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Market Information and Fisheries Management: A Multiple-Objective Analysis[1]

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Abstract.—Market issues are often critical to the regional and national benefits that can be generated from fisheries management. In actual policy analysis, however, market considerations are often treated as exogenous to the fisheries policy problem. Examples illustrate the relationships between product characteristics, market demand, and regulatory management. A multiple-objective socioeconomic policy model was formulated to demonstrate these relationships. Numerical analysis illustrated how price differences due to product quality characteristics affect the selection of regulatory controls and the attainment of policy objectives. Results demonstrated that selection of regulatory instruments, including allowable effort and mesh size, will vary depending on size-related price differences and the relative values on noncomplementary objectives such as profits and employment. Results also showed that dynamic harvest patterns for each age-class display greater differences across scenarios relative to stock size and stock composition. For the scenario where product quality and price are functions of season length, socioeconomic information was summarized in the form of policy frontiers. These frontiers demonstrate the intertemporal and capitalized trade-offs between profits, employment, and stock size. This approach has potential for use, with some limitations, within the fisheries policy-making process.

A major challenge confronting policy makers and fishery managers is the development of management systems that generate increasing social benefits even though resource supplies may be considered fully or even overexploited. Addressing this problem requires that decision makers understand how their regulations affect industry's ability to produce new benefits by improving product characteristics and developing market opportunities. Without an understanding of the relationships between market demand, global market opportunities, and fishery policy, managers risk developing strategies incongruous with market potential, thereby limiting the possible benefits of the fishery.

This issue can be placed within the context of global market trends. During the 1980s, total world fisheries production increased at an average rate of 3% per year (FAO 1992). During this same period, fisheries trade increased at an even faster rate of over 5% per year. Trade implications were especially important for Japan, Europe, and North America, which account for more than 75% of global fisheries trade. For example, by 1990 the United States had become the world's largest seafood exporter (US$2.44 billion) while still maintaining its position as the globe's second leading fish importer ($5.39 billion, second to Japan's $9.35 billion) (Josupeit 1993).

By 1990, 97 million metric tons of seafood products (round weight equivalent) were produced globally. Since 1990, however, production has been decreasing, and preliminary estimates indicated that in 1992 fisheries production totaled only 95.6 million metric tons (Josupeit 1993). A closer look at these estimates shows that most of the growth in the 1980s was due to the rapid expansion of aquacultural production and the exploitation by developing nations of marine stocks in their exclusive economic zones. In contrast, capture fishery production in most developed nations not only leveled off but in some cases decreased, and total global capture fishery production declined from a high of 86 million metric tons in 1989 to approximately 80 million metric tons in 1992 (Josupeit 1993).

These supply limitations have compelled U.S. capture-based seafood industries to become increasingly market oriented to generate new ben-

[1] An earlier version of this paper was presented at the symposium "International Trade in Fisheries: The Influence of International Trade Policy on Fishery Resources, Fishery Management, and the Fishery Management Profession." This symposium, organized by D. Talhelm and R. S. Johnston, was held at the 1989 annual meeting of the American Fisheries Society, in Anchorage, Alaska.

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efits and compete effectively in international markets. While the need to focus on markets and new market development provides a challenge for the U.S. seafood industry, it also adds an additional element to the already difficult regulatory problems confronting fisheries managers. Because the fisheries policy process has evolved primarily in response to production, conservation, and allocation issues, market-related concerns often receive only perfunctory investigation. Yet regulations controlling such factors as seasonal and temporal distribution of fishing effort, stock size and composition, fishing technology, and processing and distribution activities may directly affect marketing activities, market development, and output prices at every level of the production and distribution process. Likewise, the effects on income, profits, jobs, and consumer satisfaction may be significant, depending on how regulatory decisions affect quality of supplies, output prices, and market development. Further complicating this management issue is that policy effects may not serve all social objectives; for example, regulations that improve output market prices and industry profits could result in a decrease in fishery employment. Understanding these types of relationships is critical if managers and policy makers are to be successful in increasing fishery-related social benefits.

In the sections that follow, examples illustrate the relationship between market demand and fisheries policy. The first section reviews market issues and the relationships among price, product characteristics, and other market issues. In the second section, a numerical model is developed to show how output market prices can be related to fisheries management strategies. A multiple-objective approach is then used to illustrate the types of trade-offs inherent in attempts to maximize fishery objectives when product quality is a function of management decisions. Policy and product quality information is summarized in the form of trade-off curves and policy frontiers. The paper concludes with a discussion regarding the potential use and limitations of this approach within the fisheries policy-making process.

Value of Product Characteristics

Recognizing that captured, unprocessed seafood products are not delivered dockside as standardized commodities but often demonstrate substantial variation in product characteristics is a fundamental requisite for understanding the market implications of public policy decisions. This situation stands in sharp contrast to aquacultural production, in which much variation is controlled through breeding and production policies. In fact, it is this additional level of control that has provided market advantages to cultured products and has increased the pressures on producers of captured products to standardize product supplies and product qualities.

Product variation may include such attributes as product size and sex, coloration of skin and flesh, lipid and moisture content, and various taste and texture sensory characteristics (Love 1988). Additional variation in product attributes may be related to capture and handling techniques used during any phase of the production and distribution process. Because the form and variation of these attributes may affect market development and market prices, control over product attributes can play an important role in improving industry-related benefits. And because the private sector's attempts to control this variation are done within the constraints of regulatory policy, public policy decisions will directly and indirectly affect the extent and form of these product characteristics.

Although many U.S. fisheries are affected by some type of market-related policy issue, one of the most dramatic examples illustrating the relationship among regulatory policies, product attributes, and market-related welfare effects involves the fishery for Pacific halibut *Hippoglossus stenolepis*. In attempts designed to control effort and maintain harvest levels at limits established by the International Pacific Halibut Commission, the U.S. fishery has evolved into a handful of annual 24-h derby openings. The fishery has been characterized as not only relatively unsafe and overcapitalized, but also inefficient from both regional and national perspectives (McCaughran 1990). It has been suggested that welfare losses are related to the reduction and erratic variation in supply levels of fresh product, which is more highly demanded than frozen product, and reduction in quality of both fresh and frozen product. By an econometric analysis of the ex-vessel demand for Pacific halibut, Lin et al. (1987) showed that Pacific halibut ex-vessel price was significantly and positively related to season length. Because of these types of concerns, the Canadians have adopted transferable vessel quota programs and the United States is now in the process of developing individual fishery quotas for Pacific halibut management.

One of the most important characteristics affecting market price is product size (Gates 1974). The July 13, 1993, issue of *Seafood Price—Current*

(UBP 1993) illustrated the importance of product size to the determination of wholesale market prices for a wide range of seafood species and products. For example, shrimp showed price variation of more than 100% from the mean (e.g., Gulf of Mexico domestic brown shrimp *Penaeus aztecus*: $2.20 for 81–90 count [pieces per pound] to $10.35 for under 10 count); troll-caught coho salmon *Oncorhynchus kisutch* that had been headed, gutted, and frozen sold at prices from $2.00/lb for 2–4-lb fish to $2.80/lb for 9-lb and larger fish; and for frozen shatterpack groundfish fillet products such as Argentine hake *Merluccius hubbsi* and pollock *Pollachius virens*, increasing fillet sizes from 2–4 oz to 4–6 oz increased the prices for these two respective species from $0.88 and $1.35 per pound to $0.92 and $1.40 per pound. These variations in size-related market price may be due to a wide range of factors, including portion size and control, differences in taste, in texture, and in visual sensory characteristics, and consumer experience and behavior.

These issues can be particularly important when seafood products are sold in ethnic markets and markets outside North America. For example, markets in Japan or Europe, because of their long tradition in seafood trade and consumption, often recognize a wide range of product attributes. Although prices may appear relatively high for many seafood products sold in these markets, these higher prices reflect not only a unique cultural taste for selected items, but also a refined appreciation for product attributes. Many of the seafood products exported from the United States bring higher prices in foreign markets. For example, giant bluefin tuna *Thunnus thynnus* commands a substantially higher ex-vessel price per pound from Japanese buyers later in the season, when the oil content of the fish has increased, than earlier in the season (from $4/lb in spring up to $20/lb in autumn; UBP 1989). Sablefish *Anoplopoma fimbria* that are 2 kg or larger are priced 20–50% higher than smaller sablefish because of changes in sensory attributes (Seafood International 1990). Also, variation in oil content and flesh color between salmon species and among races of the same salmon species may greatly affect market price (Anderson 1988).

Role of Economic Analysis

By providing insight on the importance of supply-and-demand factors such as quantity of production, prices of substitute products, costs of fishing, personal income, and foreign exchange rates, economic analysis can help fisheries analysts understand how policies affect market price. Harvest regulations may have substantial economic consequences when changes in harvest levels affect not only the level of revenue but also ex-vessel product price (i.e., when the industry faces a downward-sloping demand curve). In fact this economic consideration may have occasionally prompted U.S. fisheries management councils to establish optimum yields lower than maximum sustainable yields (e.g., see NPFMC's 1981 management plan for the spider crab *Chionoecetes opilio*).

Because of the aggregate nature of most fisheries data, however, traditional economic analysis can sometimes mask important but less obvious market information. Variation in prices and quantities due to variation in product attributes may be obscured by using data that had been aggregated across space or time. Quantitative investigation implicitly based on standard commodity analysis may be incorrectly specified, and the results consequently biased. Using analysis founded only on historical trends may mislead analysts regarding future opportunities. And in imperfectly competitive markets, using data only from sectors of the fishing industry (e.g., ex-vessel level) rather than from processing or wholesale levels may result in incomplete and short-sighted analysis of market and welfare impacts related to regulatory policy.

Recognizing the importance of market information is a first step in developing more informed perspectives on fisheries management issues. However, in order to understand how this information can relate to regulatory issues, market information must be integrated with other fundamental aspects of the fisheries policy problem. Unfortunately, although enabling legislation such as the Magnuson Fishery Conservation and Management Act (MFCMA; U.S. Congress 1976) stipulates comprehensive socioeconomic policy analysis, such legislation is generally vague in describing how this information should be developed and measured (Jacobson et al. 1985). The result is that economic analysis is usually underfunded, ad hoc, and crisis driven. Policy makers and other participants in the policy process are rarely provided the opportunity to carefully consider the implications of their decisions in terms of forgone social opportunities. One consequence in the case of MFCMA, for example, is that policy behavior and policy decisions may reflect narrow political considerations rather than the MFCMA's legislative intent of improving overall national benefits (Fricke 1985).

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Multiobjective Approach to Policy Modeling

The powerful desktop computers and efficient solution algorithms that have been developed are effective tools with which fishery analysts can evaluate fisheries policy issues. With the appropriate modeling scheme and data, these tools can be used to integrate market information with other components of the policy problem to more effectively evaluate policy issues in a form consistent with legislative mandates.

Various operational techniques have been developed for generating comprehensive economic information for natural resource-based problems, including multiple-objective programming (Cohen and Marks 1975), goal programming (Willis and Perlack 1980), adaptive learning (Rausser 1978), and multilevel programming (Candler et al. 1981). Although a detailed description of these techniques is beyond the scope of this discussion, academic fisheries analysts have attempted to develop operational programming techniques for generating comprehensive socioeconomic policy information for fisheries management. Many of these approaches are summarized in Healey (1984) and Charles (1988). Various approaches have been used, including static and dynamic, single versus multiple objective, and passive versus active learning, but approaches based on multiple objectives have received the most recent attention. For example, a multiple-objective goal-programming model was developed by Drynan and Sandiford (1985) for Scottish nearshore fishing fleets, and dynamic multiobjective programming has been used by Charles (1989) and Diaz-de Leon and Seijo (1992). The most widely used multiobjective approach has been multiattribute utility analysis (MUA; Keeney and Raiffa 1976; Edwards and Newman 1982). This technique has been applied to a number of fisheries, including the New England fishery for Atlantic herring *Clupea harengus* (Healey 1984, 1985), and Skeena River salmon fishery (Hilborn and Walters 1977; Keeney 1977; Healey 1984), the Oregon coho salmon fishery (Walker et al. 1983), and a Canadian invertebrate commercial fishery (Boutillier et al. 1988).

Although the operational techniques related to the different multiple-objective approaches vary, the general modeling strategies fall into two classes: (1) those strategies designed to ultimately identify a single policy optimum, and (2) those strategies designed primarily to delineate the implications of various policy options. Techniques included within the first class are most appropriate when the policy process is relatively well ordered, involves only a few decision makers, and is short term in nature. Techniques of this class, such as MUA, use multiple-objective analysis to identify the short-run utility functions of the policy makers through the use of strategic questionnaires and then to integrate the functions with other elements of the policy problem. By this process, a single or narrow range of potentially optimal policy solutions is determined.

In contrast, approaches characterized within the second class are more useful when the policy process is disorderly, when it involves many policy participants, and when it is characterized by extensive bargaining. Operational methods included under this approach are not designed to directly determine a single optimal policy choice, but rather to reveal the implications of policy options. Information is developed for helping decision makers and agency administrators explore the policy problem, structure the policy debate, and aid policy participants in developing informed and balanced perspectives. The information can be used to help bargaining agents determine how they can best achieve their objectives given potential agreements, and to determine which policy options would involve the least-costly trade-offs (Dorcey 1986).

Description of the Numerical Policy Problem

In the examples that follow, serial optimizations were performed in a single- or multiple-objective dynamic policy framework consistent with the second class of the policy strategies summarized above. Optimizations were designed to illustrate the importance of market information and regulatory policy, and the relationship of regulatory instruments and social benefits. Although simulated data were used, these examples address many of the issues and relationships that characterize contemporary fisheries policy problems in the United States.

The hypothetical policy problem is characterized by the following set of assumptions (definitions of parameters and variables are explained in Table 1 and the model structure and functional equations are presented in Table 2).

(1) The fishery is regional and comprises only two year-classes—immature age-1 fish (X_1) and sexually mature age-2 fish (X_2). Initially, the stock is unexploited and is at maximum carrying capacity. Biological growth and reproduction functions are derived from the logistic growth equation

TABLE 1.—Variables and parameters in the hypothetical policy problem modeled.

Symbol	Definition	Value
	Parameters	
a	Proportion of age-2 fish as gametes	0.10
c	Cost per unit effort per vessel ($, millions)	0.001
d	Social discount rate	0.05
f	Annualized fixed cost per vessel ($, millions)	0.20
k_1	Carrying capacity of age-1 fish	20.00
k_2	Carrying capacity of age-2 fish	40.00
l	Crew's (including captain's) proportion of revenues	0.40
p_1	Price of age-1 fish ($/unit weight)	$4 \le p_1 \le 8$
p_2	Price of age-2 fish ($/unit weight)	$4 \le p_2 \le 8$
q_2	Catchability constant for age-2 fish	0.0001
r_1	Intrinsic growth rate age-1 fish	5.00
r_2	Intrinsic growth rate age-2 fish	2.00
s	Number of crew members per vessel (including captain)	6.00
t	Time period (year)	$0 \le t \le 17$
v	Relative value on fisheries jobs (direct)	$0 \le v \le 1$
z	Relative value on fisheries profit	$0 \le z \le 1$
	Variables	
β	Multiobjective "benefit" function	$0 \le \beta \le \infty$
E	Allowable effort (trawl periods per vessel)	$0 \le E \le 200$
L	Total direct employment in the fishery	
N	Number of vessels allowed in the fisheries	$0 \le N \le \infty$
$Q_{1,t}$	Catchability factor for age-1 fish at year t	$0 \le Q_{1,t} \le 0.0001$
$X_{1,t}$	Stock of age-1 fish at year t	$7.5 \le X_{1,t} \le 20$
$X_{2,t}$	Stock of age-2 fish at year t	$15 \le X_{2,t} \le 40$
$Y_{1,t}$	Yield of age-1 fish at year t	$Y_{1,t} \ge 0$
$Y_{2,t}$	Yield of age-2 fish at year t	$Y_{2,t} \ge 0$
π_t	Profit per vessel per year	$\pi_t > 0$
	Other constraints and conditions	
$\frac{l \cdot (p_1 Y_{1,t} + p_2 Y_{2,t})}{s}$	Average share per crew member (including captain's share) ($, millions)	≥ 0.0292
$X_{1,1}$	Initial stock of age-1 fish	20.00
$X_{1,20}$	Equilibrium stock of age-1 fish	$X_{1,20} \ge 7.5$
$X_{2,1}$	Initial stock of age-2 fish	40.00
$X_{2,20}$	Equilibrium stock of age-2 fish	$X_{2,20} \ge 15.0$
$v + z$	Sum of relative weights on benefits	1.00

and are represented by equations (1) and (2) in Table 2.

(2) Depending on the optimization, price and demand for each year-class may be a function of quantity, product size, or product quality.

(3) The fishing fleet is composed of N homogenous vessels which target only this particular species. Effort (E) is measured as a trawling-day (cruising, searching, and postcapture handling time are assumed to be inconsequential). Catch of each year-class ($Y_{1,t}$, $Y_{2,t}$) for each vessel is determined by effort (E), catchability factors ($Q_{1,t}$, q_2), and stock sizes, as summarized in equations (3) and (4) in Table 2. The catchability factor for age-1 fish is inversely proportional to mesh size; therefore, if the mesh size is set relatively large, the catchability factor can be effectively reduced to zero. The capture of age-2 fish is assumed to remain unaffected by the selection of mesh size.

(4) Each vessel has a captain and five crew members. Given an assumed low opportunity cost of capital, each vessel remains in the fleet unless the annual profit becomes negative. Opportunity costs of labor are assumed to be relatively low.

(5) Three traditional policy instruments are available for controlling the fishery: controls on mesh size (affecting the catchability of age-1 fish ($Q_{1,t}$), limits on vessel participation in the fishery (N), and limits on trips per vessel per year (E). Reduction in stock of each year-class, unless otherwise indicated, is restricted to an arbitrary level ($X_{1,t} \ge 7.5$, $X_{2,t} \ge 15.0$) selected to represent, for example, a minimum stock size that ensures the future reproductive success of the fishery. Policy controls on effort (E) and vessels (N), once selected, remain fixed across time.

(6) It is assumed that policy makers usually are concerned with various goals (national, regional,

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TABLE 2.—Structural equations and the benefit function used in policy modeling. See Table 1 for definitions of terms.

Type		Function	
Stock dynamics		$X_{1,t} = a\cdot(X_{2,t-1} - N_{t-1}Y_{2,t-1}) + \frac{r_1 a\cdot\{(X_{2,t-1} - N_{t-1}Y_{2,t-1})\cdot[1 - (aX_{2,t-1} - N_{t-1}Y_{2,t-1})]\}}{k_1}$	(1)
		$X_{2,t} = X_{1,t-1} - N_{t-1}Y_{1,t-1} + \frac{r_2\cdot\{(X_{1,t-1} - N_{t-1}Y_{l,t-1})\cdot[1 - (X_{1,t-1} - N_{t-1}Y_{1,t-1})]\}}{k_2}$	(2)
Yield equation		$Y_{1,t} = Q_{1,t}\cdot E_t\cdot X_{1,t}$	(3)
		$Y_{2,t} = q_2\cdot E_t X_{2,t}$	(4)
Profit equation		$\pi_t = (p_1 Y_{1,t} + p_2 Y_{2,t})(1 - l) - f - cE$	(5)
Benefit function[a]	Maximize:	$\beta = \sum_{t-1}^{T-20} \frac{1}{(1 + d)^t}\cdot N_t\cdot[vL + z\pi_t]$	(6)

[a] Subject to functions (1)–(5) and values, constraints, and conditions summarized in Table 1.

or both), including profits, jobs, income, stability, and conservation; but for this problem the issues focus on social efficiency, which is represented by industry profits or rents (domestic consumer surplus is zero because there is no domestic demand), and direct employment in the fishery. Because the fishery may be only part-time, employment is measured as the number of individuals that can be employed in the fleet at a minimum crew's share of $25,000 and a minimum captain's share of $50,000.

Given these characteristics of the fishery, the policy problem is to select the combination of available policy instruments that will maximize social "benefits" through time. Because, in general, social benefit functions are only hypothetical constructs and cannot in fact be estimated for any large or complex society, no single optimal combination of policy instruments can readily be calculated. Rather, by maximizing an arbitrary multiobjective "benefit" function, socioeconomic policy information can be generated by systematically changing the relative importance, or relative weights, placed on social goals (parameterizing) and then repetitively resolving the objective function (function 6 in Table 2).

The benefit function maximizes the net present value of any weighted combination of social goals (in this case, profits and employment) under the conditions of an arbitrary discount rate (here, 5%), an arbitrary time horizon (here, 20 years), and relative goal weights. Given conditions and constraints, the nonlinear algorithm (GAMS/MINOS: Brooke et al. 1988) solves the policy problem by selecting the combination of policy instruments over time that maximize the multiobjective benefit function.

Results of the Optimization Examples

Optimization Set 1: Maximizing Efficiency under Alternative Market Scenarios

In the first series of optimizations, the traditional objective of social efficiency (profit) was maximized for four different market scenarios by repetitively solving benefit function (6) (in Table 2) for the case where relative weight of efficiency (profits) is set at a value of unity and that of employment is set at zero ($z = 1$, $u = 0$). Given the conditions and constraints of the problem, the solutions provide information on the relative sensitivity of policy goals and policy instruments under different market conditions.

Table 3 and Figure 1 summarize the results from this set of optimizations. The combination of optimal policy instruments shows considerable variation over the range of market scenarios, ranging from 8.3 vessels when younger fish are priced twice as high as older fish, to 18.5 vessels when the price levels are reversed. Mesh size (the inverse of catchability ($Q_{1,t}$) is selected to be relatively small through time if per-unit prices of younger fish are relatively high, but is larger if prices of smaller fish are equal or less than prices of older fish. The level of effort remains at the allowable maximum level across all four scenarios.

Fleet profit also shows high variation over the four scenarios. The highest profit occurs when the older fish (which constitute a greater biomass) are priced higher than smaller and younger fish. The

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TABLE 3.—Results from optimizing industry rents (profits) under four different market scenarios. Harvest is given in thousands of metric tons, profits and revenues are denoted in millions of dollars, prices represent dollars per unit weight, and employment includes captain and crew. DPV = discounted present value; see Table 1 for definitions of other terms.

Policy variables	Scenario 1: $p_1 = p_2 = 5.6$	Scenario 2: $p_1 = 8$; $p_2 = 4$	Scenario 3: $p_1 = 4$; $p_2 = 8$	Scenario 4: $p_1 = p_2 = [8 - 0.4(Y_1 + Y_2)]$
Vessels (N)	17.6	8.3	18.5	10.1
Effort (E)	200.0	200.0	200.0	200.0
Mesh size effectiveness ($Q_{1,t}$)	t = 1: 0.00005 t = 2–20: 0.00000	t = 1–20: 0.00015	t = 1–20: 0.00000	t = 1–20: 0.00004
DPV fleet profit	283.6	228.0	439.0	206.9
DPV vessel profit	16.1	27.5	23.8	20.5
DPV fleet revenue	608.33	444.2	874.74	422.5
DPV fleet harvest	108.63	78.0	109.3	83.9
Fleet harvest	174.2	123.8	174.5	139.6
DPV fleet employment	1,220.9	577.8	1,286.3	698.6
Yearly employment	105.6	49.8	111.0	60.3
Market prices for year t	t = 1–20: p_1 = 5.6 p_2 = 5.6	t = 1–20: p_1 = 8.0 p_2 = 4.0	t = 1–20: p_1 = 4.0 p_2 = 8.0	t = 1: $p_1 = p_2$ = 4.1 t = 5: $p_1 = p_2$ = 5.0 t = 20: $p_1 = p_2$ = 5.5

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smallest profit occurs for the case where demand is finite (scenario 4); even though the price per unit weight approaches $8 for very small harvests, it drops relatively rapidly as supplies become greater, and over the 20-year time horizon it never exceeds $5.5.

Figure 1 shows the changes in stocks and yields for each year-class under the different scenarios. Because of the high initial level of stock and the positive discount rate, harvests and stocks start out at high levels but decrease and approach equilibrium by year 20. For the case where younger fish have a value twice as high as that of older fish, harvests of younger fish are relatively large but so are stock levels because of the lower harvest rates on the older, sexually mature fish. The opposite is generally the case when prices are equal or higher than for older fish. Except for the scenario in which there is finite demand, the total stock levels for both year-classes are similar in long-run equilibrium across the three scenarios. The stock level in long-run equilibrium is more than 10,000 metric tons higher in the case of finite demand than in the other scenarios, even though total equilibrium yield is relatively high. The stock level remains relatively high in this scenario because effort is distributed across both age-classes and harvests tend to be small in early years to maintain a relatively high price.

One additional comparison is that of the case where market price per unit weight equals $5.6 for both age-classes versus the case where prices per unit weight are $8 for younger and $4 for older fish. The price of $5.6 is, in fact, equal to the mean price calculated for harvests at maximum sustainable yield under the disaggregated pricing scenario of $8 for younger and $4 for older fish. Although fishing effort remains unchanged when the mean price is used, over twice as many vessels are allowed in the fishery and the mesh size is increased after year 1 to its maximum level (Table 3). Stocks and yields of age-2 fish are relatively higher over time when the mean price rather than the disaggregated price is used (Figure 1). Also, even though the yield of age-1 fish becomes zero after year 1 in the case when the mean price is used, the total long-run equilibrium stock of age-1 and age-2 fish is still somewhat higher than when disaggregated prices are used.

Optimization Set 2: Policy Frontiers

The second set of optimizations illustrates how multiobjective methods may be used to generate socioeconomic policy information when selection of regulatory instruments indirectly affects product quality, product attributes, and market price. The problem was adjusted in three ways to accommodate this analysis: (1) the objective of employment was included in the analysis (i.e., $z, v \geq 0$; $z + v = 1$); (2) the objective of biological stock conservation was also added by establishing different constraints on minimum stock biomass (30,000, 40,000, or 50,000 metric tons); and (3) shorter fishing seasons (E) were assumed to result in lower product quality or fewer marketing opportunities (or both), thereby leading to lower ex-

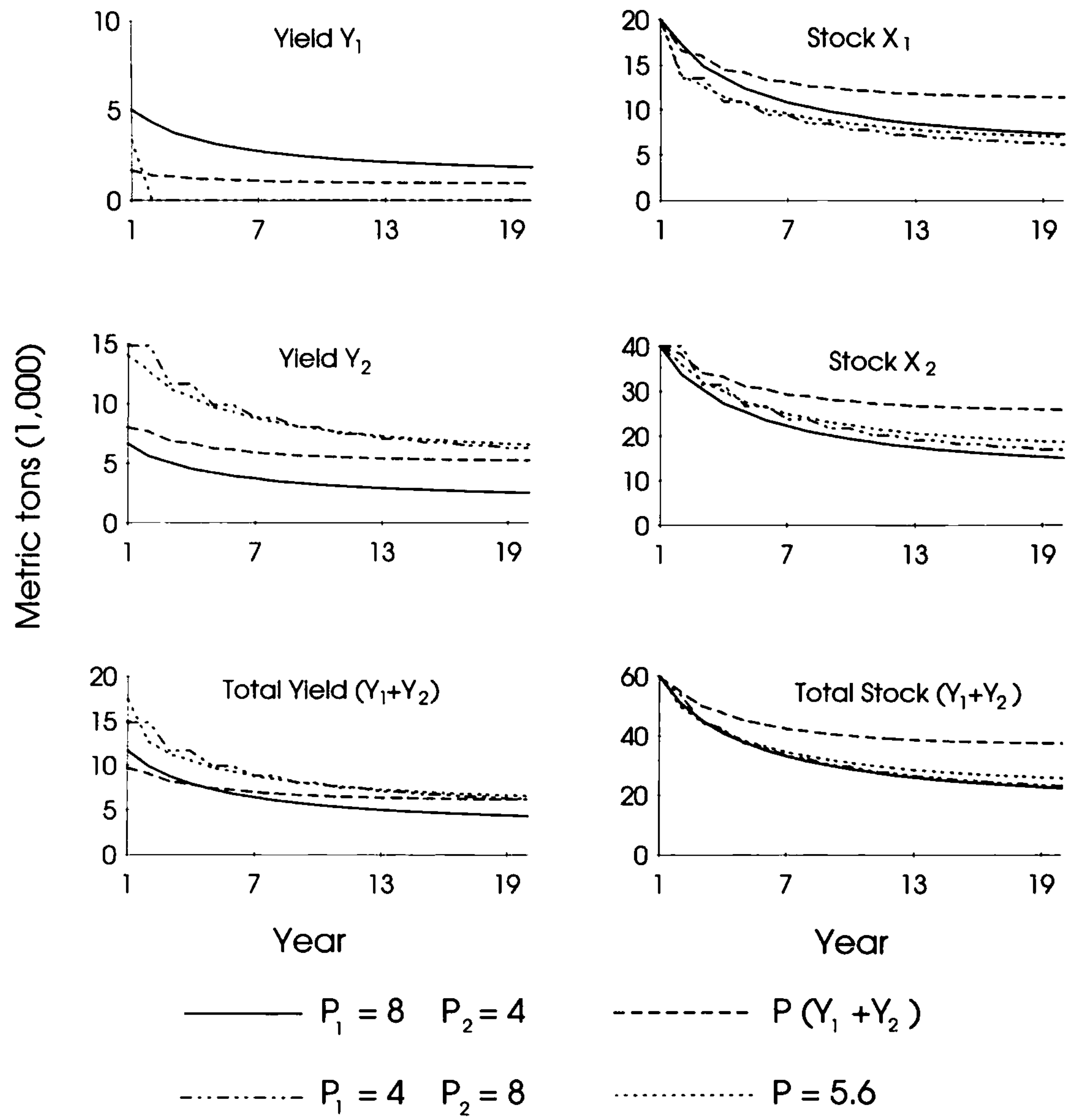

FIGURE 1.—Optimal stocks and yields when industry profits are maximized under different market scenarios (scenarios 1–4 in Table 3).

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vessel prices as represented by the following equations:

$$p_{1,t} = 8 - [0.0216 \cdot (200 - E)], \text{ and}$$

$$p_{2,t} = 4 - [0.0108 \cdot (200 - E)].$$

To generate socioeconomic and biological policy information, the multiobjective benefit function was repetitively solved with varied relative weights on the two policy objectives (profits and employment) at each of the three levels of minimum stock biomass. The results are summarized in Table 4. Rows 1 and 2 show the results when market price is not affected by season length for the case where either employment or profits are valued at unity. Whether the market price is independent of or dependent upon effort makes no different in the cases where profits are maximized, because the level of effort remains unaffected (row 1 compared with row 3). However, in the case of

TABLE 4.—Policy variables calculated by maximizing a multiobjective policy function for different biological stock constraints when output market prices are a function of season length (except in rows 1 and 2). Harvests and stocks are given in thousands of metric tons, profits and revenue are denoted in millions of dollars, prices represent dollars per unit weight, and employment includes captain and crew. See Table 1 for definitions of terms.

	Relative weight assigned to:		Policy instrument			Stock		Yield		Price		Policy goals		
												Annual fleet employment	Capitalized value	
Row	v	z	N	E	$Q_{1,20}$	$X_{1,20}$	$X_{2,20}$	$Y_{1,20}$	$Y_{2,20}$	p_1	p_2		Fleet employment	Fleet profit
					Stock constraint: $X_1 + X_2 \geq$ 30,000 metric tons									
1[a]	0.000	1.000	8.0	200.0	0.000160	9.60	20.50	1.800	3.30	8.0	4.0	40.0	52.2	223.9
2[a]	1.000	0.000	79.5	15.0	0.000150	11.80	24.40	2.100	2.90	8.0	4.0	477.0	5,523.7	39.8
3	0.000	1.000	8.0	200.0	0.000116	9.55	20.45	1.780	3.28	8.0	4.0	48.0	557.2	223.9
4	0.032	0.968	10.2	200.0	0.000069	9.22	20.78	1.300	4.20	8.0	4.0	60.9	705.5	221.0
5	0.063	0.937	39.6	79.6	0.000000	8.30	21.70	0.000	6.83	5.4	2.7	237.0	2,749.7	57.8
6	0.125	0.875	40.3	76.2	0.000000	8.70	22.70	0.000	6.96	5.3	2.7	241.6	2,798.1	52.5
7	1.000	0.000	41.2	70.3	0.000000	9.75	24.70	0.000	7.14	5.2	2.6	247.0	2,862.3	27.6
					Stock constraint: $X_1 + X_2 \geq$ 40,000 metric tons									
8	0.000	1.000	7.4	200.0	0.000077	12.64	27.40	1.420	4.02	8.0	4.0	44.0	510.9	204.5
9	0.032	0.968	9.0	200.0	0.000043	12.30	27.70	0.947	4.97	8.0	4.0	53.9	624.5	202.0
10	0.063	0.937	39.3	61.5	0.000000	11.70	28.30	0.000	6.84	5.0	2.5	236.0	2,731.5	36.5
11	0.125	0.875	39.4	61.3	0.000000	11.70	28.30	0.006	6.80	5.0	2.5	236.4	2,737.6	35.8
12	1.000	0.000	40.0	61.5	0.000000	11.70	28.30	0.000	6.90	4.4	2.2	239.0	2,767.4	16.2
					Stock constraint: $X_1 + X_2 \geq$ 50,000 metric tons									
13	0.000	1.000	4.4	200.0	0.000074	16.10	33.90	1.100	3.00	8.0	4.0	26.6	308.3	143.6
14	0.032	0.968	5.5	200.0	0.000040	15.90	34.10	0.690	3.70	8.0	4.0	32.7	379.9	142.0
15	0.063	0.937	28.8	50.7	0.000000	15.50	34.50	0.000	5.00	4.9	2.4	172.7	2,000.1	17.6
16	0.125	0.875	28.8	50.7	0.000000	15.50	34.50	0.000	5.00	4.9	2.4	172.7	2,000.1	17.6
17	1.000	0.000	29.0	32.4	0.000064	16.10	33.90	0.973	3.20	4.4	2.2	174.0	2,015.0	3.9

[a] Market price is independent of effort.

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maximizing employment, the policy controls and objectives are heavily impacted by the reductions in product quality and price as a function of season length (row 2 compared with row 7): employment and profits are cut by half and the season length is extended by over 60 d. In addition, the total stock is conserved at relatively higher levels in the case where employment is maximized and price is not a function of season length. This higher level of conservation is due to the large number of vessels, their high aggregate fixed costs, and the need to reduce variable costs (which are a function of stock size) while maintaining some positive level of profit in the fishery.

At any of the three biomass constraint levels, as employment is considered increasingly more valuable than profit, more vessels are allowed into the fishery, season length is reduced, prices decrease, and harvests of age-2 fish tend to increase (rows 3–17 in Table 4). As the size of the minimum spawning stock biomass increases for any given set of weights on employment and profit, the fishery is generally characterized by fewer vessels, less effort, lower catchability (larger mesh size), smaller yields, and lower prices. As the constraint in increased from 30,000 to 50,000 metric tons, employment and profit decrease substantially for all solutions.

The type of information summarized in Table 4 can also be used to generate three types of policy frontiers: dynamic, equilibrium, and capitalized (Figures 2, 3). Figure 2 illustrates the intertemporal or dynamic frontiers and pathways generated by solving the set of policy problems for a minimum spawning biomass of 30,000 metric tons (rows 3–7 in Table 4). The unbroken, kinked surfaces trace out the dynamic and equilibrium policy frontiers by linking together the combinations of employment and profit generated by optimizing the weighted multiobjective function. Points along each frontier, besides those levels of employment and profit generated by solutions, demonstrate "approximate" levels of employment and profit that would be generated by solving the benefit function for other relative weights on profit and employment objectives. The five broken lines, or time paths, show the changes over time for each policy goal for each set of relative weights on social

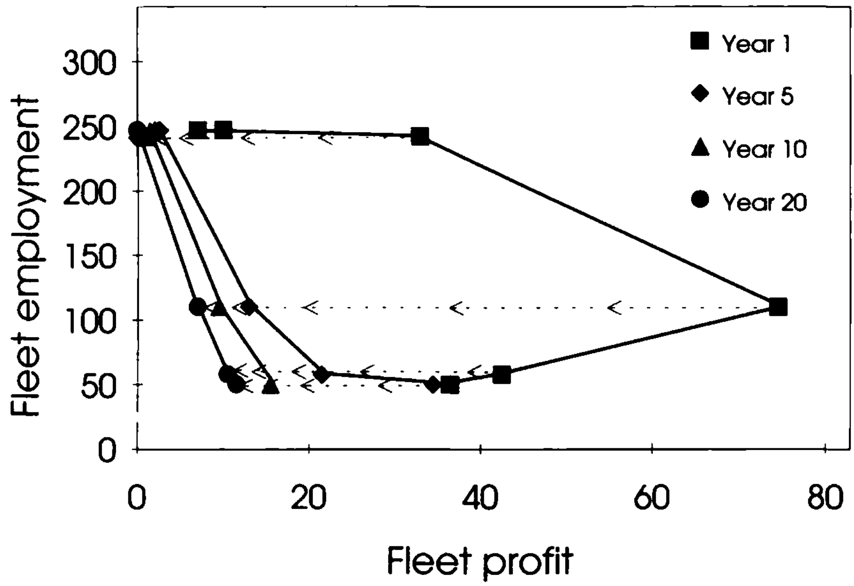

FIGURE 2.—Dynamic and equilibrium policy frontiers for the constraints noted in rows 3–7 of Table 4.

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goals. Changing any of the characteristics of the policy problem, including constraints, price or cost data, or policy instrument choice set, would change the position and shape of both the frontiers and the intertemporal policy pathways.

Figure 3 illustrates the capitalized policy frontiers, given the policy solutions summarized in Table 4. The capitalized frontiers describe the relationship of the total discounted levels of employment and profit summed across time for each set of relative goal values for each minimum spawning biomass. Associated with each point along the frontier is a unique regulatory policy strategy, and in the case of mesh size, a dynamic policy strategy.

The shape and position of the three policy isoclines in Figure 3 may be compared in order to understand the relative sensitivity of the alternative policy goals to the constraint on stock size. A comparison of the isoclines shows that profit is relatively more sensitive to stock conservation than the employment goal. For both social goals, increasing the stock constraint from 30,000 to 40,000 metric tons results in only a small relative change in employment and profit. However, moving from 40,000 to 50,000 metric tons has relatively severe effects on profit and relatively moderate effects on employment. For example, when profit is weighted relatively high, both profit and employment are reduced by approximately 30%; conversely, for the case where employment is weighted relatively high, employment is still reduced by approximately 30%, but profits are reduced 86%.

The capitalized frontiers represents the combination of the highest social goals that could be realized for any combination of weights v and z given the constraint on biomass. For any given constraint on biomass, an interior position (i.e., a point located within rather than on a frontier boundary) would represent not only an inferior set of realized policy goals, but also an inferior set of associated regulatory policy instruments. As for the case of dynamic frontiers, solving the policy problem for additional goal values would increase the number of vertices, and an infinite set of solutions for alternative goal values would generate a smooth concave frontier.

The relationships between employment and profit as represented by the capitalized frontier could also be summarized in the form of a regression equation:

$$\text{employment} = 2{,}913.8 - 0.046\cdot(\text{profit})^2;$$

SEs of the regression parameters are 34.05 and 0.006, respectively, and adjusted $r^2 = 0.99$.

The regression demonstrates the nonlinear relationship of employment and profit. At relatively low levels of employment, (i.e., where z values are relatively high), regulatory controls may be used to increase employment without a large sacrifice in profits. However, as employment levels increase (i.e., as v becomes large relative to z), it takes

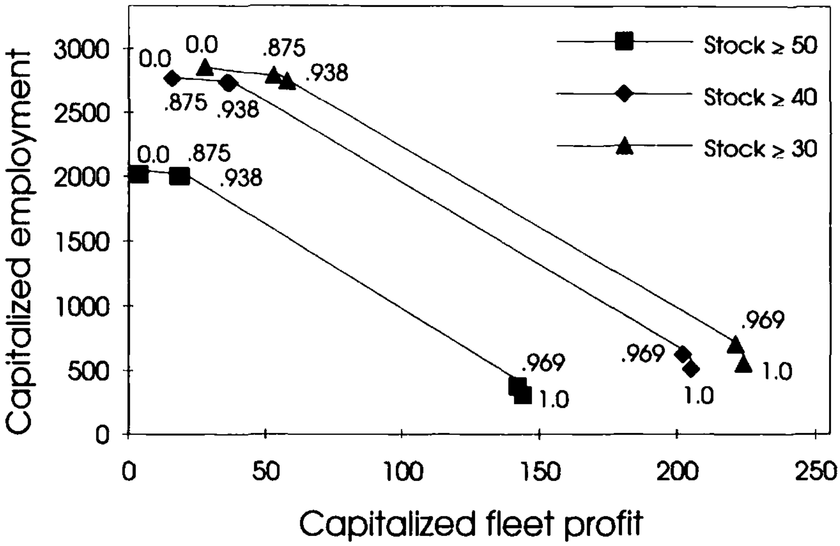

FIGURE 3.—Capitalized policy frontiers for three minimum stock constraints, given the policy solutions summarized in Table 4. The number by each point is the relative weight assigned to the profit objective. Stock levels are given in thousands of metric tons.

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increasingly larger sacrifices in profit to employ individuals in the fishery. This can be demonstrated by taking the partial derivative of the regression equation with respect to profits:

$$(\partial\text{employment})/(\partial\text{profit}) = -0.092\cdot\text{profit}.$$

For any given level of capitalized profits, the derivative demonstrates the marginal relative sacrifice in capitalized employment necessary to gain one unit of capitalized profits. It describes the instantaneous change in employment (i.e., the slope of the capitalized frontier for any possible profit level), and is characterized by the unique set of relative social values (i.e., v and z) and policy instruments that generated this particular level of employment and profit. For example, at a profit level of $57.8 million, the instantaneous change in capitalized employment with respect to capitalized profits is 5.32, which implies that 188,000 capitalized dollars of profit must be sacrificed in order to gain one additional capitalized job. It remains for the policy-making process to determine whether such a trade-off is in the regional or national interest.

Discussion

This paper emphasizes three important and interrelated issues: (1) the potential role of market information in fisheries management; (2) the degree to which alternative regulatory controls affect levels of social benefits; and (3) the value of comprehensive models for developing information critical for the fisheries policy process.

The numerical approach illustrates the ways in which formal models may be used to structure policy problems and explore policy issues. The two sets of optimizations demonstrate how systematic analysis can help managers determine the "sensitivity" of policy solutions to changes in the policy problem. The analysis shows the potential value of moving away from standard commodity analysis by illustrating the relationships between market demand, product attributes, and management decisions. The analysis also illustrates that social objectives are often not complementary, and therefore, it may be difficult to determine a single level of optimal product quality characteristics for a publicly managed resource. However, what remains possible is to configure trade-offs in a form consistent with the needs of a pluralistic management process.

As with any analytical technique, however, the dynamic multiobjective model is not without limitations. Multiobjective models generate large quantities of economic information but also require a relatively large number of inputs. Risk and uncertainty, which characterize most fisheries policy problems, add additional complexity, as does the forecasting of future stocks, technology, and market prices. However, if risk does not affect all solutions to the same degree, then one advantage of using multiobjective techniques is that it is pos-

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sible to generate confidence bounds, which vary depending on policy instruments and objectives. In addition, the structure of multiobjective models is consistent with the need to conduct comprehensive sensitivity analysis. Given limited budgets and alternative information needs, multiobjective techniques can help analysts determine which types of information should be improved and how research budgets should be allocated.

Finally, as with other policy tools, benefits must be compared to costs when formal policy models are being developed. Analysts must decide when the benefits of additional complexity are outweighed by the costs. In making this assessment, however, the benefits of the type of approach discussed in this paper may extend beyond that of providing comprehensive economic-policy information. The model is an interdisciplinary framework that can help policy makers understand the fisheries policy problem and can generate information useful for guiding and constraining the public policy process. By incorporating and emphasizing factors such as market information, this approach can broaden the policy focus to encompass more than the effects on biological stocks and yields in order to address issues of human welfare as well. Broadening this focus can thus accelerate the evolution of the fisheries policy process toward a policy structure more congruous both with the operation of dynamic markets and with the behavior of those who directly and indirectly benefit from using the resource. The result should be a policy process more consistent with the goals of improving regional and national benefits.

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