Evaluating Tradable Property Rights for Natural Resources: The Role of Strategic Entry and Exit

Sylvia Brandt[1]

Abstract:

This paper presents an econometric approach to the evaluation of environmental regulation using tradable property rights. Existing empirical research on this issue, which compares overall industry efficiency before and after the introduction of new regulations, conflates two distinct phenomena: efficiency changes due to exit of excess capital, and changes in the efficiency of individual firms. Because the regulatory process induces firms of different types to enter and exit the industry at different rates, the true efficiency and equity effects of tradable property rights cannot be assessed without correcting for these changes in sample composition. This paper examines the impact of regulatory change in the Mid-Atlantic surf clam fishery, using an econometric model that separates its effects on industry structure and vessel efficiency. The analysis finds that, contrary to widely held belief, tradable property rights did not disproportionately benefit either large fishing firms or highly integrated firms.

Keywords: fisheries, efficiency, regulation, property rights

JEL Classification: L1, L5, L2, Q2

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THE ROLE OF STRATEGIC ENTRY AND EXIT [*]

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ABSTRACT

This paper presents an econometric approach to the evaluation of environmental regulation using tradable property rights. Existing empirical research on this issue, which compares overall industry efficiency before and after the introduction of new regulations, conflates two distinct phenomena: efficiency changes due to exit of excess capital, and changes in the efficiency of individual firms. Because the regulatory process induces firms of different types to enter and exit the industry at different rates, the true efficiency and equity effects of tradable property rights cannot be assessed without correcting for these changes in sample composition. This paper examines the impact of regulatory change in the Mid-Atlantic surf clam fishery, using an econometric model that separates its effects on industry structure and vessel efficiency. The analysis finds that, contrary to widely held belief, tradable property rights did not disproportionately benefit either large fishing firms or highly integrated firms.

I.   INTRODUCTION

This paper analyzes the impact of regulatory change – in this case, the implementation of tradable property rights – on efficiency in a resource-based industry. We find that simply measuring industry-level changes in efficiency obscures both the change in efficiency of production and the distribution of efficiency gains. In particular, industry-level change can result from changes in the efficiency of individual productive units, or from changes in the composition of the industry. We show that rent-seeking behavior of firms will change the composition of the industry prior to policy change, and that this shift will upwardly bias estimates of efficiency change. By analyzing panel data with firm identifiers, this paper empirically demonstrates rent-seeking behavior during policy negotiations and estimates the distribution of efficiency gains over industry participants.

Economic theory establishes that a given environmental standard can be met at a lower cost under well-defined tradable property rights than under traditional command-and-control regulation.[1]   Significant recent research has empirically evaluated tradable property rights systems in areas such as the U.S. Acid Rain Program[2] and more recently in U.S. fisheries[3]. However, in measuring the impact of policy change, it is necessary to account for the behavioral response of regulated firms to the design of the new policy. Rent-seeking behavior has been

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[1] For example, D.W. Montgomery, Markets in Licenses and Efficient Pollution Control Programs, 74 J. Econ. Theory 941 (1972). For the case of fisheries see D. Moloney, D. and P. Pearse, Quantitative Rights as an Instrument for Regulating Commercial Fisheries, 36 Journal of Fisheries Research Board Canada. 859 (1979).

[2] For a comprehensive review see A. Denny Ellerman et al., Markets for Clean Air: The U.S. Acid Rain Program (2000).

[3] An extensive analysis includes R. Quentin Grafton *et al*., Private Property and Economic Efficiency: A Study of a Common-Pool Resource, 38 J. Law & Econ. 679 (2000). The authors measure change in efficiency using three different random samples in the British Columbia halibut fishery. The years in which the samples were taken include 1988 (the year a small group of fishermen requested individual fishing quotas), 1991 (the first year of a trial program), and 1994 (the second year that the quotas were tradable).

documented in the case of tradable emissions permits;[4] this paper looks at analogous behavior in response to the design of tradable property rights. The results demonstrate that firms' forward-looking behavior biases estimates of both the change in efficiency of vessel production and the distribution of these gains across firm and vessel types.

While command-and control regulation of fisheries often produces tremendous overcapitalization and inefficient use of capital,[5] tradable property rights are predicted to eliminate inefficient vessels and increase the efficiency of remaining capital[6]. In the long run, tradable property rights should result in the cost-minimizing fleet; therefore, their effectiveness can be measured by comparing levels of efficiency under the competing policy approaches[7].

Carefully measuring the impact of this strategic behavior is especially important given current policy debates over tradable property rights systems. However, measuring relative efficiency is complicated by the effect of incentives during the policy negotiations that precede the implementation of tradable property rights. In commercial fisheries, property rights have

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[4] See Paul. L. Joskow & Richard Schmalensee, The Political Economy of Market-Based Environmental Policy: The U.S. Acid Rain Program, 41 J. Law & Econ. 37 (1998) and Juan-Pablo Montero *et al*., A Market-Based Environmental Policy Experiment in Chile, 35 J. Law & Econ. 267 (2002).

[5] Gear restrictions, trip limits and limits on the number of allowed fishing hours are often met with increased capital in the fishery. A classic case is the halibut fishery, in which increasingly strict command-and-control regulations were circumvented by increasing capitalization. At the peak capitalization the entire year's allowable harvest could be harvested in a single day, commonly referred to as the Halibut Derby.

[6] For a comparison of labor productivity across fisheries with differing property rights structures see Richard J. Agnello and Lawrence P. Donnelley, Property Rights and Efficiency in the Oyster Industry, 18 J. Law & Econ. 521 (1975). Additional reviews of property rights in fisheries include Keith E. Casey *et al*., The Effects of Individual Vessel Quotas in the British Columbia Halibut Fishery, 10 Marine Resource Econ. 211 (1995). Gerry Geen & Mark Nayar, Individual Transferable Quotas In The Southern Bluefin Tuna Fishery: An Economic Appraisal Marine Resource Economics, 5 Marine Resource Econ. 365 (1988); R. Linder, H. Campbell, & G. Bevin, Rent Generation During the Transition to a Managed Fishery: The Case of the New Zealand ITQ System, 7 Marine Resource Econ. 229 (1992).

[7] Previous studies of economic benefits of tradable property rights over command-and-control include simulations of cost savings with the technically minimum size fishing fleet and elimination of excess capital under costly reversibility and uncertainty. See Quinn Weninger and Richard Just, Assessing Efficiency Gains from Individual Transferable Quotas: An Application to the Mid-Atlantic Surf Clam and Ocean Quahog Fishery, 80 Amer. J. Agr. Econ. 750 (1998); and Quinn Weninger and Richard Just, Firm Dynamics with Tradable Output Permits, 84 Amer. J. Agr. Econ. 572 (2002). This study uses a larger panel of vessels as well as unique firm identifiers, making it possible to evaluate the efficiency change by type of firm (integrated or independent).

historically been allocated *a gratis* based on the total past harvests of boats,[8] a principle that is

likely to be incorporated into national legislation. As a result, firms that foresee a policy change

will adapt their current behavior to maximize their benefits under the new policy[9].

Political debate has surrounded the economic evaluation of the industry studied in this

paper, the Mid-Atlantic surf clam fishery[10]. The resulting controversy over the distribution of

gains and losses from policy change in this and other domestic fisheries has dominated the

national debate, frustrated attempts to introduce policy alternatives, and led to lawsuits against

the regulatory agency[11].

The econometric issues involved in measuring growth of efficiency and distribution of

these gains over types of firms are similar to those involved in identifying the relationship

between firm size and firm growth, beginning with Gibrat; however, attrition of firms can lead to

sample selection bias if the disturbance of the selection equation is correlated with the

disturbance of the growth equation[12]. This paper explores the consequences of policy-induced

attrition in estimating efficiency gains on the vessel level. In addition, this paper examines how

behavior prior to the policy change exaggerates the potential for sample selection bias.

There is ample evidence that tradable property rights are not implemented as an

exogenous shock, but are anticipated by fishing firms and incorporated into their economic

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[8] National Research Council, Sharing the Fish (1999).

[9] Anecdotal evidence of this rent seeking behavior is available for the Alaskan halibut and sablefish individual tradable quota programs. See National Research Council, *supra* note 8, for a discussion.

[10] The surf clam and ocean quahog fishery has been cited both as successful and a failed tradable property rights system. For conflicting views see, National Research Council, *supra* note 8 and *Reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act before the Subcomm. of Fisheries Conservation, Wildlife and Oceans Comm. on Resources*, 4-5 (2002) (statement of William Hogarth, Assistant Administrator for Fisheries, National Marine Fisheries Service, U.S. Department of Commerce).

[11] Two example of lawsuits over this issue are: *Sea Watch International, et al. v. Secretary of Commerce*, 762 F. Supp. 370 (1991) and *Alliance Against IFQs, et al. v. Secretary of Commerce* 84 F.3d 343 (9thCir. 1996). The plaintiffs in *Sea Watch International, et al., v. Robert Mosbacher* argue that the property rights system violated the national equity and fairness standard, National Standard Four of the Magnuson-Stevens Act, because it is intended to drive a particular group of individuals - single vessel owners and small fleet owners - out of fisheries.

[12] Bronwyn Hall, The Relationship Between Firm Size and Firm Growth in the US Manufacturing Sector, 35 J. of Industrial Econ. 583 (1987).

decisions[13]. This anticipation of policy reform produces three effects: re-entry into the industry by marginal firms to "stake their claim" for quotas; increased effort in order to increase the size of that claim; and a spike of exits after policy change. This adaptive behavior determines both the relative efficiency of vessels in the fishery and the types of firms (vertically integrated, horizontally integrated, or independent) that make up the industry. As a result, simply comparing mean efficiency levels before and after policy change suffers from sample selection bias, because strategic behavior affects the composition of the industry and hence the sample. This paper shows the direction and scale of this bias when measuring changes in efficiency, and estimates mean efficiency change after correcting for sample selection. In addition, it identifies what types of vessels and firms gain the greatest benefits from tradable property rights.

II. THEORETICAL MODELS OF SAMPLE SELECTION

This section presents two alternative models of firm behavior under property rights implementation: one in which firms do not play a role in policymaking, and one in which they do. These models demonstrate two points: first, participation in the regulatory process changes the composition of the industry *prior to* policy change; and second, firms that remain in the industry after policy change are systematically different from those firms that do not. Mean aggregate efficiency under the two polices is driven primarily by the composition of the fleet; only after correcting for strategic behavior and sample selection is it possible to estimate the change in efficiency of individual vessels.

Because this paper is concerned with forward-looking firm behavior, complications such as uncertainty, stochastic population, and so on are disregarded in favor of specifically relevant behavior. A common approach to limiting capital in fisheries is to ration licenses or permits to

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[13] All regional fishery management council meetings are open to the public and are preceded by mailings to stakeholders and multiple forms of public notice.

harvest. Typically, there are only nominal fees to obtain licenses; consequently, in many

fisheries, the total number of licenses $\overline{N}$ exceeds the number of licenses being used in any year

(where n_t = "active licenses" in year t, $\overline{N} \geq n_t$)[14]. Because licenses in federal commercial

fisheries are granted to vessels, not vessel owners, the total number of licenses defines the

population of *vessels* permitted to harvest, not the number of fishing *firms* (which is less than or

equal to the number of vessels). From the firm's perspective, an unutilized fishery license is an

option to enter that fishery in the future. In this model, licensed but inactive vessels can re-enter

the fishery in the future: this potential for additional harvesting is termed "latent effort"[15].

Therefore, the stylized model encompasses two regulatory states: regulation by license

limitations with latent effort, and regulation by transferable property rights. The transition

between states is compared under two scenarios of firm behavior. In the first scenario, firms are

naïve in that they do not foresee the introduction of property rights: in the second scenario, firms

are informed of the negotiation of property rights and anticipate their introduction.

A.   *Scenario One: No Policy Expectations*

We begin by describing the transition from limited licenses to tradable property rights

without the expectation of policy change. Following the classic model of the competitive

fishery, each fishing firm faces an exogenously given price (p) and population (x) of fish[16].

Define the harvest (h_i) of each vessel as a function of the vessel's standardized fishing effort

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[14] The granting of licenses may be restricted by participation requirements. In some cases replacement of vessels
lost at sea and capital improvements are strictly regulated to preserve the initial distribution of vessel technologies.
[15] Between 1995 and 2000 the federal government spent $130 million in "buyback" programs. In order to reduce
latent effort, these funds were used to purchase fishing permits, fishing gear, and vessels from fishermen in three
fisheries - New England groundfish, Bering Sea pollock and Washington State salmon.
[16]   A review of fisheries economics is Gordon Munro, Mathematical Bioeconomics and the Evolution of Modern
Fisheries Economics, 54 Bulletin of Math. Bio. 163 (1992).

(E_i), the fish population biomass (x), and a constant that reflects the catchability of the fish

given its population ($q = q(x)$, where $q > 0$):

(1) $h_i = H(E_i, x, q)$

The ith vessel has a net revenue flow given by the difference between the revenue from

the harvest (ph_i) and the variable cost for the effort expended ($c_i(E_i)$). The vessel's cost

function is defined to include the vessel's opportunity cost in any alternative fisheries. Under

command and control regulation, the firm's level of effort must be less than the regulatory cap on

effort, $\overline{E}$, and the last vessel to re-enter the fishery must not exceed the number of allowable

licenses, $\overline{N}$.

(2) $\begin{aligned} E_i &\leq \overline{E} \\ n_t &\leq \overline{N} \end{aligned}$

Thus the constrained optimization for effort is[17]:

(3) $L = pH(E_i, x, q) - c_i(E_i) - \mathbf{1}_1\left(E_i - \overline{E}\right)$

Activity in the industry is then determined by a firm's short-run choice of the optimal

level of effort and the firm's long-run choice of the optimal level of capital (vessels). A vessel

will harvest if it can cover its minimum average variable cost, r_i; otherwise the optimal level of

effort will be zero. Thus, in the short run, the fishing firm maximizes its current net revenue

taking the population and price of fish as given, which yields the following first order condition:

(4) $\begin{aligned} c_i'(E_i) + \mathbf{1}_1 &= pH'(E_i, x, q) & \text{if} & \quad pH'(E_i, x, q) \geq r_i \\ E_i &= 0 & \text{if} & \quad pH'(E_i, x, q) < r_i \end{aligned}$

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[17] In the dynamic setting the change in the population of fish is driven by the difference between the growth rate of the population and the aggregate harvest over all vessels. Note that as in the open access case, each vessel does not take into account its harvest on the total impact on the population of the fish. Here we are not comparing the social optimum to the industry outcome, but industry outcomes under alternative regulations.

The level of capital in the industry is determined by the exit of currently active vessels and re-entry of vessels that have licenses but are not currently active. In order to compare the salient changes in behavior, we use a simple model of re-entry and exit. We assume perfect foresight of prices of harvest and effort and zero costs of re-entry and exit. For the empirical case presented here these are reasonable approximations[18]. Exit occurs when a vessel's marginal revenue falls below its minimum average cost. Because the cost function includes the opportunity cost represented by alternative fisheries, vessel j will re-enter the fishery when the exit condition is reversed. Entry will continue until the largest number of vessels that can break even is reached with the only binding constraint being the total number of vessels with licenses, $\overline{N}$. The exit condition for a currently active fishing vessel, i, and the entry condition for a potential fishing vessel, j, are summarized as:

$$(5) \quad \begin{array}{ll} pH'(E_i, x, q) < r_i & \text{Exit condition for vessel } i \\ pH'(E_i, x, q) > r_j & \text{Re-entry condition for vessel } j \end{array}$$

Under license limitations, the total number of boats active is determined by the exit and re-entry conditions for the inframarginal vessels with average cost, r_n, for which

$$(6) \quad r_n = pH'(E_i, x, q)$$

At any point in time, all licensed vessels could be ranked in ascending order by minimum average cost (descending order by marginal efficiency):

$$(7) \quad r_1 \leq r_2 \leq ... \leq r_n$$

Conditions (4) through (7) describe the fishery under command and control regulation limiting both capital and effort.

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[18] In this empirical example, long-run contracting between processor and harvester ensured stable output prices. In addition, because the vessels that exit and re-enter are moving between fisheries, the costs of exit and re-entry are relatively minimal.

The standard fishery model differs under tradable property rights, because the regulatory constraint is not on inputs (effort and capital) but rather on outputs. The vessel's total harvest must not exceed the vessel's allocated quota (8), where the total harvest quota, $\overline{Q}$, is the sum of each individual vessel's harvest quota.

$$
(8) \quad
\begin{aligned}
h_i &\le Q_i \\
\overline{Q} &= \sum_{i=1}^{n} Q_i
\end{aligned}
$$

Once the market for quotas is established, there is a price, m, for a unit of harvesting quota. The price per unit of quota can be interpreted as the opportunity cost incurred by using the quota to harvest rather than selling it to the next vessel. The property right to harvest then becomes an additional capital asset to the firm. The vessel's choice of effort level under transferable property rights is a modification of (4):

(9)

$$
\begin{cases}
L = pH(E_i, x, q) - m[H(E_i, x, q) - Q_i] - c_i(E_i) - \mathbf{1}_2(H(E_i, x, q) - Q_i) \\[2mm]
\text{F.O.C.} \\
c_i'(E_i) + \mathbf{1}_2 H'(E_i, x, q) = (p - m)H'(E_i, x, q) \quad \text{if} \quad (p - m)H'(E_i, x, q) \ge r_i \\
E_i = 0 \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \text{if} \quad (p - m)H'(E_i, x, q) < r_i
\end{cases}
$$

The total number of vessels actively harvesting is determined by the re-entry/exit condition, which differs from (5) by the opportunity cost of holding the quota rather than selling it at price m.

$$
(10) \quad
\begin{aligned}
(p - m)H'(E_i, x, q) &< r_i \quad && \text{Exit condition for vessel } i \\
(p - m)H'(E_i, x, q) &> r_j \quad && \text{Re-entry condition for vessel } j
\end{aligned}
$$

Under tradable property rights, the exit condition (10) reflects the cost of the new capital asset, the quota. Thus the condition for the inframarginal fishing vessel (6) becomes:

(11) $r_{\hat{n}} = (p - m)H'(E_i, x, q)$

Therefore, under tradable property rights the average cost $r_{\hat{n}}$ of the inframarginal vessel is less than that of the inframarginal vessel under license limitations r_n, thus $r_{\hat{n}} < r_n$. Otherwise stated, the marginal vessel is more efficient under tradable property rights than under license limitations.

This is the standard model of a fishery under command and control and under tradable property rights. In contrast, the next section extends the standard model by allowing firms to be aware of policy negotiations and impending policy changes, with implications for both firm behavior and overall fleet composition.

B.   Scenario Two: Anticipated Policy Change

The previous section demonstrates that the efficiency of the inframarginal firm depends on the current period's policy instrument, where the change in efficiency is a discrete event at the time of the policy change. This section focuses on the period preceding actual implementation of tradable property rights, involving lengthy negotiations and significant industry participation in policy design and approval. Although economists envision initial distribution of property rights via auction, regulatory history shows that initial allocation is typically based on past production[19]. Therefore, firm behavior is characterized here using a stylized two-period model where harvesters maximize profits and expect to receive allocations based on their historical harvests. In this extended model, anticipation of impending policy change produces a change in behavior in the current period; empirical evidence of this change is presented in Section III.

Policy periods are distinguished with a time subscript: period 1 is the period of license limitations and property rights negotiations, and period 2 is the period of tradable property

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[19] National Resource Council, *supra* note 8 and Montero *et al.*, *supra* note 4.

rights[20]. The profit functions for each period are extensions of the profit functions in the first

scenario. The quota allocation rule, $A\left[\,H(\,E_1,x_1,q_1)\,\right]$, grants each firm quota as an increasing

function of its harvest in the first period. Although its specific functional form varies, the

allocation of quota as an increasing function of previous production is consistent across

fisheries[21]. The general allocation rule is given by:

$$(12) \quad Q_i = A\left[H\left(E_1,x_1,q_1\right)\right] \quad \text{where} \quad \frac{\partial A}{\partial H} > 0$$

Forward-looking behavior dictates choosing effort in each period to maximize the two-

period profit function, where the second period profit is discounted by $\boldsymbol{d}$ and regulations are

binding on the individual vessels. Thus the objective function for the representative vessel is

(13)

$$L = p_1 H(E_1,x_1,q_1) - c(E_1) - \boldsymbol{1}_1\left(E_1 - \bar{E}\right) +$$
$$\boldsymbol{d}\left\{p_2 H(E_2,x_2,q_2) - m(H(E_2,x_2,q_2) - A\left[\,H(\,E_1,x_1,q_1)\,\right]) - c(E_2) - \boldsymbol{1}_2\left[(H(E_2,x_2,q_2) - A\left[\,H(\,E_1,x_1,q_1)\,\right]\right]\right\}$$

The first-order conditions in period one and period two are given by (14). Note the additional

term "strategic effort effect" in the first-order condition for period one.

F.O.C. w.r.t E_1

$$(14) \quad \frac{\partial c}{\partial E_1} + \boldsymbol{1}_1 = \frac{\partial H}{\partial E_1}\left(p_1 + \underbrace{\boldsymbol{d}\frac{\partial A}{\partial H}\left(m + \boldsymbol{1}_2\right)}_{\text{strategic effort effect}}\right)$$

F.O.C. w.r.t E_2

$$\frac{\partial c}{\partial E_2} + \boldsymbol{1}_2\frac{\partial H}{\partial E_2} = \left(p_2 - m\right)\frac{\partial H}{\partial E_2}$$

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[20] For the ease of exposition, the subscript for the individual vessel, i, is suppressed

[21] In all five U.S. fisheries that have implemented tradable property rights, initial quotas were allocated based on vessels' harvest over a defined timeframe. See National Research Council, *supra* note 8.

These first-order conditions show how firms modify their behavior *prior to* property rights implementation in order to maximize their initial allocation. In period one, effort is increased until the marginal cost of effort equals the marginal profit of harvests *plus* the discounted marginal profit from the additional quota allocation in the second period. Thus the expectation that quota will be allocated based on past production increases the incentives for production.

Because quota are allocated to vessels, not firms, a firm that retires a vessel before property rights are implemented loses its claim to that vessel's harvest. Therefore, the second effect of forward-looking behavior is that the re-entry/exit condition must be adjusted to reflect the benefits of initial quota allocation. In period one, the equilibrium re-entry/exit condition includes the additional "strategic entry effect" term, which reflects the discounted value of the additional quota allocated in the period two:

$$(15) \quad r_{\bar{n}} = \left(p_1 + \underbrace{\boldsymbol{d}m \frac{\partial A}{\partial H}}_{\text{strategic re-entry effect}} \right) H'(E_i, x, q)$$

The effort conditions and exit/re-entry conditions for the representative firm are summarized in TABLE 1. Notice that the difference between the naïve and forward-looking models occurs in the first period *prior* to the actual policy change.

TABLE 1:

EFFORT AND RE-ENTRY/EXIT CONDITIONS

	Effort Condition	Equilibrium Re-entry/exit Condition

Naïve model

Period 1
$$\frac{\partial c}{\partial E}+\boldsymbol{l}_1=p_1\frac{\partial H}{\partial E} \qquad\qquad r_n=p_1\frac{\partial H}{\partial E}$$

Period 2
$$\frac{\partial c}{\partial E}+\boldsymbol{l}_2\frac{\partial H}{\partial E}=(p_2-m)\frac{\partial H}{\partial E} \qquad r_{\hat{n}}=(p_2-m)\frac{\partial H}{\partial E}$$

Forward-looking model

Period 1
$$\frac{\partial c}{\partial E_1}+\boldsymbol{l}_1=\frac{\partial H}{\partial E_1}\left(p_1+\underbrace{\boldsymbol{d}\frac{\partial A}{\partial H}(m+\boldsymbol{l}_2)}_{\text{strategic effort effect}}\right) \qquad r_{\bar{n}}=\left(p_1+\underbrace{\boldsymbol{d}m\frac{\partial A}{\partial H}}_{\text{strategic re-entry effect}}\right)\frac{\partial H}{\partial E_1}$$

Period 2
$$\frac{\partial c}{\partial E_2}+\boldsymbol{l}_2\frac{\partial H}{\partial E_2}=(p_2-m)\frac{\partial H}{\partial E_2} \qquad r_{\hat{n}}=(p_2-m)\frac{\partial H}{\partial E_2}$$

Thus we can rank the average costs of the inframarginal fishing vessel, r, and the level of

effort, E, under the three states:

(16)
$$r_{\bar{n}} > r_n > r_{\hat{n}}$$
$$E_{\bar{n}} < E_n < E_{\hat{n}}$$

where

$\bar{n}$ = license limitations, forward-looking model

n = license limitations, naive model

$\hat{n}$ = tradable property rights, both models

These two models identify three important behavioral factors that must be incorporated

into econometric models. First, in the period prior to policy change, vessels will increase effort

in order to maximize their initial quota allocations. Second, the threshold for re-entry is lower

under the forward-looking model, and so the vessels that re-enter in anticipation of policy change will be less efficient than if there is no such expectation. Third, vessels that exit after policy change will by design be the least efficient.

These factors have important implications for the empirical analysis of efficiency under the competing policies. Observed changes in mean efficiency under the two policies will be largely driven by changes in industry composition (that is, the efficiency of the inframarginal vessel). Strategic behavior in the negotiation period – primarily re-entry of particularly inefficient vessels – will upwardly bias simple estimates of change in mean efficiency. In order to assess efficiency gains across firm types – and thereby measure relative benefits from policy change – it is necessary to compare vessels that were active in both periods, correcting for sample selection.

The next section presents empirical evidence of the strategic behavior predicted in the model presented above.

III.   EMPIRICAL EVIDENCE OF STRATEGIC BEHAVIOR

In the preceding model, strategic firm behavior *prior* to actual policy implementation leads to changes in industry composition, implying the need to correction for sample selection bias when evaluating the efficiency impact of tradable property rights. This section provides empirical evidence of this predicted behavior. The first sub-section measures change in production effort and change in exit/re-entry of vessels; the second sub-section shows that the vessels that re-entered the fishery during the negotiation period and those that exited immediately after policy change were significantly less efficient than those vessels that remained in the fishery. The evidence is drawn from sixteen years of input and output data from the Mid-Atlantic surf clam industry.

A.   Changes in Effort and Vessel Re-entry

The Mid-Atlantic surf clam and ocean quahog fishery was chosen for this analysis because it has a history of innovative management and has been a touchstone in the debate over the distribution of gains of tradable property rights. This fishery provides almost the entire supply for domestic processed clam products[22]. Data used to estimate the models are from the National Marine Fishery Service logbook reporting system, which documents every harvesting trip taken by every vessel[23]. In 1976 legislation was enacted restricting allowable fishing time and limiting access for a period of fourteen years. By the mid-1980s, however, rapid growth in harvesting capacity and resulting inefficiencies led to a proposal to implement a property rights system; from the mid 1980s through 1988, council meetings were dominated by the contentious issue of distributing quotas among the industry participants[24]. Throughout the period, however, it was clear that allocations would be based in some form on each vessel's catch history[25].

The most common allocation scheme used in fisheries at that time was to grant individual allocations in proportion to the catch history of each vessel. Therefore, while harvesters were maximizing their current profit, they expected to receive an allocation based on their catch history, as characterized in the second stylized model above. The allocation formula was

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[22] National Marine Fisheries Service, Fisheries of the United States (1999). While two clam species, the surf clam and ocean quahog, can be harvested with the same vessel, subject to gear modifications, the surf clam fishery is the dominant fishery both in terms of value of the resource and harvest effort.

[23] Compliance with reporting regulations is rated as high. See Dayna Matthews, Beyond ITQ Implementation: A Study Of Enforcement Issues In The Mid Atlantic Surf Clam And Ocean Quahog Individual Transferable Quota Program (1997).

[24] The policy negotiations throughout this entire period focused solely on the surf clam fishery. The addition of ocean quahogs, an imperfect substitute, to the tradable property rights plan occurred in the final stages of policy revisions.

[25] The formal discussion of ITQs began with a discussion paper written and circulated by the management council in 1986. For more, see Mid-Atlantic Fishery Management Council, Limited Entry, the Magnuson Act and the National Standards (1986). The plan to design and implement tradable property rights went through several revisions. See Mid-Atlantic Fishery Management Council, Amendment Eight: Fishery Management Plan for the Atlantic Surf Clam and Ocean Quahog Fishery: Draft (1988).

finalized in 1988,[26] and the first full year of tradable property rights was 1991. After

implementation the quotas were disaggregated from vessels and could be traded as a second form

of capital.

The first indicator that firms anticipated the implementation of property rights is an

increase in harvesting effort. Because of existing regulation, firms could not simply increase

their time spent harvesting. While quantities of time, gear, and fuel are all measurable inputs,

the quality of the labor input and utilization of the observable inputs are unobserved. Given that

the technology remained essentially unchanged throughout this period, an increase in

unobservable effort is reflected in an increase in average catch. As TABLE 2 shows, the period

of negotiation of property rights was marked by a significant increase in the average harvest of

surf clams per vessel. Between 1983 and 1984 there was an unprecedented 21% increase in

bushels harvested per vessel, at the same time that the number of vessels in the fishery was

increasing. The harvest of surf clams per vessel over 1985-1988 was, on average, 26% higher

than 1980-1984. At the same time, harvest per vessel in the ocean quahog fishery – the

alternative opportunity for surf clam vessels - actually declined.[27] Over 1985-1988 the harvest of

quahogs per vessel was, on average, 4% *lower* than during 1980-1984[28]. At the same time,

fishing firms increased their competitiveness in the race for shares of the property rights by

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[26] The National Oceanic and Atmospheric Administration approved the final version of the tradable property rights
program in 1990. See Mid-Atlantic Fishery Management Council, Amendment Eight, Fishery Management Plan for
the Atlantic Surf Clam and Ocean Quahog Fishery (1990). The surf clam allocation included vessel catch (80%)
and vessel capacity (20%). For vessels harvesting surf clams, the historical catch was equal to the vessel's total
harvest over 1979-1988 (counting the years 1985-88 twice and dropping the vessel's worst two years). Each
vessel's catch ratio was the vessel's historical catch divided by the sum of all vessels' historical catch. The vessel's
cost factor was equal to the product of the vessel length, width and volume. The vessel's cost ratio was equal to the
vessel's cost factor divided by the sum of the cost factors over all vessels. The vessel's initial surf clam allocation
was: surf clam initial allocation percentage = 0.8 (catch ratio) + 0.2 (cost ratio)
[27] Recall that in this period, there was no expectation that tradable property rights would be implemented for the
ocean quahog fishery.
[28] Over the entire period 1983-1989 there were insignificant changes in populations of the two clam species.

replacing smaller vessels with larger vessels; in 1987 the mean vessel was 11% larger in gross

registered tonnage than in 1983[29].

TABLE 2: CHARACTERISTICS OF SURF CLAM FISHERY 1980-2000

Year	Average Surf Clam Bushels per Boat	Average Substitute Bushels per Boat	Number of Active Vessels
1980	15,150	56,957	127
1981	16,069	61,453	123
1982	17,416	75,367	115
1983	20,615	86,909	117
1984	24,933	69,526	119
1985	22,379	71,399	130
1986	22,088	57,878	144
1987	19,858	66,803	142
1988	22,624	72,087	134
1989	21,025	71,453	135
1990	24,328	82,543	128
1991	35,646	98,772	75
1992	47,666	114,853	59
1993	53,485	133,665	53
1994	60,567	128,094	48
1995	68,792	128,565	37
1996	75,568	121,984	34
1997	73,139	138,034	33
1998	76,302	162,395	31
1999	76,905	163,926	33

Source: Mid-Atlantic Fishery Management Council, Overview of the Surf Clam and Ocean Quahog

Fisheries and Quota Recommendations for 2001 (2000).

While firms were increasing harvesting effort, the threshold for vessels to re-enter the

fishery was lowered. As seen in TABLE 2, the decline in the number of vessels harvesting surf

clams reversed in the mid-1980s, and the number of vessels increased 23% between 1983 and

1986 and remained high until after property rights were implemented. This period also saw a

shift in ownership of capital: between 1983 and 1987 the largest fishing firm increased its

capital by six units to bolster its claim to future property rights. Processing firms, who could

receive a property right only through ownership of harvesting vessels, also increased vessel

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[29] The industry means for 1984 and 1987 are 111 and 123 gross registered tons, respectively.

ownership to accumulate future property rights, the median processor acquiring an additional vessel during the negotiations and then decreasing its vessel ownership by 50% immediately after property rights were separated from vessels. The processor with the greatest number of vessels acquired four vessels prior to the policy change and decreased its vessel ownership by 75% within the first three years of tradable property rights.

B.   Changes in Vessel Efficiency

The previous sub-section discusses changes in effort and in participation in the industry during property rights negotiations. To evaluate the efficiency impact of tradable property rights, however, it is necessary to establish how strategic behavior affected the efficiency of the inframarginal producer. Empirical estimates of vessel efficiency for 1984-1999 demonstrate two significant differences among vessels. First, vessels that stayed in the fishery under tradable property rights were significantly more efficient than those that exited the fishery after policy change. Second, vessels that re-entered the fishery during the negotiation period were significantly less efficient than all other vessels. This strategic behavior determines which vessels are observed in each period, affecting estimates of the change in efficiency. In order to separate the effect of strategic behavior from the effect of the new policy, the econometric model must correct for this effect[30].

Each vessel's annual efficiency is calculated by first estimating a stochastic production function for the industry. The stochastic production function breaks the deviation from the theoretical production function into two sources, production inefficiency and white noise; it is

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[30] Additionally, the results imply that the allocation of property rights should take into account the strategic behavior of producers in constructing the allocation formulas so as to reduce incentive for socially inefficient behavior prior to implementation. The topic of allocating tradable property rights given forward-looking behavior is addressed in our working paper.

written as an ordinary production function with the addition of a one-sided inefficiency term, indicating the distance from the production frontier for a given vessel in each year.[31]

In the surf clam fishery, the log of outputs is modeled as linear in the log of inputs (fuel, labor, and capital) and the log of the population of the resource.[32] Thus the regression equation for firm i is linear in logarithms of output (harvest, h) and inputs (*fuel, labor* and *capital, population*) and allows for inefficiency (u) and white noise (v)[33]:

$$h_i^* = a + b_{fuel}(fuel_i) + b_{labor}(labor_i) + b_{population}(population) + b_{capital}(capital_i) + v_i - u_i$$
where:

(17) $\quad i = 1,2,...,N \times T$

$\quad v_i \sim N(0, s_v^2)$

$\quad u_i \geq 0,$ where u_i distributed as the normal truncated at zero of $N(m, s_u^2)$

$\quad e_i = v_i - u_i$

$\quad s = \left(s_u^2 + s_v^2\right)^{1/2}$

$\quad g = \dfrac{s_u^2}{s_u^2 + s_v^2}$

Despite its asymmetric distribution, the compound error term, $\left(v_i - u_i\right)$, can be estimated using maximum likelihood estimation[34]. The parameter g reflects the appropriateness of using the stochastic production function over a deterministic production function[35].

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[31] Disaggregating natural variation, or white noise, from the inefficiency term is particularly appealing in modeling output in an industry such as a fishery in which weather and other natural forces can cause normal variation in output.

[32] The fuel input reflects distance and speed traveled. Labor is the measure of total man-hours spent harvesting. The measure of capital is the length of the vessel, a standard proxy in the fisheries economics literature. The measure of population of the clams reflects resource scarcity, where the population of clams is a type of natural capital.

[33] This specification of the production function follows George Battese, Tim Coelli and T. Colby, Estimation of Frontier Production Functions and the Efficiencies of Indian Farms Using Panel Data from ICRISAT's Village Level Studies, 5 J. of Quantitative Econ. 327 (1989).

[34] See William Greene, Econometric Analysis (2000).

[35] Following established literature, we use the parameterization of σ and γ from G.E. Battese and G.S. Corra, Estimation of a Production Frontier Model With Application to the Pastoral Zone of Australia, 21 Australian J. of

The panel data consists of vessels that harvested surf clams over 1983-1999 yielding a total of 1298 unique observations (vessel-year observations). Summary statistics for the inputs and outputs of the stochastic production function are shown in TABLE 3.

TABLE 3:

SUMMARY STATISTICS FOR HARVESTS AND EXPLANATORY VARIABLES OF PRODUCTION FUNCTION

Variables	1983-1990	1991-1999	1983-1999
Harvest			
Mean	9.57	9.78	9.63
Standard deviation	1.21	1.16	1.20
Capital (vessel length)			
Mean	4.41	4.42	4.41
Standard deviation	0.24	0.18	0.23
Labor (crew hours)			
Mean	7.13	7.10	7.12
Standard deviation	0.95	1.13	1.00
Fuel (gallons)			
Mean	9.28	9.20	9.26
Standard deviation	0.96	1.17	1.02
Population of clams (metric tons of biomass)			
Mean	14.09	14.01	14.06
Standard deviation	0.04	0.03	0.05

NOTE. – There are 947 observations in the Command and Control period, 351 observations in the Tradable Property Rights period, and 1298 observations overall.

The coefficients and standard errors for the estimated stochastic production function are presented in TABLE 4, which shows that all the parameters for the inputs chosen by the harvester (*fuel*, *labor*, *length*) are positive and statistically significant at the 1% level[36]. The population of clams is not statistically significant, reflecting the relative stability of population

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Agricultural Econ. 169 (1977). Note that γ does not have chi-square distribution because the hypothesis that it equals zero means that it is on the boundary of the parameter space. Since the restriction is on the boundary space, the distribution of the test statistics for gamma is a mixed chi-square.

[36] The null hypothesis of constant returns to scale in all inputs and both vessel and resource capital (fuel, labor, population, capital) is not rejected at the 5% level.

over the entire time period.[37] The parameter γ is significant at the 1% level, implying that

technical inefficiency exists in the production function and accounts for more than the variation

from random white noise and that a stochastic frontier production is appropriate[38]. The

importance of the parameters of the stochastic production function is in the estimation of

efficiency of each vessel-year observation.

TABLE 4

MAXIMUM-LIKELIHOOD ESTIMATES OF STOCHASTIC PRODUCTION FUNCTION,
1983-1999

	ln(Harvest in Bushels)	
Constant	6.216	(4.104)
Fuel	0.409[**]	(0.054)
Labor	0.455[**]	(0.059)
Population	0.337	(0.288)
Length	0.418[**]	(0.074)
σ^2	0.961	(0.048)
γ	0.940[**]	(0.010)
σ_u^2	0.903	
σ_v^2	0.058	
Log likelihood	-1134.762	

NOTE. – Standard errors are in parentheses. The parameter estimates are the coefficients on the log of

output in logs from the production function with a compound error term. The model uses a total of 1298

vessel-year observations.

** Significant at the 1 percent level.

To estimate the change in efficiency of an individual vessel, the efficiency score of each

vessel-year was estimated. Technical efficiency is expressed as the ratio of the vessel's mean

production, conditional on the observed levels of factor inputs and firm effects, to the maximum

level of production, conditional on the same levels of inputs, but assuming those inputs are

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[37] Since the recovery of the population following the die-off of the clams in the mid-70s, both the population and total allowable harvests have been very stable.

[38] The calculated likelihood ratio for γ is 325.2.

utilized optimally[39]. The efficiency score of each vessel-year is defined as the vessel-year's

output conditional on its inefficiency term, u_i, relative to the production frontier (maximum

output with inefficiency term equal to zero)[40].

$$(18) \quad efficiency_i = \frac{\mathrm{E}\left(h_i - u_i, e_i\right)}{\mathrm{E}\left(h_i - u_i = 0, e_i\right)}$$

Thus, the efficiency score is bounded by zero and one, and a score closer to one indicates

a higher level of efficiency. TABLE 5 presents the mean efficiency scores over four categories

of vessels and three time periods. The four categories of vessels are defined by their re-entry or

exit decisions. "All" refers to all active vessels, regardless of re-entry/exit decision; "survivors"

are vessels that continued to harvest in the fishery after the transition to tradable property rights;

"exit" includes those vessels that ceased harvesting after the policy change; and "re-entrants" are

vessels that re-entered the fishery seeking to claim a share of future property rights. The three

time periods are the negotiation period (1984-1990), the tradable property rights period (1991-

1999), and the entire period (1984-1999).

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[39] Battese, G. Tim Coelli and T. Colby, Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India, 3 J. Productivity Analysis 153 (1992).
[40] Note that the total disturbance, e_i, not the inefficiency term, u_i, is directly observed. The inefficiency term is estimated conditional on the observable total error.

TABLE 5:

MEAN EFFICIENCY SCORES OVER POLICY PERIODS BY EXIT CHOICE

	Command and Control, 1984-1990		Tradable Property Rights, 1991-1999		1984-1999	
	Mean		Mean		Mean	
All	0.567	(0.189)	0.609	(0.176)	0.579	(0.186)
Survivors	0.594	(0.187)	0.645	(0.173)	0.625	(0.180)
Exit	0.539	(0.190)	0.510	(0.202)	0.538	(0.190)
Re-entrants	0.455	(0.273)	NA	NA	0.455	(0.273)

NOTE. – Standard errors are in parentheses. Over the period 1984-1999, there are 1202 total observations of which 319 are of vessels that did not exit, 538 are of vessels that exit after policy change, and 9 of vessels that re-entered during negotiations. By definition the "re-entrants" are not observed under tradable property rights thus these statistics are not applicable (NA).

The mean efficiency of all vessels under tradable property rights is 7% higher than under command and control, but this includes the effect of the shift in fleet composition. To estimate the change in mean vessel-level efficiency, we must answer two questions. First, what was the change in efficiency for vessels that harvested both before and after the transition to tradable property rights? Second, did those vessels that continued to produce under tradable property rights ("survivors") differ systematically from those vessels that exited the industry ("exit")?

As TABLE 5 shows, the average efficiency of survivors was higher under tradable property rights than under command and control[41]. In addition, the mean efficiency scores of the sub-groups (survivors, exit, and re-entrants) show systematic differences between them. During the command and control period, those vessels that would remain in the industry were more

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[41] The null hypothesis of equal means is rejected at the 0.1% significance level.

efficient that those that would exit after property rights,[42] implying that the survivor group would have remained more efficient than the exit group, regardless of the policy change. Vessels that entered during the negotiation period (re-entrants) are significantly less efficient than any other group – as predicted by the theoretical model above. In summary, the three groups can be ranked as follows:

$$efficiency \ (\text{re-entrant}) < efficiency \ (\text{exit}) < efficiency \ (\text{survivor})$$

The change in industry composition brought on by policy negotiations had a significant effect on mean efficiency, as illustrated by the time series in FIGURE 1. The trough in mean efficiency during 1986-1988 was caused by substantial re-entry of inefficient vessels. Once quota ownership was separated from vessel ownership, there was a drastic decline in the number of vessels in the fleet, which was concurrent with an upward turn in mean efficiency after 1990.

Because vessels that exit after policy change are generally less efficient than those that remain, the attrition after the policy change (exit) is correlated with the compound error term, $e_i = v_i - u_i$, producing selection bias. In addition, vessels entering the fishery during the policy negotiation period are distinguished by significantly below-average efficiency. These re-entrants, therefore, downwardly bias the estimated mean efficiency level prior to policy implementation; as a result, estimates of the *change* in mean efficiency level will significantly overstate the true change in efficiency. To correct for this bias and estimate the distribution of efficiency gains across firm and vessel types, a regression model allowing for sample selection is presented in the next section.

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[42] The null hypotheses of equal means between those that exit and those that survive is rejected at the 2% significance level.

IV.   REGRESSION RESULTS: DISTRIBUTION OF EFFICIENCY GAINS

Two economic goals of tradable property rights are the elimination of overcapacity and increasing the efficiency of remaining vessels. At first glance, it appears that these goals were achieved in the surf clam fishery; from 1987 to 1993, the average level of efficiency in the fishery as a whole increased by 14%, while the number of vessels harvesting decreased by 63%. Despite these aggregate economic benefits, however, this dramatic change in the fishery created substantial turmoil in policy discussions over tradable property rights. The essential economic and legal question of "Who gains from tradable property rights?" remained unanswered. One reason for this controversy is that simply looking at the mean efficiency of the industry as a whole obscures the comparative impact of tradable property rights on different types of vessels and firms. Two central issues are how are gains are distributed across vessel size categories and across firm types[43]. This section presents regression results that show the importance of forward-looking behavior and attrition in estimating both changes in vessel-level efficiency (in contrast to aggregate industry efficiency) and comparative gains in efficiency across vessel and firm types.

In order to isolate the effect of policy change on vessel-level efficiency, it is necessary to look at the change in efficiency for a vessel that harvested under command and control (CC) and then under tradable property rights (TPR). This change in efficiency relative to the starting efficiency is:

$$(19) \quad growth \ in \ efficiency \ = \ \frac{efficiency_{TPR} - efficiency_{CC}}{efficiency_{CC}}$$

One possibility might be to measure this growth in efficiency for the industry as a whole, or for all vessels that operated both before and after the policy change. However, the empirical

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[43] Vessels are categorized into size classes based on their total gross registered tonnage; firm types include independent firms, harvesters vertically integrated with processing or distribution operations, and horizontally integrated harvesters

results described in the previous section indicate the potential problems with this approach. First, the vessels that entered the industry immediately prior to the policy change were particularly inefficient. Second, vessels that remained in the industry after the policy change were significantly more efficient than those that exited after implementation. These findings demonstrate the importance of sample selection: in fact, there are several distinct groups of boats, and their relative presence in the industry shifted significantly over time. Therefore, simply applying (19) to the industry as a whole will conflate this change in industry composition with the change in vessel-level efficiency brought about by new policy.

The econometric model presented here begins with vessel-level efficiency estimates and adds a second step that estimates the determinants of the *change in vessel efficiency*[44], correcting for biases caused by sample selection. This model is analogous to that used elsewhere to study the relationship between firm size and firm growth[45]. The model compares a representative year for each period: 1987 for command and control and 1993 for tradable property rights. 1987 was chosen for the initial period because it includes the complete set of vessels that harvested in the fishery; 1993 was chosen to reflect an initial period of restructuring during which vessels adjusted to the new harvesting strategy[46]. Thus equation (19) becomes:

$$(20) \quad growth\ in\ efficiency = G = \frac{efficiency_{1993} - efficiency_{1987}}{efficiency_{1987}}$$

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[44] For examples of this procedure in which estimated firm-level efficiencies are regressed on firm specific variables, see M.M. Pitt and L.F. Lee, Measurement and Sources of technical Inefficiency in the Indonesian Weaving Industry, 9 J. of Development Econ. 43 (1981).

[45] In the manufacturing sector it has been observed that small firms that have slow or negative growth are more likely to disappear from the panel than are large firms. Because of the selective attrition the growth rate of firms is observed only for those firms that do not exit over the panel. A selection model is necessary to model the relationship between firm size and growth. See Hall *supra* note 12. Likewise, the current paper relies on the Heckman selection model to examine the determinants of the change in efficiency.

[46] By reducing the window of analysis to the years 1987-1993, we capture the significant restructuring after the policy change while reducing reduce the influence of changes in other aspects of the system.

The growth in efficiency, however, is only observed for vessels that do not exit the industry. As described in the previous section, these vessels are distinct from those vessels that remain in the industry and those vessels that re-entered during negotiations. The determinants of efficiency change are vessel age (*age*), type of firm that owns the vessel (*firm*=1 for integrated, 0 for independent), and vessel size in gross registered tonnage (GRT) (*size*=1 for GRT>100, 0 otherwise). However, a vessel is observed under tradable property rights only if it chooses not to exit after the policy change. To determine the factors relevant to the selection equation we conducted fieldwork in the industry. Interviews of harvesters and testimony at meetings of the Mid-Atlantic Council clam industry indicate that there are three critical factors to the exit decision: the number of contracts a vessel has with processors (*contracts*), vessel age (*age*), and profit (*profit*).

The selection model captures these effects and models the change in efficiency conditional on the decision to exit or to continue harvesting. Because all harvests in the surf clam fishery go into processed products, contractual relationships with processors are crucial to harvesters' viability. The institutional norm in this fishery is a long-run relationship with processors, both in the form of written contracts and mutual understandings, where violations of trust can have significant consequences for locating a buyer of clams[47]. The variable *contracts* is the number of processors a vessel delivers to in each year, relative to the industry mean.

Another important factor in the exit decision is the age of the vessel itself. First, older vessels have increased wear and older technology, and are more likely to be retired by horizontally integrated harvesters. Second, for independent harvesters, vessel age is positively

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[47] The surf clam fishery has been the subject of anthropological studies of natural resource use. For comprehensive reviews see Bonnie McCay *et al*., Individual Transferable Quotas in Canadian and U.S. Fisheries, 28 Ocean and Coastal Mgmt. 85 (1995); and Bonnie McCay and Carolyn Creed, Social Structure and Debates on Fisheries Management in the Mid-Atlantic Surf Clam Fishery, 13 Ocean and Coastal Mgmt. 199 (1990).

correlated with the length of time the harvester has been in the industry, and hence older vessels are more likely to be owned by owners who are close to retirement age.

The third important driver of the exit decision is vessel profit, which has an obvious interpretation. The summary statistics for vessels are presented in TABLE 6 and TABLE 7.

TABLE 6:

SUMMARY STATISTICS FOR EXPLANATORY VARIABLES IN SELECTION MODEL

	Mean	
Growth in Efficiency	0.265	(0.630)
Age in 1987	22.583	(19.117)
Relative number of contracts in 1987	0.248	(0.175)
Relative profit in 1987	.006	(0.004)

NOTE. – Standard deviations are in parentheses.

TABLE 7:

FREQUENCY OF FIRM AND VESSEL TYPES

	Vessel Size in 1987	
Firm type in 1987	<= 100 GRT	> 100 GRT
Independent	20	17
Fleet or vertically integrated	29	66

Therefore the regression model is:

$$G_i = \boldsymbol{a}(contracts) + \boldsymbol{a}_{\text{age}}(age_i) + \boldsymbol{a}_{\text{firm}}(firm_i) + \boldsymbol{a}_{\text{size}}(size_i) + \boldsymbol{e}_{1i}$$

the firm is observed in the second period if

$$\boldsymbol{b}(c) + \boldsymbol{b}_{\text{contracts}}(contracts_i) + \boldsymbol{b}_{\text{age}}(age_i) + \boldsymbol{b}_{\text{profit}}(profit_i) + \boldsymbol{e}_{2i} > 0$$

(21)   where

$$\boldsymbol{e}_1 \sim N(0, \boldsymbol{s})$$
$$\boldsymbol{e}_2 \sim N(0, 1)$$
$$corr(\boldsymbol{e}_1, \boldsymbol{e}_2) = \boldsymbol{r}$$

For comparison the data are used to estimate two models, one in which selection issues are ignored, and one in which the determinants of efficiency change are estimated given the selection equation. The results are given in Table 8.

A.   Results ignoring sample selection

The first set of results in Table 8 shows the coefficients and significance levels for an OLS regression of change in relative efficiency on vessel age, firm type, and vessel size[48]. The regression covers all vessels that harvested in both 1987 and 1993, and therefore includes vessels that chose not to exit over the period. In these results, the mean growth in efficiency of a new, small (≤100 GRT) vessel owned by an independent firm is 0.786, which is significant at the 1% level. The relevant interpretation of the constant is that the mean efficiency change was positive rather than negative for those vessels that remained in the industry. Overall the model explains only 4% of the variation in efficiency growth.

Of particular interest from a policy and economic perspective is whether firm integration or size of capital is related to efficiency growth. In these results, ignoring the systematic re-entry and exit of vessels, none of the other variables of interest has any explanatory power. If the disturbances of the survival equation and the growth equation are not correlated, then these

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[48] Note that while the efficiency score is bounded from below and above, this regression uses the growth in efficiency. Thus the variable *growth* is not censored, and a Tobit regression is unnecessary.

results would contradict arguments that tradable property rights systematically favor one type of harvester over another. To fully answer the question, however, it is essential is to correct for the types of firms that are in the panel, because as shown previously those vessels that exited had lower efficiency than those that did not exit, even under command and control.

Table 8: Determinants of Change in Efficiency, 1984 to 1993

	OLS		Heckman Selection	
Constant	0.786**	(0.287)	0.638**	(0.255)
Age	-0.028	(0.019)	-0.069**	(0.018)
Firm	-0.140	(0.209)	-0.389*	(0.186)
Size	-0.123	(0.331)	0.232	(0.234)
Constant			0.832**	(0.362)
Relative number of contracts			-2.944**	(0.875)
Age			-0.076**	(0.017)
Relative profit			107.853**	(38.620)
Log likelihood			-78.061	
ρ			0.960**	(0.035)
p-value of ρ			0.01	
Number of observations	41		115	
Censored observations			74	
Uncensored observations			41	

NOTE. – Standard errors are in parentheses.
* Statistically significant at the .05 level.
** Statistically significant at the .01 level.

To address the potential bias caused by less efficient vessels' strategic *re-entry prior* to policy change and *attrition afterward*, the Heckman selection model is used, with results reported in Table 8. The first test for sample selection issues is whether the error terms of the regression equation for growth and the selection equation are correlated. The estimated correlation between the error terms is $\rho=0.96$ and is statistically significant at the 5% level; this result indicates that the estimates of the regression equation will be upwardly biased if sample selection is ignored.

The estimates of the selection equation suggest that contracting relationships and vessel age are the most important determinants of exit. The coefficient for the relative number of contracts is -2.944 and is statistically significant at the 1% level, the negative coefficient reflecting the importance of loyalty to processors. Tradable property rights enabled processors to ensure a regular supply of clams to match their production schedules by contracting with a smaller number of harvesters[49]. Thus, in the period of restructuring after tradable property rights were implemented, the more contracts a harvester had relative to the number of total processors, the less likely the harvester was to remain in the industry. Older vessels were also more likely to exit the industry, suggesting that fleets rationalized by eliminating older capital. The coefficient for vessel age is -0.076 and is statistically significant at the 1% level. As expected the coefficient for vessel profit is positive (107.853) and statistically significant at the 1% level.

The combined effect of sample selection is that after the implementation of tradable property rights, the remaining vessels were on average newer, contractually related to fewer processors, and more profitable. The positive and statistically significant correlation between the

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[49] Based on ownership of tradable quota, processors can coordinate harvests with production. Processors can also affect harvesting schedules by coordinating the leasing or provisioning of additional quota in order for the harvesters to meet the production requirement.

disturbances of the two equations suggests that the initial estimates of the change in efficiency were biased upwards, as is verified by the results in Table 8.

Given that those vessels that stayed were more efficient on average to start with, the first question is how changes in efficiency correspond to vessel and firm traits. When correcting for the correlation between the disturbances of the survival equation and the efficiency growth equation, the mean change in the efficiency of a new, small vessel owned by an independent firm is still positive, but is smaller than estimated by the OLS model (0. 638 in the Heckman model, 0.786 in the OLS model).

In addition, these sample selection issues have important implications for the estimated relationships between growth in efficiency and characteristics of the harvester. The coefficient on age is negative (-0.069) and statistically significant at the 1% level, indicating that older vessels are less able to exploit the flexibility provided by the new policy to achieve efficiency gains. There are two possible explanations of this effect: either the older vessels have older captains who are less likely to adapt to new tactics rewarded by tradable property rights, or older vessels are less easily re-purposed as required by tradable property rights.

The most important policy implications are presented by the coefficients on firm structure and vessel size, because they directly address the concern that tradable property rights unfairly benefit large producers at the expense of small producers. By including both firm type and vessel size, the model captures two key issues in this equity debate. The first is the fear that tradable property rights favor large vessels over smaller ones[50]. However, the coefficient for vessel size (recall that *size*=1 if GRT>100, 0 otherwise) provides counterevidence of discrimination against small vessels; although positive (0.232), the *size* coefficient is not statistically significant (p-value=0.32).

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[50] National Research Council, *supra* note 8.

Second is the fear that tradable property rights facilitate domination of the industry by either vertically or horizontally integrated fishing firms[51]. This concern was explicitly addressed in the national debates over property rights in US fisheries. Recall that the coefficient on firm type (*firm*=0 for independents, 1 for integrated firms) is not statistically significant in the OLS regression; however, in the selection model, the coefficient is negative and statistically significant at the 5% level. The implication is not only that independent firms were not unfairly damaged, but that they actually increased efficiency more than integrated firms. This negative relationship between firm integration and efficiency change highlights the importance of addressing sample selection issues.

While looking at the aggregate change in efficiency in the industry as a whole can show the scale of total benefits resulting from policy change, it leaves unanswered the fundamental and politically important issue of equity. By contrast, this model addresses this issue by estimating efficiency change on the vessel level. The results are important because they contradict the common, naïve belief that efficiency gains accrued predominately to large vessels or integrated firms. While there are potential inequities in any policy, inequities are not an inherent quality of tradable property rights, but depend on the way property rights systems are designed and implemented. And in order to accurately assess the impact of a policy change, it is necessary to carefully distinguish between its effect on industry composition and its effect on firm-level efficiency, rather than simply measuring the change in efficiency as a whole.

V.   CONCLUSIONS

Economists have long recognized the theoretical benefits of replacing command-and-control regulation with tradable property rights in fisheries management. Not only should excess capital exit the industry, but remaining vessels should become more efficient; no longer

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[51] National Research Council, *supra* note 8.

subjected to rigorous input and output constraints, harvesters can adjust inputs and make

harvesting decisions to operate at the most efficient rate.[52] Despite these seemingly clear

theoretical benefits, however, tradable property rights are still far from the norm in fisheries

management. In the United States, policy debates concerning market-based regulatory systems

center on a single key question: who benefits? Empirical studies attempting to sort out this

thorny issue must cope with the realities of the complex processes by which new policies are

negotiated and implemented. Invariably, firms take advantage of the policy negotiation period to

stake their claims to benefits under the new system, complicating simple before-and-after

analyses that ignore firms' strategic behavior.

In the surf clam fishery, the result was that large numbers of economically inefficient

vessels re-entered the industry in the final years of command-and-control regulation, seeking to

establish claims to initial quota allocations that could then be used by other vessels or sold on the

market. These high-cost vessels then exited the fishery once the quotas were allocated. This

short-term influx of inefficient vessels made the gains due to tradable property rights seem

greater than they actually were, since efficiency was artificially low in the years prior to policy

change. Correcting for this distortion – by separating vessel entry and exit from changes in

individual vessel efficiency – gives a more accurate picture of the benefits provided by tradable

property rights.

This analysis is also critical to understanding the equity effects of tradable property rights

– how gains in efficiency are distributed across different types of vessels and firms. Because this

econometric model isolates vessel-level efficiency from industry structure effects, it is possible

to see how different classes of vessels were affected by the new policy. The results would be

surprising to many participants in the current policy debate over tradable property rights. After

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[52] Tradable property rights provide the flexibility to optimally choose fishing grounds, departure and arrival ports, days on which to harvest, and crew composition.

correcting for the effects of strategic re-entry and attrition, we found that older vessels enjoyed a smaller efficiency gain than younger vessels, which is not itself surprising. More interestingly, individual vessel size had no effect on efficiency gains, and independent firms actually benefited more than did vertically or horizontally integrated firms. These last two conclusions directly contradict the common belief that market-based regulatory systems unfairly benefit large and integrated firms at the expense of smaller, independent firms.

This example demonstrates several important points concerning the economic analysis of regulatory change. First, regulatory changes are not pure exogenous shocks, but are lengthy processes in which affected firms are intimately involved; as a result, these firms engage in strategic behavior in anticipation of new policies, clouding any assessment of their impact. Second, this strategic behavior has its own effects on industry composition and efficiency, and must be isolated in order to measure the change in efficiency of individual firms or classes of firms. And third, this correction produces results that are significantly different from those obtained otherwise – and, in this case, results with significant impact on the current debate over tradable property rights in fisheries management.

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FIGURE 1

EFFICIENCY VERSUS PARTICIPATION