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A Tale of Two Clams: Policy Anticipation and Industry Productivity

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Keywords: Fisheries, resource regulation, productivity, property rights

JEL Classification: L1, L5, L2, Q2

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**A TALE OF TWO CLAMS:
POLICY ANTICIPATION AND INDUSTRY PRODUCTIVITY^{*}**

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Abstract

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I. Introduction

The challenge of environmental economics is to achieve both biological conservation and economic efficiency. As a result, the relationship between regulation and productivity is of central importance to the field. Two of the leading forms of environmental regulation are command-and-control (limitations on inputs such as capital or effort) and tradable property rights systems. The economic literature establishes that, under general assumptions, a given environmental standard can be met at a lower cost under tradable property rights than under command-and-control.¹ However, this has not translated into general acceptance of tradable property rights in public policy.

Fisheries management in particular is an area where competing regulatory approaches have led to volatile policy debates and economic inefficiencies. The current national fisheries legislation, the Magnuson-Stevens Act of 1996, establishes biological conservation as the primary goal and economic efficiency the secondary goal of fisheries management.² This raises the following economic question: what regulatory tool maximizes economic efficiency, given the biologically determined total allowable harvest? In fisheries, traditional command-and-control has generally led to tremendous overcapitalization,³ while tradable property rights should theoretically limit the number of fishermen and result in optimal harvesting capacity.⁴

Therefore, one measure of comparison is productivity under the competing policy approaches.

A great deal of empirical work has focused on comparing productivity across different regulatory approaches and regulatory changes. This research generally treats policy change as an exogenous shock, ignoring the ability of firms to change their behavior during the transition period. However, it is possible that expectations of policy change have a significant impact on productivity – prior to the actual implementation of a new regulatory policy. If firms do in fact

adjust their behavior during the transition period, then any analysis of productivity must separate the effects of behavioral shifts before and after policy change.

This paper calculates productivity over three policy eras: command-and-control, transition (command-and-control regulation concurrent with negotiations over tradable property rights), and tradable property rights. Productivity is calculated for both the Mid-Atlantic surf clam and ocean quahog fisheries in order to demonstrate the impact of firms' expectations on industry productivity (as expectations differed in the two fisheries). The results show that firms that anticipate implementation of property rights will change their behavior during the transition period, with measurable effects on overall productivity. In the surf clam fishery, while the new property rights regime was being negotiated, firms raced to maximize their production, thus depressing productivity; in the quahog fishery, by contrast, tradable property rights were implemented without negotiation, and with no prior change in firm behavior.

II. Regulatory Approaches and Measuring Productivity

A. Regulatory Debates in Renewable Resources: Mid-Atlantic Clam Fisheries

Fisheries regulation has long been a flashpoint in the controversy between command-and-control regulation and tradable property rights. The need for fisheries regulation of some sort is well established. Open-access fisheries are often cited as one of the classic examples of market failure due to externalities: in the absence of property rights, the individual fisherman does not take into consideration the effect of his harvest on the total available stock, resulting in endemic overfishing.

In order to limit excessive exploitation, federal fisheries have historically been regulated through command-and-control policies: limits on the number of hours that fishing is allowed,

the type of gear allowed, and other inputs. Evaluation of command-and-control in fisheries has shown serious economic inefficiencies, safety hazards, and detriments to the ecosystem (National Research Council, 1999). In addition to these economic inefficiencies and safety concerns, these policies have generally also failed in their primary goal of protecting marine resources (National Marine Fishery Service, 1996; National Research Council, 1999; Gauvin et al. 1995). This evidence has provoked interest in the use of tradable property rights – known in fisheries as individual transferable quotas, or ITQs – to regulate marine resources.

The Mid-Atlantic surf clam and ocean quahog fisheries have been governed by both command-and-control and ITQs. As the first U.S. Federal marine fisheries to implement tradable property rights, they remain of central interest in assessing the relative merits of tradable property rights and command-and-control in fisheries (for a discussion see GAO, 2002). Both fisheries were subject to command-and-control regulation from 1979 through 1989 but have been governed by ITQs since 1990. While tradable property rights were implemented in both fisheries concurrently, in the years prior to implementation it was generally believed that tradable property rights would affect the surf clam fishery only.⁵ Therefore, the two fisheries provide a unique view of two industries with similar inputs and outputs but differing expectations concerning regulatory policy.

With annual production valued at over \$48 million, the Mid-Atlantic surf clam and ocean quahog fisheries provide almost the entire supply for domestic processed clam products (NMFS, 1999), including canned clam chowder, canned minced clams, canned sauces and juices, and breaded products. Both clam species grow slowly, live on the floor of the ocean, and do not move. They are clustered in groups known as beds, whose location and density are common knowledge in the industry, and harvested using hydraulic dredges. Ocean quahogs are found in

deeper waters than surf clams, thus necessitating larger vessels with more horsepower and gear appropriate to harvesting in deeper waters.

By the mid-1980s, rapid growth in harvesting capacity and its resulting inefficiencies triggered a debate over establishing tradable property rights. As with other overcapitalized fisheries, command-and-control in the surf clam fishery was progressively restrictive, ratcheting down the allowed fishing time as the season's allowable harvest was gathered in a shorter and shorter time. The time each vessel was allowed to harvest surf clams fell by 28% from 1980 to 1982 and another 88% from 1983 to 1986. As **Table 1** shows, the average annual quota and harvests of surf clams and ocean quahogs increased slightly between 1980-84 and 1985-1989, and since 1989 have remained relatively stable. Abundance of both clam species fluctuates very little over the harvesting season.

Moving toward an ITQ system to regulate these fisheries required a means of allocating the initial property rights, or harvesting quotas. Although the economic literature prefers auctioning off initial property rights, such auctions have proved to be politically unviable in the United States as well as in other nations' fisheries. From the beginning of negotiations over a tradable property rights system for surf clams in the mid-1980s, it was clear that allocations would be granted *gratis* based on some form of historical harvest quantities.⁶ A critical aspect of the allocation mechanism was that property rights would be distributed on a *vessel* basis, not directly to *vessel owners*; thus, the property right asset was embedded in the vessel asset. Prior to the negotiation period, there were some vessels that were licensed to harvest surf clams and ocean quahogs but were not actively utilized; the expectation of a future property right created the incentive to harvest with these vessels in order to establish a historical record of harvests. As

a result, while the number of *licensed* vessels could not change due to the moratorium of 1979, the number of *active* vessels did increase during the negotiation period of 1985-1989.⁷

During the negotiation period, there were more vessels active in the surf clam fishery than in the prior period, an increase primarily due to the re-entrance of previously inactive large vessels. From 1980 to 1984, the median number of vessels in the fishery was 119; from 1985 to 1989, the median number was 138, with a peak of 144 in 1986. This movement of vessels back into the fishery was a direct consequence of the decision to distribute rights to active vessels, and increased pressure on the clam population.

The formula for distributing allocations was finalized in 1989, with initial allocations based on individual vessels' catch history, and the new property rights system was implemented in 1990. At this point, the property right was disaggregated from the vessel and could be traded as a separate asset. As predicted by economic models, there followed a significant reduction in the number of vessels in the industry, with the median number of active vessels falling to 56 in the 1990-1995 period. The remainder of this paper expands on these statistical observations to look closely at the relationship between regulation and overall industry productivity.

B. Empirical Evidence of Productivity and Regulation

The relationship between environmental regulation and productivity has motivated a wide range of empirical research. One area of active research centers on the "Porter Hypothesis," which suggests that there are opportunities where both environmental externalities can be reduced and productivity can be increased (Porter and van der Linde, 1995). Despite the large volume of work in this area, the nature of this relationship remains a contentious issue (see for example Palmer et al. (1995), Boyd and McClelland (1999)). Much of the current literature compares productivity under varying levels of severity of the environmental constraints (see

Barbera and McConnell (1990), Gollop, and Roberts (1983), Färe, et al. (1989)). Recent studies have focused on the investor-owned electricity industry (Knittel, 2002) and oil refineries (Berman and Bui, 2001).

There is also a significant body of literature comparing the productivity of privately-owned versus publicly-owned firms (see Hausman and Neufeld (1991) for an empirical analysis of electric utilities; see Nelson (1981) for a review of economic research on productivity). Some recent empirical work has focused on the change in efficiency due to restructuring and deregulation in the electric power industry (Kleit and Terrell, 2001).

In general, when evaluating the productivity impact of regulation, it is necessary to establish a baseline for comparison, because changes in environmental policy alter the incentives of economic actors (Jaffe et al. 2002). Because firms in the surf clam fishery acted in anticipation of policy change, while firms in the quahog fishery did not, the baseline must be established in the period prior to policy *negotiation* – a significant difference from other analyses that simply compare periods immediately before and after policy *implementation*. As a result, this paper differs from numerous studies of productivity and regulation (for a review of natural resource industries see Simpson, 1999) by explicitly isolating the effect of firms' policy expectations. The importance of these expectations can be clearly seen by comparing these two industries, where firms had opposite policy expectations.

Available data on the surf clam and ocean quahog fisheries makes it possible to calculate productivity over three distinct policy environments: command-and-control, transition, and tradable property rights. This three-period analysis demonstrates the crucial importance of firm expectations and their resulting strategic behavior in assessing productivity change – behavior

that would be invisible to a simple two-period analysis centered on the actual implementation of the new regulatory regime.

III. Empirical Investigation

By comparing two industries with opposite policy expectations over three distinct regulatory periods, this paper makes it possible to isolate the effect of those expectations on industry productivity. To do so, this paper uses the standard Tornqvist index approach to calculating total factor productivity.

Total factor productivity (TFP_t) - the ratio of aggregate output (Y_t) to aggregate inputs (X_t) - has a lengthy history in economics beginning with the work of Solow in 1957 and continuing with Jorgenson (1990) and Griliches (1998). In order to compare TFP over multiple years, it is natural to create a TFP index, defined as TFP in year t relative to TFP in a reference year; this index is the ratio of the production function evaluated at two different periods in time, holding the input bundle constant. The rate of change in productivity is then the logarithmic derivative of this index with respect to time (\dot{TFP}). In the natural resource context we are interested in changes relative to the change in the level of the resource (population abundance, for fisheries); thus, if the abundance of the clams (A_t) is a multiplicative factor in the production function, then we can divide through by abundance ($\hat{Y}_t = Y_t / A_t$).

Two difficulties arise in calculating this measure of productivity change: (1) creating aggregate inputs and outputs and (2) the discrete nature of the data. This paper employs the established approach of using the Tornqvist discrete approximation of the Divisia index, in which inputs are weighted by their cost shares (for input i, S_i). If there is more than one output,

then outputs are likewise weighted by their revenue shares (R_i). (In our case, each fishing trip is for one output only.) The rate of change of total factor productivity [TFP] is then:

$$(1.1) \quad \dot{TFP} = \ln \left(\frac{\hat{Y}_t}{\hat{Y}_{t-1}} \right) - \sum_{i=1}^N 0.5(S_{t,i} + S_{t-1,i}) \ln \left(\frac{X_{t,i}}{X_{t-1,i}} \right)$$

Taking antilogs of (1.1) gives:

$$(1.2) \quad \frac{TFP_t}{TFP_{t-1}} = \frac{\hat{Y}_t}{\hat{Y}_{t-1}} - \prod_{i=1}^N \left(\frac{X_{t,i}}{X_{t-1,i}} \right)^{-0.5(S_{t,i} + S_{t-1,i})}$$

The equations for rate of change in TFP (1.1) and the chain index of TFP (1.2) have several desirable properties. Diewert showed that if the technology can be represented as a homogenous translog function then the Tornqvist index is exact.⁸ The translog production function provides for great flexibility because it is a second-order approximation to any arbitrary twice-continuously-differentiable production function (Diewert, 1976). Although an individual vessel's fishing trip is likely to have a fixed-proportions technology, there is significant variation across vessels (for example, in captain experience, age of vessel, etc.). These non-conformities may be used to justify the use of a smooth function to approximate an aggregate production function (Berck et al., 1988). Additionally, it can be shown that the Tornqvist index is exact for the generalized Leontief production function (Chambers, 1988). Constructing an index is a nonparametric approach; therefore, it does not require restrictive assumptions about the functional form of production. The index number approach uses only observable data and can be used to estimate productivity change without estimating cost, production or profit functions.

Conversely, there are drawbacks to this standard measure of TFP. One criticism of the index number is that it does not allow for the decomposition of productivity change into its

components of technical change and efficiency change. However, this analysis is concerned with the effect of regulation on the sum of technical change and efficiency change. Of more consequence is the assumption that firms are profit maximizers (inputs are chosen optimally) and face competitive input and output markets. In the case of the clam industry, the variable factor inputs are fungible across alternative fisheries, making it reasonable to assume that the input market is near enough to competitive that inputs would be paid approximately their marginal products in the absence of command-and-control.

This paper calculates the Tornqvist index of productivity change in order to measure the impact of policy change – and expectations of policy change – on industry productivity.

C. Data

The data for this analysis are drawn from sixteen years of observations, from 1980 to 1995, on the Mid-Atlantic ocean quahog and surf clam fisheries. The two primary sources are: the National Marine Fishery Service (NMFS) vessel logbooks (in accordance with the Fisheries Conservation and Management Act of 1976 (Public Law 94-265) and pursuant to 16 U.S.C. 1801, which records inputs and outputs for each fishing trip for each vessel (including time at sea, time spent fishing, quantity harvested, gear type, etc); and the Mid-Atlantic Fishery Council Federal Management Plan #8 (FMP #8). In order to harvest either surf clams or ocean quahogs in federal waters, vessels must have a valid license from the National Marine Fishery Service and maintain a vessel logbook; therefore, the data used in this paper include all vessels active in the federal fisheries during this time period.

The Tornqvist index of TFP relies on measuring aggregate inputs and output. The measure of output is the harvest for each vessel class in the Economic Exclusive Zone by federally licensed vessels. Output for any given trip is the quantity of surf clams or ocean

quahogs harvested.⁹ Annual surf clam industry output is the sum of output for each vessel class weighted by the revenue share ($R^j = PY^j/PY$) for that vessel class ($Y = \sum_j R^j Y^j$, for j = class one and class two). Output prices are reported in processors' records submitted to the Mid-Atlantic Fishery Management Council in accordance with regulation of seafood processors.¹⁰

The aggregate input is a function of the quantity used and price of each input. Inputs include harvesting capital (fishing vessel), gear (supplies used during a fishing trip), fuel, and labor (fishing crew). Specific inputs are calculated as follows:

- The major form of capital is the fishing vessel, which can be used to harvest either surf clams or ocean quahogs with minimal gear change. Each vessel is registered with NMFS, at which time characteristics such as gear type, number and size of dredges, and vessel size (in gross registered tonnage, or GRT) are reported. Fishing vessels are differentiated into two size categories based on vessel weight (small = vessels less than or equal to 100 GRT; large = vessels greater than 100 GRT). The quantity of capital in each fishery is calculated by aggregating the number of vessels reporting harvests in federal logbooks each year by vessel size categories.
- Use of fuel is a function of total time spent fishing and the number of vessels in each size class as reported in FMP #8 (page 48). The price per gallon of number two diesel marine fuel is from the Energy Information Agency.
- Gear costs by vessel class per trip are approximately \$1,500 for class one and \$2,500 for class two (calculated using FMP #8). Capital service prices are assumed to be the sum of 5% of the book value of capital plus repair costs and

depreciation (Berman and Bui, 2001.) Estimates of the value of capital are from FMP #8.

- Quantity of labor used is expressed in man-hours and calculated as the number of crew members per vessel multiplied by the number of hours at sea, then aggregated over all harvesting vessels. For each vessel class, labor costs are estimated as 33% of annual gross revenue.¹¹

The aggregate input is the sum over each vessel class of the quantities of the individual inputs (vessels, gear, fuel and labor), weighted by cost shares for each vessel class and input combination.

$$S_i = \sum_{j=1}^2 \left(\sum_{l=1}^4 \frac{W_l X_{i,j,l}}{C} \right)$$

(1.3)

C = total industry cost
 W_i = cost per unit of input i

Descriptive statistics for variables used in the Tornqvist TFP index are shown below in **Table 2** through **Table 5**. **Table 2** shows the mean cost in the surf clam fishery by input and vessel size over the three periods of analysis. As would be expected, costs for larger vessels exceed those for small vessels in all time periods. The cost shares by vessel size and input for the surf clam fishery are shown in **Table 3**. The most significant change was the general decrease in the cost share for fuel after 1984, with a corresponding increase in the labor cost share. A summary of costs by input and vessel size for the ocean quahog fishery is displayed in **Table 4**. Ocean quahogs are harvested primarily by larger vessels which are able to travel to the clam beds in deeper waters. The crew's remuneration for quahogs reflects the lower price paid per unit of harvested quahog relative to surf calms. The average annual costs and cost shares for the ocean

quahog fishery, shown in **Table 5**, reflect the dominance of the larger vessels with lower labor costs relative to fuel, gear and capital costs.

IV. Results

Annual productivity over 1980-1995 is calculated for the surf clam and ocean quahog fisheries using the Tornqvist index of total factor productivity. The key issue of interest is how productivity in the two clam fisheries differs over the three relevant periods (1980-1984, 1985-1989, and 1990-1995). The results are summarized by species and policy period in **Tables 6** and **7**¹². For both species, the average productivity level decreases during the transition period (negotiation of property rights) and then increases after implementation of tradable property rights.

Comparing the indexes for the separate fisheries reveals a potential pattern of strategic behavior by forward-looking firms in the surf clam fishery. While the two fisheries had similar annual average productivity levels in the early 1980s, their paths diverged during the transition period, when a tradable property rights system was being negotiated for surf clams. During the first period (command-and-control), the average annual total factor productivity was 1.07 for the surf clam fishery and 1.02 for the ocean quahog fishery. During the transition period when industry was negotiating property rights for surf clams only, the average TFP in the surf clam industry (characterized by property rights negotiations) decreased by 5.5 percent, while the quahog fishery (with no negotiations) experienced little more than a 1 percent decline. After the implementation of tradable property rights, productivity in the surf clam fishery increased almost 9 percent, while the increase in the quahog fishery was approximately 4 percent. The depression of total factor productivity in the surf claim fishery during property rights negotiations reflects

firms' increased capital holdings as they returned previously inactive vessels to the fleet. The recovery of productivity in the surf clam fishery after the implementation of ITQs reflects the retirement of these vessels once the immediate reason for their use (establishing catch histories) no longer applied.

The changes in TFP in the two fisheries illustrate how firms adjusted the allocation of capital across the fisheries in response to changes in expected returns. Together, the surf clam and ocean quahog fisheries can be thought of as a “manmade natural” experiment (Rosenzweig and Wolpin, 2000) in which the control industry is the quahog fishery and the surf clam fishery is subjected to the “experiment” of new policy expectations. The increase in productivity under property rights (1990-95) relative to under command and control (1980-84) was similar in both fisheries (2.8% and 2.4% for surf clams and ocean quahog, respectively), reflecting long-term trends, including the shift from command-and-control to ITQs. But in the short term, differing policy expectations caused productivity to follow a markedly different path in each fishery. The implication for economic evaluations is clear. The 8.9% increase in productivity greatly overstates the gains from implementing property rights, because it is a result of the negotiation prior to the policy change.

In addition to the level of TFP, we can examine the rate of change in productivity during the alternative policy periods, as shown in **Table 8**. During command-and-control (1980-1984), the surf clam fishery had an average annual growth rate of productivity of 7.2%, while the quahog fishery achieved only a 2.4% average growth rate. In the transition period (1985-1989), the average growth rate in both fisheries fell to less than 1%; however, the change in the growth rate was greater in the surf clam fishery than in the quahog fishery. This steeper decline in productivity growth in the surf clam fishery can be attributed to the accumulation of capital to

maximize property rights allocations. The average productivity growth rate in the surf clam fishery rebounded to 9% after implementation of ITQs to compensate for this period of reduced growth (as inefficient vessels were withdrawn from use), while the average growth rate in the quahog fishery increased more modestly to 4.4%.

These annual productivity growth rates over the policy periods show a significant productivity slowdown in the surf clam fishery induced by policy expectations, while the quahog fishery, where there was no expectation of a policy change, did not experience such a slowdown. The results in Table 8 also help assess the real productivity impact of ITQs. On first glance, the 9% annual growth rate in the 1990-1995 period appears to indicate a rapid increase due to ITQs; however, some of this growth is undoubtedly due to firms' reversing the actions they took in the transition period. As a result, productivity growth after ITQs should more reasonably be compared to productivity growth during the command-and-control period prior to property rights negotiations.

V. Conclusion

Although tradable property rights enjoy a number of theoretical advantages over traditional command-and-control regulation, current policy debates question whether those advantages are achieved in practice. This paper addresses the central question of whether tradable property rights increase overall industry productivity, as predicted in theory. Rather than simply comparing productivity before and after the moment of official policy change, it looks in depth at the transitional period during which new regulations are negotiated in order to assess the impact of policy expectations and strategic behavior on industry productivity. The Mid-Atlantic surf clam and ocean quahog fisheries provide an appropriate "manmade natural"

experiment for addressing this question. Participants in the surf clam fishery expected that tradable property rights would be allocated based on vessels' historical harvests, while participants in the ocean quahog fishery had no such expectation.

The results imply that both the public negotiation of a tradable property rights system and the design of the property rights allocation scheme can depress productivity prior to actual implementation of the new system. Because firms knew that surf clam quotas were to be allocated based on vessels' recorded catch and size, the opportunity cost of keeping a vessel inactive increased during the negotiation period; as a result, additional capital flowed into this already overcapitalized fishery. The result was a significant depression of productivity and stagnation of productivity growth. In contrast, in the quahog fishery - where there was no anticipation of property rights - overall productivity trends did not change prior to the actual implementation of property rights.

This analysis has implications for both the economic analysis of environmental regulation and the actual design of that regulation. Because productivity in the surf clam fishery was temporarily depressed during the negotiation period, a simple comparison of productivity immediately before and after the official policy change (in 1990) would yield an exaggerated measure of the actual productivity gains realized. In order to accurately characterize the direction and scale of productivity change, it is necessary to minimize the "bias" caused by firms' anticipatory behavior. This can be done by identifying the period during which firms may respond to the new incentives created by expected policy change, and ensuring that the analysis establishes a baseline *prior* to this transitional period.

In addition, the results have two important implications for the design of tradable property rights systems for natural resource industries. First, if property rights are allocated to

vessels rather than directly to capital owners, capital owners can only ensure their maximum share of property rights by keeping vessels in production, regardless of whether this is economically efficient. Second, this incentive to over-invest in capital is directly affected by the weight given to harvests during the actual negotiation period; at one extreme, if allocations are based solely on harvests during this period, capital owners will have exaggerated incentives to maximize harvests at virtually any cost, without regard for efficiency or productivity in the short term. The productivity slowdown observed in the surf clam fishery could be either exacerbated or reduced through careful consideration of these policy levers.

In fisheries where negotiations over tradable property rights are ongoing, such as the Pacific sablefish and Gulf snapper fisheries, regulators should pay close attention to the impact of policy expectations on firms' strategic behavior and on industry productivity. In these fisheries in particular, the expiration of the moratorium on expanding the use of ITQs has in all likelihood already motivated firms to increase their use of capital, with a consequent reduction in productivity. To counter this inefficient behavior, regulators should seek to design allocation schemes that do not reward such inefficient and productivity-reducing behavior. And when it is time for economists to one day evaluate the impact of ITQs on these and other fisheries, they should likewise ensure that their analyses incorporate the impact of this strategic behavior, rather than accepting the distorted picture drawn by simple before-and-after comparisons. Otherwise, economics threatens to create more confusion than clarity in the ongoing debate over ITQs.

Table 1: Descriptive Statistics, 1980-1995

		Surf Clams			Ocean Quahogs		
		Harvests	Quota	Abundance	Harvests	Quota	Abundance
1980-1984	mean	2,256	2,250	129,941	3,254	3,900	410,720
	standard dev.	442.25	410.41	19,510.99	425.27	223.61	2,287.36
1985-1989	mean	2,956	3,229	157,509	4,576	5,620	399,480
	standard dev.	150.62	104.69	3,275.91	288.07	531.04	4,842.73
1990-1995	mean	2,804	2,803	141,268	4,742	5,267	380,967
	standard dev.	191.26	116.35	3,431.62	139.59	186.19	6,575.61

Note: All values in thousands of bushels

Source: MAFMC, Overview of the Surf Clam and Ocean Quahog Fisheries and Quota

Recommendations for 2001 (August 2000)

Table 2: Summary Statistics on Costs in Surf Clam Fishery

	1980-1984		1985-1989		1990-1995	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Fuel small	3,095,490	663,484	876,667	197,571	478,027	192,359
Fuel large	5,535,936	1,388,005	1,961,205	542,754	1,458,933	180,002
Labor small	4,054,691	972,841	4,288,724	646,231	2,751,052	478,926
Labor large	6,810,016	466,451	7,846,086	1,527,126	6,483,273	620,326
Gear small	2,047,609	290,234	1,233,063	123,074	817,848	188,668
Gear large	3,245,121	570,950	2,192,493	79,063	2,328,019	176,429
Capital small	7,411,387	926,904	5,962,129	584,111	1,857,691	1,295,555
Capital large	13,987,844	1,929,010	15,187,317	930,154	7,215,774	3,462,495

Note: All costs are in 1999 dollars (deflated using the US-CPI).

Source: MAFMC (2000)

Table 3: Cost Shares in Surf Clam Fishery, 1980-1995

	M	N	O	P	Q	R	S	T	U
45		Fuel		Labor		Gear		Capital	
46		Small	Large	Small	Large	Small	Large	Small	Large
47	1980-1984	0.07	0.12	0.09	0.15	0.04	0.07	0.16	0.30
48	1985-1989	0.02	0.05	0.11	0.20	0.03	0.06	0.15	0.39
49	1990-1995	0.02	0.06	0.12	0.29	0.04	0.10	0.07	0.30

Source: Authors' calculations

Table 4: Summary Statistics on Costs in Ocean Quahog Fishery

	1980-1984		1985-1989		1990-1995	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Fuel small	477,983	105,347	421,463	196,641	476,792	70,173
Fuel large	4,759,477	578,300	4,071,835	1,033,224	3,574,913	598,073
Labor small	481,618	184,628	700,354	231,445	1,088,369	192,610
Labor large	5,390,330	353,228	6,613,275	274,989	6,546,522	785,403
Gear small	554,072	198,031	625,992	226,858	725,673	55,372
Gear large	5,347,277	753,775	7,080,994	396,350	6,419,658	290,100
Capital small	1,563,080	597,950	1,392,704	304,037	711,534	269,183
Capital large	8,396,428	1,152,913	10,841,919	792,471	5,577,928	1,243,126

Note: All costs are in 1999 dollars (deflated using the US-CPI).

Source: MAFMC (2000)

Table 5: Cost Shares in Ocean Quahog Fishery, 1980-1995

	Fuel		Labor		Gear		Capital	
	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2
1980-1984	0.02	0.18	0.02	0.20	0.02	0.20	0.06	0.31
1985-1989	0.01	0.13	0.02	0.21	0.02	0.22	0.04	0.34
1990-1995	0.02	0.14	0.04	0.26	0.03	0.26	0.03	0.22

Source: Authors' calculations

Table 6: Tornqvist Index of Total Factor Productivity in Fisheries by Policy Era

	Surf Clams		Ocean Quahogs	
	Mean	Standard Deviation	Mean	Standard Deviation
1980-1984 Command & Control	1.071	0.180	1.022	0.085
1985-1989 Transition	1.012	0.066	1.009	0.057
1990-1995 Property Rights	1.102	0.076	1.046	0.060

Source: Authors' calculations.¹³

Table 7: Percent Change in Tornqvist Index of TFP over Policy Periods

Policy Periods	Surf Clams	Ocean Quahogs
1980-1984 to 1985-1989	-5.5%	-1.2%
1985-1989 to 1990-1995	8.9%	3.7%
1980-1984 to 1990-1995	2.8%	2.4%

Source: Authors' calculations.

Table 8: Average Annual Productivity Growth Rates, 1981-1995

Period	Surf Clams	Ocean Quahogs
1981-1984	7.18% (0.17)	2.35% (0.08)
1985-1989	0.97% (0.07)	0.82% (0.06)
1990-1995	9.47% (0.07)	4.40% (0.06)

Source: Authors' calculations.

Note: Standard deviations of growth rates over policy periods are given in parentheses.

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¹ For reviews see Hahn and Noll (1982) for application to pollution, Moloney and Pearse (1979) for the first application to fisheries, and Varian (1989) on the compensation mechanism. Ellerman et al. (2000) provide a review of the U.S. experience with property rights under the Acid Rain Program.

² National Standard One for fisheries management states, "Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimal yield from each fishery for the United States fishing industry." National Standards Five and Seven state that management must consider efficiency and cost minimization (Title III Section 301).

³ Gear restrictions, trip limits, and limits on the number of allowed fishing hours are often met with increased capital in the fishery. For example, by 1978, the capital in the surf clam fishery was large enough to harvest the entire year's quota in only 15 days (Keifer, 1992). For further discussion on fishery regulation and models, see Conrad (1999) pages 32-58.

⁴ Additionally, given a competitive market quota, the market price for quota should be equivalent to the Pigovian tax (Clark, 1980). In reality, asymmetric information destroys this equivalence (see Weitzman (1974) on cost uncertainty and Stavins (1998) on benefit and cost uncertainty).

⁵ For example, see *Sea Watch International, et al. v. Secretary of Commerce*, 762 F. Supp. 370 (1991).

⁶ The formal negotiations over ITQs began with a discussion paper written and circulated by the management council in 1986 (MAFMC, 1986). Amendment Eight: Fishery Management Plan for the Atlantic Surf Clam and Ocean Quahog Fishery was approved by the Mid-Atlantic Fishery Management Council in cooperation with the National Marine Fisheries Service and the New England Fishery Management Council in 1988 (MAFMC, 1988).

⁷ As noted by Weninger and Just (2002) the firm decision to enter or exit is influenced by both uncertainty and imperfect capital malleability.

⁸ According to the economic theory, an index is "exact" for a specific production function if it is derived from that particular function.

⁹ On a given fishing trip, the vessel harvests either surf clams or ocean quahogs, but never both.

¹⁰ Prices are converted from meat weights to bushels using 1 bushel=17 pounds of meat weights for surf clams and 1 bushel=10 pounds of meat weights for quahogs.

¹¹ In the clam industry, wages are paid as a direct percentage of the gross revenue. Amendment 8 (NMFS, 1990) reports that the share going to crew averages 1/3. This rate was verified in field interviews over 2000-2001.

¹² To verify the calculations of TFP, the author compared the results from this study to previously published studies. The levels of productivity of these fisheries are similar to those estimated in other fisheries during periods of technological innovation (see for example, Jin et al. (2002)).

¹³ The measures of total factor productivity are calculated using the chain method for indexes.