EVALUATING TRADABLE PROPERTY RIGHTS FOR NATURAL RESOURCES:

THE ROLE OF STRATEGIC ENTRY AND EXIT *

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THE ROLE OF STRATEGIC ENTRY AND EXIT

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 real change in productive efficiency and the distribution of efficiency gains. This is because industry-level change can result from changes in individual productive efficiency, or from changes in industry composition. First, we show how firms' rent-seeking behavior changes industry composition prior to policy change, upwardly biasing estimates of efficiency change. Second, we show that analyses ignoring the bias produced by this behavior do not capture the relationship between firm characteristics and efficiency change. While research in labor economics has previously modeled treatment effects with sample selection and attrition bias, this paper highlights these econometric issues in policy evaluation and design for natural resources. By analyzing panel data with firm identifiers, this paper empirically demonstrates rent-seeking behavior during policy negotiations and the effect of attrition bias, and estimates the distribution of 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

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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).
Command and control in fisheries, in the form of gear restrictions, trip limits and limits on the number of allowed fishing hours, are 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.

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

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 documented in the case of tradable emissions permits;[4] this paper looks at analogous behavior in fisheries. In fisheries, an individual transferable quota, or individual fishing quota, is a share of the annually specified total allowable harvest. The Magnuson-Stevens Act states that an individual fishing quota shall be considered a permit and does not constitute a right or title to any fish *before they are harvested*. For purposes of discourse, the term tradable property right will be used in this paper. While the empirical literature on tradable property rights provides important insights into their performance, the implications of unbalanced panel data on econometric estimates have received little to no attention[5]. In commercial fisheries, property rights have historically been allocated *a gratis* based on the total past harvests of boats,[6] 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. The results of this paper show the effect of firm behavior on estimates of both the change in vessels' productive efficiency and the distribution of these gains across firm and vessel types.

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[3] 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 current 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) and addresses the econometric issues of change in industry composition. 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).

[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] For example, the comprehensive review by Grafton et al. notes that the data are unbalanced; however, sample selection is ignored in the analysis.

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

By demonstrating both the presence of policy-induced attrition and the effects of this bias on econometric estimates of efficiency, this paper contributes to the current legislative dialogue on designing tradable property rights in U.S. fisheries. During the 1995-2002 moratorium on the implementation of tradable property rights in U.S. Federal fisheries, nationally-publicized negotiations were held over the potential design and implementation of tradable property rights systems.[7] Legislative hearings and testimony on the topic have favored the over-weighting of recent harvests in determining the allocation of property rights.[8] The results of this paper call this position into question; specific policy recommendations are presented in the concluding section.

II. EMPIRICAL EVIDENCE OF STRATEGIC BEHAVIOR AND NONRANDOM ATTRITION

The econometric issues involved in measuring efficiency growth 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[9]. The 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

[7] For example, NOAA issued a News Release for a public April 2002 meeting to discuss the design of a tradable property rights system for red snapper, which would be submitted to a referendum of the current participants in the fishery.

[8] See for example Senate Committee on Commerce, Science and Transportation, Subcommittee of Oceans and Fisheries, May 2, 2001 and Senate Bill 637 of the 107th Congress, First Session, March 28, 2001.

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

efficiency levels before and after policy change suffers from sample selection bias, because firm behavior in response to policy affects the composition of the industry and hence the sample.

Although economists envision initial distribution of property rights via auction, regulatory history shows that initial allocation is typically based on past production[10]. Furthermore, unlike the case of retroactive tax policies that are designed to reduce inefficient rent-seeking behavior, allocation formulas in fisheries tend to exacerbate the rewards of rent-seeking behavior by placing additional weight on recent harvests. Although its specific form varies, the allocation of quota as an increasing function of previous production is consistent across fisheries. In all five U.S. fisheries that have implemented tradable property rights, initial quotas were allocated based on vessels' harvest over a defined timeframe, and in each case there was significant industry participation in the policy process.[11] Therefore, during command-and-control and negotiations over property rights, harvesters expect to receive allocations based on their historical harvests, with added weight given to the last years prior to tradable property rights.

After implementation of tradable property rights, the property right is disaggregated from the vessel and may be traded by the firm. Immediately after implementation of tradable property rights there will be a reduction in the fleet due to (a) the exit of vessels that were used to expand effort and maximize the allocation of tradable property rights and (b) the exit of vessels that delayed exit in order to retain their firm's claim to property rights. In the long-run equilibrium those vessels that remain in the fishery are by design the most efficient.

A second point of departure of economic models from actual policy is how ownership of the historical harvests is defined. The federal regulatory framework recognizes fishing vessels as the regulatory unit, not the firms that own vessels. Because licenses are granted to vessels, not vessel

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[10] National Resource Council, *supra* note 6 and Montero *et al.*, *supra* note 4.
[11] See National Research Council, *supra* note 6.

owners, the total number of licenses defines the population of *vessels* permitted to harvest, not the number of fishing *firms*. From the firm's perspective, licensed but inactive vessels can re-enter the fishery in the future. Because quotas 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; thus, the expectation that quota will be allocated based on past production changes the activity in the industry in two ways. First, vessels that would have exited the industry under command and control delay their exit in order to retain the claim to tradable property rights. Second, firms have the incentive to increase effort by returning formerly unutilized vessels to operation.

A. Evidence of Strategic Behavior

The current regulatory framework implies a shift in the composition and quantity of capital in the fishery prior to allocation of property rights, and there is evidence of this behavior in the first U.S. Federal fishery to implement tradable property rights. The Mid-Atlantic surf clam and ocean quahog fishery - which provides almost the entire supply for domestic processed clam products - was chosen for this analysis because it has a history of innovative management and has been a touchstone in the debate over tradable property rights. This fishery has been widely cited both as successful and a failed tradable property rights system[12]. Much of the debate over tradable property rights in U.S. fisheries centers on the concern that participants' relative positions in the fishery will change- in particular the fear that small-scale fishermen will be disadvantaged relative to larger producers. Despite the economic arguments that ITQs produce gains in the *aggregate*, this fundamental debate over the *distribution* of gains from increased efficiency, and of losses from

[12] For conflicting views see, National Research Council, *supra* note 6 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).

restructuring, remains a persistent debate [13]. The 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[14].

The data used to estimate the models in this paper are from the National Marine Fishery Service logbook reporting system, which documents every harvesting trip taken by every vessel[15]. The data set permits differentiation of firm type based on their size and on their degree of integration (defined by vertical integration with processing sector [VI], horizontal integration across boats [HI], or no integration [independents]). Second the data distinguish large vessels [more than 100 gross registered tons] from small vessels. These data allow us to explicitly address the equity concerns surrounding tradable property rights, because these firm and vessel characteristics are central to the debate over property rights in this and other fisheries.

The tension between small-scale harvesters and larger-scale harvesters and processors has been a recurrent theme in fisheries management and was a volatile issue in the clam fishery, reportedly affecting every management decision over the 1980s. The dominant social stratification in the fishery is firms characterized as processor owned (vessels and/or ITQs owned by a firm that processes clam products) or not processor owned. A firm not owned by a processor is then distinguished by the number of vessels it owned while it was harvesting clams: independent firms own less than three vessels and fleet firms own more than two vessels[16]. In 1983, 74% of

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[13] National Research Council, *supra* note 6.

[14] 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).

[15] 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).

[16] 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).

harvesting firms were independents, 10% were fleet owners, and 16% were vertically integrated firms. Additional details on the institutional aspects of the industry are found elsewhere[17].

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. Throughout the period it was clear that allocation of property rights would be assigned to vessels in proportion to the catch history of each vessel. This fishery provides an account of how economists and regulators differ in their views of tradable property rights.

Previous economic literature suggests that capital can be a strategic choice variable to improve one's position in an industry[18] and evidence exists to support its strategic use in this fishery. This process in the surf clam industry began in the mid-1980s and quickened when the Council responsible for the surf clam management circulated a discussion paper on the use of tradable property rights[19]. After deciding to use a property right approach, the Council established an Industry Advisory Committee that met over a period of two years to discuss the specifics of the allocation formula[20]. The regional used a decidedly participatory process to developing the quota allocation method including the industry in the numerous committee and Council meetings to discuss allocation schemes. To provide equal information, any industry member could request that

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[17] See Brandt, S. The Equity Debate: Distributional Impacts of Individual Transferable Quotas, forthcoming Ocean and Coastal Management ; McCay and Creed, *supra* note 16.

[18] See Rimjhim Aggarawl and Tulika Narayan, Does Inequality Lead to Greater Efficiency in use of Local Commons? 47 JEEM. 163 (2004); Mary Deily, Niccie McKay and Fred Dorner, Exit and Inefficiency, 35 J. of Human Resources. 734 (2000); Pankaj Ghemawat and Barry Nalebuff, Exit, 16 Rand. 184 (1985).

[19] See Mid-Atlantic Fishery Management Council, Amendment Six, Fishery Management Plan for the Atlantic Surf Clam and Ocean Quahog Fishery (January 1986).

[20] B. McCay, Initial Allocation of Individual Transferable Quotas in the US Surf Clam and Ocean Quahog Fishery, in Shotton, R. (ed.) Case Studines on the allocation of transferable quota rights in fisheries. FAO Fisheries Technical Paper, No. 411. Rome, FAO. 2001.

the Council provide the exact allocation he/she would get under any of proposed allocation scheme[21].

Rational economic behavior implies that while harvesters were maximizing their current profit, they expected to receive an allocation based on their catch history, leading to significant changes in the utilization of capital in the fishery. These changes are illustrated in Figure 1. From 1980 through 1984, there was a general decline in the number of vessels in the clam industry; however, the decline in the number of vessels harvesting surf clams reversed in the mid-1980s, the number of vessels increasing 23% between 1983 and 1986 and remaining high until after property rights were implemented. The capital in the industry peaked in the late 1980s - the precise period that was weighted most heavily in the allocation formula. The incentives created by impending property right allocation were also reflected in the number of active firms. Between 1983 and 1986 there was a 19 percent increase in number of firms harvesting clams, and after ITQs the number of firms that harvested clams fell 26 percent from 1986 to 1991 and 43 percent from 1991 to 1999. This period also saw a shift in ownership of capital: processing firms, who could receive a property right only through ownership of harvesting vessels, amassed capital during this negotiating period. The median processor acquired an additional vessel during the negotiations and then decreased 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.

The participants themselves pointed to the amassing of capital by competing participants as an unfair outcome of the policy process[22]. In plaintiffs' testimony in *Sea Watch, et al. v. Secretary*

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[21] Mid-Atlantic Fishery Management Council. Amendment #8, Fishery Management Plan for the Atlantic Surf Clam and Ocean Quahog Fishery: Final Approved. 1990 (See Appendix 6).
[22] K.A. Marvin, Protecting Common Property Resources through the Marketplace: Individual Transferable Quotas for Surf Clams and Ocean Quahogs, 16 Vermont Law Review. 1127(1992).

of Commerce[23], the sale of a vessel in the surf clam fishery commanded a premium of $50,000 to $150,000 over the value of the vessel itself. The plaintiffs stated explicitly that this difference reflected the anticipated value of the future property rights associated with the vessels' historical catch. Additionally, in the authors' extensive interviews of current fishing firms, individuals confirmed that they did in fact buy vessels solely for the property rights associated with them[24]. In fact, after property rights were allocated some of these recently acquired vessels were sold at a minimum scrapped price of $1.00. Furthermore, there was reported to be a major effort by industry participants urging political representatives to address the issue of fair allocation. After the implementation of property rights there was a noticeable effect was the significant decline in attendance of the Council meetings[25].

Other plausible explanations for the increase in the number of vessels in the fishery include changes in price of clams, abundance of clams, or management rules. Statistics on the industry suggest that these changes do not fully explain the change in capital in the fishery. For example, the coefficient of variation on abundance is a mere 5% over the entire period. Furthermore neither stock assessments nor reports of fishermen indicate any localized depletion. Likewise the allowable harvest set by the management council was markedly stable, and demand had no significant shifts. Consequently the price also exhibited decidedly little variation. Change in allowable fishing time under command and control, presents a more complicated picture. In the later part of the command and control, the time vessels were allowed to be harvesting was reduced relative to that in the early 1980s. While we cannot prove that anticipation of policy change was the sole reason for the increase in capital, there is credible evidence to support the conclusion that it paid an important role

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[23] *Sea Watch International, et al. v. Secretary of Commerce*, 762 F. Supp. 370 (1991).
[24] Over the spring of 2000, we interviewed over half of the independent and vertically independent firms and the majority of the horizontally integrated firms.
[25] Clay Heaton, personal communication.

and that it is important in measuring the impact of the change itself. Specifically, the new vessels are distinct from the existing vessels in their mean levels of efficiency a distinction that needs to be reflected in the estimation. The question is then, how much of the increase in capital can be attributed to the change in the attributes of command and control versus the anticipation on the policy change?

In the clam industry, the allocation formula was finalized in 1988, and the first full year of tradable property rights was 1991. The surf clam allocation was a weighted average of vessel historical catch (80%) and vessel capacity (20%). The historical catch was defined as 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 final allocation formula reflected the dynamics of the policy process. The definition of historical catch directly rewarded those firms that expanded harvesting during the negotiation, and the inclusion of the cost factor was in response to complaints from recent participants who had invested in larger vessels but did not have lengthy histories of harvests[26].

The system was designed such that the ITQ is the percentage of the total allowable catch held by the vessel. Once the total allowable catch has been determined (in quantity of bushels) the vessel's allocation is its ITQ (in percentage) multiplied by the total allowable harvest. The allocation is the quantity of bushels that the vessel has a right to harvest. There were no restrictions placed on concentration of ownership. Amendment Eight permitted a firm to retain ownership of its ITQ even if it terminated harvesting and sold its capital, allowing the firm to lease its quota to harvesters. After implementation, when quotas were disaggregated from vessels and could be

[26] See McCay *supra* note 20.

traded as a second form of capital, there was a significant reduction in the fleet, with the number of vessels decreasing 56 percent between 1988 and 1992. In summary, the onset of policy negotiations reversed an ongoing contraction in the fishing fleet, triggering a short period of expansion that was just as quickly reversed once tradable property rights went into effect.

It is worth noting that the surf clam fishery is not unique the level of public participation in the US policy process. A principal motivation for having eight regional Fishery Management Councils was to facilitate industry involvement and create a participatory system[27]. There was wide discussion of implementation of property rights in the wreckfish industry, the second ITQ system in a federal fishery, claiming a significant portion of every council meeting during the development of the plan over 1990-1991[28]. The fishery expanded from only 5 vessels in 1988 to 40 vessels in 1990 and to as many as 60-70 vessels in 1991 with much of the increase over 1990-91 from retrofitted shrimp trawlers[29]. Much of the debate centered on the allocation of property rights of "historic" harvesters relative to new entrants. The process of establishing a property right system for the Alaskan halibut and sablefish industry spanned fifteen years with substantial public involvement. The North Pacific Management Council explicitly identified the entrance of vessels staking a claim on allocation of property rights, as a problem in determining initial allocations[30]. This potential for licensed vessels to commence harvesting is termed "latent effort", and an indication of the potential scale of latent harvest is that over $130 million was spent to purchase fishing permits, fishing gear,

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[27] Summary of 2003 NOAA Fishery Constituent Sessions, December 2003, Washington, D.C.

[28] South Atlantic Fishery Management Council, Final Amendment 5 (wreckfish ITQs), Regulatory Impact Review, Initial Regulatory Flexibility and Environmental Assessment for the Snapper/grouper Fishery of the South Atlantic Region. 1991.

[29] See Gauvin, J.R., Initial Allocation of Individual Transferable Quotas in the US Wreckfish Fishery, in Shotton, R. (ed.) Case Studines on the allocation of transferable quota rights in fisheries. FAO Fisheries Technical Paper, No. 411. Rome, FAO. 2001.

[30] Hartley, M. and M. Fina, Allocation of Individual Vessel Quota in the Alaskan Pacific Halibut and Sablefish Fisheries in Shotton, R. (ed.) Case Studines on the allocation of transferable quota rights in fisheries. FAO Fisheries Technical Paper, No. 411. Rome, FAO. 2001.

and vessels from fishermen in three fisheries - New England groundfish, Bering Sea pollock and Washington State salmon.

B. Nonrandom Attrition

The previous section provides evidence that firms changed their behavior prior to and after implementation of regulatory change. Of particular importance is the decision to continue to participate in the industry or to exit, because a goal of tradable property rights is to reduce the overcapacity in fisheries and bring capital to an optimal level. If there is a correlation between the participation decision and efficiency, then empirical analysis should account for the nonrandom aspect of which firms are observed in the periods under comparison. Not only will nonrandom attrition bias estimates of the change in mean efficiency, it will also bias estimates of the correlates of efficiency change, including firm and vessel types. Addressing this econometric issue is necessary to inform current debates over the regulatory process.

Strategic behavior in the negotiation period – primarily re-entry of particularly inefficient vessels and delayed exit – 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. This section uses sixteen years of input and output data from the Mid-Atlantic surf clam industry to perform this analysis. The results show 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.

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 frontier into two sources, production inefficiency and white noise; it is 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] Disaggregating natural variation, or white noise, from the inefficiency term is particularly appealing in modeling an industry such as a fishery, where weather and other natural forces can cause normal variation in output.

Often in empirical studies of production the parameters of the stochastic production function are of secondary interest. The primary interest in this study is characterizing the mean distance to the frontier under the two policies and types of participants. Thus the next section briefly explains how the distance to the frontier is estimated and describes the correlation of efficiency with the participation decision. Summary statistics for the inputs and outputs of the stochastic production function are shown in Tables 1 and 2.

[Tables 1 and 2 about here]

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 observation *i* is linear in logarithms of output (harvest, *h*) and inputs (*fuel*, *labor, capital, population*), because initial estimations using a translog production function suggested using the Cobb-Douglas production function[33]. The regression allows for inefficiency (*u*) and white noise (*v*), and despite its asymmetric distribution, the compound error term, $(v_i - u_i)$, can be estimated using maximum likelihood estimation[34]. The mean of the systematic component, u_i, is conditioned on the attributes that are thought to affect inefficiency including, firm type (dummies for horizontal

[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] For a comprehensive review of measuring productive efficiency see Kumbhakar and Lovell (2000).
[34] See William Greene, Econometric Analysis (2000).

integrated, *HI*, or vertically integrated, *VI*) and vessel size (dummy variable for vessels over 100 tons, *size*). The parameter g reflects the appropriateness of using the stochastic production function over a deterministic production function, and the null hypothesis of no inefficiency is rejected[35].

$$
\begin{aligned}
&h_i^* = b_o + b_{fuel}(fuel_i) + b_{labor}(labor_i) + b_{population}(population) + b_{capital}(capital_i) + v_i - u_i \\
&u_i = a_o + a_{HI}(HI_i) + a_{VI}(VI_i) + a_{size}(size_i) + e_i \\
&\text{where:} \\
(1)\quad &i = 1,2,\ldots, N \times T \\
&v_i \sim N(0, s_v^2) \\
&u_i \sim N^+(m, s_u^2), \text{ distributed with truncation point at zero}
\end{aligned}
$$

$$
\begin{aligned}
&e_i = v_i - u_i \\
&s = \left(s_u^2 + s_v^2\right)^{1/2} \\
&g = \frac{s_u^2}{s_u^2 + s_v^2}
\end{aligned}
$$

Stochastic frontier analysis has several advantages over ordinary least squares (OLS). First, the inclusion of the one-sided error term avoids any bias in the intercept that would be present in an OLS model if inefficiency were to exist. Second, the stochastic production approach allows us to compare the change in efficiency over the two policy periods. Because we are interested in both the mean change in efficiency as well as the differences between firm and vessel types, the stochastic frontier approach is preferred.

The data consist of vessels that harvested surf clams over 1983-1999, yielding a total of 1248 unique observations (vessel-year observations). The coefficients and standard errors for the

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[35] 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.

estimated stochastic production function are presented in the appendix in Table 3, which shows that all the parameters for the inputs chosen by the harvester (*fuel*, *labor*, *capital*) are positive and statistically significant at the 1% level[36]. The coefficient for horizontal integration is negative and statistically significant at the 1% level indicating that the mean inefficiency for horizontally integrated firms (*HI*=1) is less than that for independent firms (base case). The coefficient for vertical integration (V*I*=1) is also negative, but it is not statistically significant. The data suggest that vessels in the large category (*size*=1) have a lower mean inefficiency than do smaller vessels. The parameter γ is significant at the 1% level, indicating 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[39].

[Table 3 about here]

The coefficients of the stochastic production function describe the characteristics of the harvesting process. We can then compare the mean distance from this best practice frontier under the competing policy periods, as discussed in the following sections. Aggregate gains from the transition from command and control to tradable property rights come from two sources: the firms that make the decision to exit should be less efficient relative to the industry mean, and eliminating the constraints of command and control should allow harvesters to operate closer to the production frontier under tradable property rights. To compare efficiency under the two policies and test for nonrandom attrition, 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

[36] The negative coefficient on the population may reflect the carrying capacity.

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

[40] For a comprehensive review of measuring productive efficiency see Fried et al, 1993.

inputs and firm effects, but assuming those inputs are utilized optimally[41]. Recall that the stochastic component of the production frontier, the random deviations from the frontier, has mean zero. 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)[42].

$$(2) \qquad efficiency_i = \frac{\mathrm{E}\left(h_i | u_i, e_i\right)}{\mathrm{E}\left(h_i | u_i = 0, e_i\right)}$$

The efficiency score is a ratio bounded by zero and one, and a score closer to one indicates a higher level of efficiency. We can use the vessels' annual efficiency scores to compare: 1) change in an individual vessel's efficiency given firm type and vessel characteristics, and 2) mean efficiency of groups of vessels defined by their participation decisions. This section addresses the second point to demonstrate the presence of strategic behavior and nonrandom attrition. The first issue is addressed in Section III, using econometric techniques from the labor economics literature on workplace participation.

Table 4 presents the mean efficiency scores over four categories of vessels and three time periods. The three time periods are command and control (1984-1990), the tradable property rights period (1991-1999), and the entire period (1984-1999). 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

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[41] See for example, 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).

[42] 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.

rights. The question about nonrandom attrition can be expressed as: did those vessels that continued to produce under tradable property rights ("survivors") differ systematically from those vessels that exited the industry ("exit")?

[Table 4 about here]

As Table 4 shows, the mean efficiency scores of the sub-groups (survivors, exit, and re-entrants) have systematic differences between them. During the command-and-control period, those vessels that would remain in the industry were more efficient that those that would exit after property rights, and vessels that entered during the negotiation period (re-entrants) were significantly less efficient than any other group[43] - as would be expected given firms' strategic behavior. The 1984-1990 period saw the greatest spread in mean efficiency, with the mean efficiency of the exit group over 50% greater than that of the re-entrant group and the mean efficiency of survivors about 8% higher than for the exit group. Thus not only did the amount of capital increase during negotiation of tradable property rights, but the capital that did enter to gain tradable property rights was the least efficient. In summary, the three groups can be ranked as follows:

efficiency (re-entrant) < *efficiency* (exit) < *efficiency* (survivor)

Previous policy analyses compared an economic indicator pre- and post-tradable property rights[44]. This approach is equivalent to comparing the efficiency of all participants under command and control to the efficiency of survivors alone under tradable property rights, which would indicate an increase in efficiency of a little over 10%. However, to assess the impact of regulatory change on firm-level efficiency, it is necessary to compare the mean efficiency of survivors under command

[43] The null hypotheses of equal means between those that exit and those that survive is rejected at the 1% significance level.
[44] See Grafton, *supra* note 3 and Weninger *supra* note 3.

and control with the mean efficiency of survivors under tradable property rights, indicating an increase of less than 2%. Still, because the decision to participate is correlated with efficiency (and hence profit), there is a bias induced by looking only at the efficiency of the survivor. Thus the next section models the change in efficiency of each vessel, given that the owning firm decided to operate it after the implementation of tradable property rights.

Exiting vessels are less efficient than survivors, indicating that attrition after the policy change (exit) is correlated with the compound error term, $e_i = v_i - u_i$. In addition, vessels entering during the 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.

III. REGRESSION RESULTS: DISTRIBUTION OF EFFICIENCY GAINS

Two economic goals of tradable property rights are eliminating 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 mean level of efficiency in the fishery as a whole increased, while the number of vessels harvesting decreased by 63%. As Table 4 shows, the average efficiency of survivors was higher under tradable property rights than under command and control. Despite these aggregate economic benefits, however, this dramatic change in the fishery created substantial turmoil in policy discussions. The essential economic and legal question, "Who gains from tradable property rights?," remained unanswered. One reason for this controversy is that

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

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.

To estimate the change in mean efficiency we first address the issue of correlation between the compound error term and the participation decision by estimating a logit regression for the decision to leave the industry (*exit*=1) or stay (*exit*=0). The predicted probability of exit then provides an instrument for the participation decision. Second, we condition the distribution of the inefficiency term on the relevant attributes from the base case in Table 3 and include the predicted probability of exit.

The complete model is in Equation 3. The logit regression for participation reflects the considerations that were reported during field interviews to be central to decision to exit or to continue harvesting including contractual relations with a buyer and profit. 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, in the form of both written contracts and mutual understandings, where violations of trust can have significant consequences for locating a buyer of clams[46]. The variable *contracts* is the number of processors a vessel delivers to in each year, relative to the industry mean. The second important driver of the exit decision is vessel profit, which has an obvious interpretation. Last we allow the mean probability of exit to vary by firm type by including the indicator variables (*VI*, *HI*).

[46] This issue has been discussed in the anthropological literature on fisheries. For comprehensive reviews see Bonnie McCay *et al*., *supra* note 16 and McCay and Creed, *supra* note 16.

Therefore the regression model is now:

$$h_i^* = b_o + b_{fuel}(fuel_i) + b_{labor}(labor_i) + b_{population}(population) + b_{capital}(capital_i) + v_i - u_i$$
$$u_i = a_o + a_{HI}(HI_i) + a_{VI}(VI_i) + a_{size}(size_i) + a_{exit}(\hat{exit}_i) + e_i$$

The participation equation is:

(3)

$$\Pr(exit = 1) = F\left[j_0 + j_{\text{contracts}}(contracts_i) + j_{\text{profit}}(profit_i) + j_{VI}(VI_i) + j_{HI}(HI_i)\right]$$

and

$F(z) = \dfrac{e^z}{1+e^z}$ is the cumulative logistic distribution

[Table 5 about here]

The estimates of the exit equation suggest that contracting relationships, profit and vertical integration are the most important determinants of exit. The coefficient for the number of contracts is 0.21 and is statistically significant at the 1% level, the positive 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[47], and harvesters contracting with multiple processors were seen as disloyal. Thus, in the period of restructuring after tradable property rights were implemented, the more contracts a harvester had, the less likely the harvester was to remain in the industry. Profit has the expected sign and is statistically significant. Relative to independents, vertically integrated firms were more likely to exit while horizontally integrated firms were less likely than independents.

[Table 6 here]

Table 6 presents the regression results for the stochastic production function with the instrument for exit. Recall that μ is the conditional mean of the *in*efficiency term. The coefficient on

[47] 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.

predicted exit is positive and statistically significant at the 1% level, confirming the pattern seen in Table 4 that those that exited (*exit*=1) had higher mean inefficiency than those that stayed (*exit*=0). The negative and statistically significant coefficients on the other variables suggest that integrated firms and large vessels have lower mean inefficiency than do independent firms and small vessels. There are two critical differences between the regression results in Table 3 and Table 6. When we correct for the exit decision, the effect of the vessel size is smaller while that of vertical integration is larger relative to the base case. These differences add a dimension to the policy discussion which focuses on "large versus small" fishers. Specifically the results highlight the importance of distinguishing between vessel attributes and firm type, a distinction that is not clear in current legislation and policy discussions.

[Table 7 here]

To explore this issue more, the mean efficiency scores under the two policies by firm and vessel characteristics are in Table 7. After tradable property rights the increase in mean efficiency for vertically integrated firms (over 10%) was substantially greater than that for independents and horizontally integrated firms (4 and 3.5%, respectively). While independents have the lowest mean efficiency under tradable property rights, it is important to note that this ranking is not different under tradable property rights than under command and control. In contrast, the ranking of vertically integrated and horizontally integrated firms does change with the introduction of tradable property rights with vertically integrated firms having the greatest mean efficiency. This result introduces the complexity that both the existence and type of integration are important considerations in predicting outcomes.

The increase in mean efficiency was 13% for smaller vessels whereas it was a negative 1% for large vessels. The disproportionate gain in efficiency of small vessels reflects the disadvantages they faced under command and control. Traditional input restrictions placed a premium on the ability to harvest as fast as possible during limited harvesting periods, favoring firms with greater total capacity and greater flexibility of labor. Under tradable property rights, harvesting can be spread over the entire season, reducing the size advantage of large vessels.

Comparing the efficiency scores in Table 7 to the analogous statistics for the base case shows the importance of using an instrument for the exit decision. Under the base case the pattern for vessel size is the same as that for Table 7. Small vessels have a greater gain in mean efficiency than large vessels, but in the base case the size of the efficiency gain for small vessels is substantially understated (7%). The statistics for firm types under the base case differ from those in Table 7. Under the base case, independents exhibited substantial gain in efficiency (9%) while the mean efficiency of horizontally integrated firms decreased (-0.7%). The results from the base case and the second model would suggest different policy designs and judgments in the lawsuits against the regulatory agency.

While aggregate efficiency change in the industry as a whole shows 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 contradict the common, naïve belief that efficiency gains accrued predominately to large participants and emphasize the need to distinguish between vessel and firm attributes. 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.

IV. 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 the remaining vessels should become more efficient; no longer subjected to rigorous input and output constraints, harvesters can adjust inputs and make harvesting decisions to operate at the most efficient rate.[48] 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

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

econometric model isolates vessel-level efficiency from industry structure effects, it is possible to see how different classes of vessels and firms were affected by the new policy. The results would be surprising to many participants in the current policy debate over tradable property rights. After correcting for the effects of strategic re-entry and attrition, we found that smaller vessels gained more than large, independent firms tied horizontally integrated firms, and vertically integrated firms gained more than other firm types.

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.

These results have specific implications for future tradable property rights regimes in fisheries. First, at the start of negotiation, a control date should be established after which harvests will not count toward the allocation of property rights. While this is contrary to the current direction of legislative debates, which reward current participation in the fishery, it will eliminate the incentive firms otherwise have to expand effort and employ inefficient capital, which depresses productivity and puts added pressure on the fishery. Second, tradable property rights should be allocated to firms, rather than to individual vessels; this will prevent firms with superior access to financial capital (and information about impending policy changes) from buying up vessels solely for the purpose of accumulating property rights. Third, if equitable allocation of tradable property rights is a stated goal, then the process of how allocations will be determined needs to be made transparent. Last, Federal guidelines for economic evaluation of fisheries should address the sample selection issues created by any policy change, in order to correctly measure the impact of policy on both productive efficiency and the distribution of benefits.

Together, these changes will mitigate the suboptimal effects of policy transition and increase the overall benefits of tradable property rights systems. Perhaps most importantly, careful assessment of sample selection issues will help more accurately measure the true efficiency and equity impact of tradable property rights, in the process helping to clarify the ongoing debate over fisheries regulation.

TABLE 1:

SUMMARY STATISTICS FOR EXPLANATORY VARIABLES IN SELECTION MODEL AND PRODUCTION FUNCTION

Variables	1984-1990 Mean (std. deviation)	1991-1999 Mean (std. deviation)	1984-1999 Mean (std. deviation)
Harvest	21797	37814	26238
	(14339)	(36306)	(24985)
Capital (vessel length)	86	85	85
	(23)	(16)	(21)
Labor (crew hours)	394	558	437
	(352)	(533)	(430)
Fuel (gallons)	15627	21089	17632
	(15116)	(21008)	(17320)
Population of clams (metric tons of biomass)	1323029	1209634	1288320
	(36762)	(30805)	(62934)
Number of contracts	5.8	3.5	5
	(3.6)	(2.8)	(3.6)
Profit (1990 dollars)	169005	277002	188,026
	(116043)	(256792)	(169000)

NOTE. –There are 866 observations in the Command-and-Control period, 382 observations in the Tradable Property Rights period, and 1248 observations overall.

TABLE 2:

FREQUENCY OF FIRM AND VESSEL TYPES

	Vessel Size in 1987	
Firm type in 1987	<= 100 GRT	> 100 GRT
Independent	21	19
Fleet	18	30
Vertically integrated	11	36

TABLE 3:

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

ln(Harvest in Bushels)	Coefficient	Standard Error
Constant**	24.26	3.50
Fuel **	0.44	0.06
Labor**	0.39	0.06
Population**	-1.56	0.25
Capital**	0.33	0.06
µ		
Constant**	-143.16	45.76
Horizontally integrated**	-110.50	40.63
Vertically integrated	-29.02	20.93
Size**	-124.99	42.62
s^2	101.21	30.84
g	0.99	.002
s_u^2	101.11	30.84
s_v^2	.10	.008
Log likelihood	-835.56	

NOTE. –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 1248 vessel-year observations.

* Significant at the 5 percent level. ** Significant at the 1 percent level.

TABLE 4:

MEAN EFFICIENCY SCORES OVER POLICY PERIODS BY EXIT CHOICE

	Command and Control, 1984-1990	Tradable Property Rights, 1991-1999	1984-1999
	Mean (standard deviation)	Mean* (standard deviation)	Mean (standard deviation)
All	0.699	0.759	0.715
	(0.185)	(0.144)	(0.177)
Survivors	0.758	0.772	0.766
	(0.126)	(0.125)	(0.125)
Exit	0.705	0.646	0.702
	(0.171)	(0.226)	(0.174)
Re-entrants	0.464	NA	0.464
	(0.262)		(0.262)

NOTE. –Over the period 1984-1999, there are 1248 total observations of which 879 are of vessels that did not exit, 318 are of vessels that exit after policy change, and the remaining are of vessels that re-entered during negotiations.

* This mean includes some vessels that exited within a year of implementation of tradable property rights, while survivors include only those vessels that continued to harvest even after transition. By definition the "re-entrants" are not observed under tradable property rights; thus these statistics are not applicable (NA).

TABLE 5:

PARTICIPATION DECISION

Exit	Coefficient	Standard Error
Constant**	-1.83	0.15
Contracts**	0.21	0.02
Profit**	$-1.65e^{-6}$	$4.67e^{-7}$
Horizontally integrated*	-0.40	0.20
Vertically integrated**	0.69	0.19
Log likelihood	-659.21	
Hosmer-Lemeshow $?^2$	11.68	
Number of observations	1248	

NOTE. –The outcome variable, exit, is equal to one if the firm leave the fishery and zero otherwise.
* Significant at the 5 percent level. ** Significant at the 1 percent level.

TABLE 6:

STOCHASTIC PRODUCITON FUNCTION WITH INSTRUMENT FOR SELECTION

Harvest	Coefficient	Standard Error
Constant**	21.67	3.44
Fuel**	0.41	0.06
Labor**	0.43	0.06
Population**	-1.38	0.24
Capital**	0.37	0.06
μ		
Constant**	-104.67	28.16
Horizontally integrated**	-91.88	27.54
Vertically integrated**	-99.37	28.90
Size**	-41.03	12.93
Predicted-Exit**	224.73	63.30
s^2	39.71	10.03
g	0.97	0.001
s_u^2	39.60	10.03
s_v^2	0.10	0.01
Log likelihood	-800.75	
Number of observations	1248	

NOTE. ** denotes statistical significance at the .01 level.

TABLE 7

MEAN EFFICENCY BY FIRM AND VESSEL ATTRIBUTES

	Firm Type				Vessel Size		
	Independent	Horizontally Integrated	Vertically Integrated	All	<= 100 GRT	>100 GRT	All
Command and Control	0.701	0.782	0.744	0.742	0.672	0.792	0.742
	(0.155)	(0.164)	(0.175)	(0.167)	(0.199)	(0.118)	(0.167)
Tradable Property Rights	0.729	0.809	0.822	0.778	0.761	0.782	0.778
	(0.160)	(0.086)	(0.120)	(0.137)	(0.131)	(0.138)	(0.137)

NOTE. -Standard deviations are reported in parenthesis.

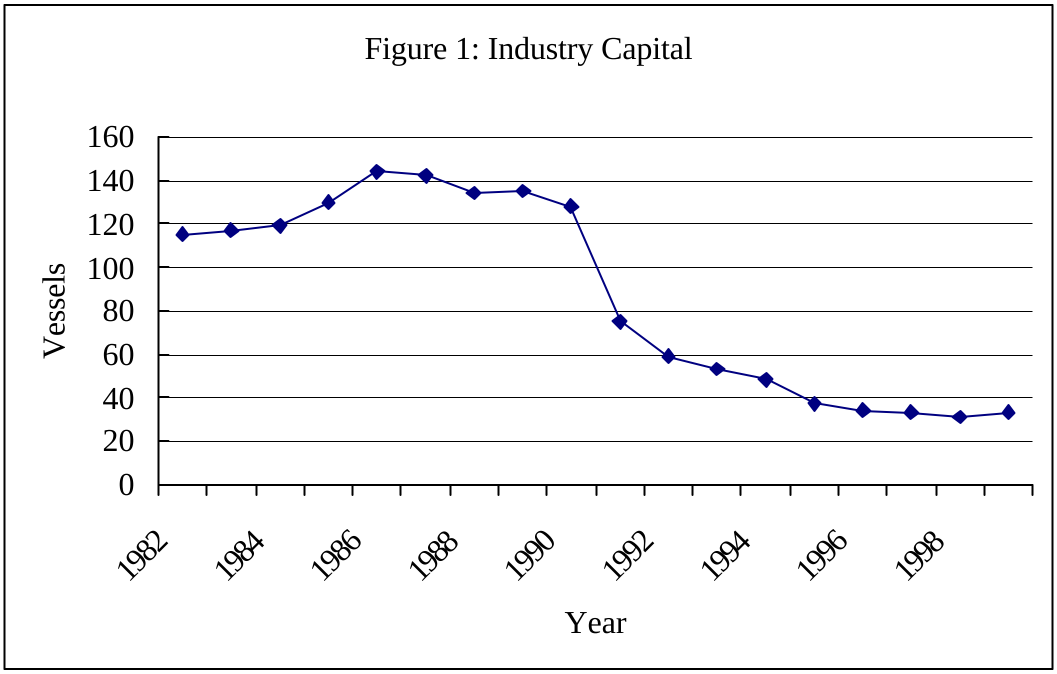
Figure 1: Industry Capital
Vessels
160
140
120
100
80
60
40
20
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year

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