0	0	0

```
6 0 84 11.9 9  .095 3.15 0 0 0 1 0 0 0
6 0 84 11.7 9  .095 3.15 0 0 0 1 0 0 0
6 0 84 16.0 9  .095 3.15 0 0 0 1 0 0 0
6 0 84 13.7 9  .095 3.15 0 0 0 1 0 0 0
6 0 84 11.4 9  .095 3.15 0 0 0 1 0 0 0
6 0 84 12.6 8  .095 3.15 0 0 0 1 0 0 0
6 0 84 10.6 7  .095 3.15 0 0 0 1 0 0 0
6 0 84  8.6 6  .095 3.15 0 0 0 1 0 0 0
6 0 84 12.0 1  .095 3.15 0 0 0 1 0 0 0
1 0 89  8.8 0  .095 3.15 0 0 0 0 1 0 0
1 1 85  9.7 0 -.007 3.18 0 0 0 0 1 0 0
1 1 88  5.9 0 -.142 3.04 0 0 0 0 1 0 0
2 0 88  9.3 0  .095 3.15 0 0 0 0 1 0 0
3 1 85  4.8 0  .173 3.84 0 0 0 0 1 0 0
3 0 87  6.5 0  .095 3.15 0 0 0 0 1 0 0
4 1 84 13.5 2  .173 3.84 0 0 0 0 1 0 0
4 1 84  8.4 6  .173 3.84 0 0 0 0 1 0 0
5 1 84  7.7 9 -.142 3.04 0 0 0 0 1 0 0
5 0 85  9.7 0  .095 3.15 0 0 0 0 1 0 0
6 0 84 11.5 9  .095 3.15 0 0 0 0 1 0 0
6 0 84  9.0 9  .095 3.15 0 0 0 0 1 0 0
6 0 84 10.8 9  .095 3.15 0 0 0 0 1 0 0
6 0 84  9.4 9  .095 3.15 0 0 0 0 1 0 0
6 0 84  8.9 9  .095 3.15 0 0 0 0 1 0 0
6 0 84  9.0 9  .095 3.15 0 0 0 0 1 0 0
6 0 84  9.9 9  .095 3.15 0 0 0 0 1 0 0
6 0 84 10.5 7  .095 3.15 0 0 0 0 1 0 0
4 1 84 10.7 2  .173 3.84 0 0 0 0 0 1 0
4 1 84 10.9 5  .173 3.84 0 0 0 0 0 1 0
6 0 84  8.0 9  .095 3.15 0 0 0 0 0 1 0
6 0 84  9.8 9  .095 3.15 0 0 0 0 0 1 0
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6 0 84 10.6 3  .095 3.15 0 0 0 0 0 1 0
1 1 84  6.1 7 -.045 3.79 0 0 0 0 0 0 1
1 0 89  9.8 0  .095 3.15 0 0 0 0 0 0 1
4 1 84 10.8 1  .173 3.84 0 0 0 0 0 0 1
5 0 85  6.8 0  .095 3.15 0 0 0 0 0 0 1
5 1 84  9.1 3 -.142 3.04 0 0 0 0 0 0 1
5 0 85  9.0 0  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.5 9  .095 3.15 0 0 0 0 0 0 1
6 0 84 11.6 9  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.6 9  .095 3.15 0 0 0 0 0 0 1
6 0 84 10.6 9  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.5 7  .095 3.15 0 0 0 0 0 0 1
6 0 84  8.7 2  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.9 9  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.6 9  .095 3.15 0 0 0 0 0 0 1
6 0 84  9.9 9  .095 3.15 0 0 0 0 0 0 1
6 0 84 10.0 7  .095 3.15 0 0 0 0 0 0 1
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