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A Laboratory Assessment of Tradable Fishing Allowances

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Abstract *Transferable allowance management systems are receiving increased attention from fishery managers and stakeholders alike. We use a laboratory experiment in which human subjects play the role of fishers to evaluate the promised economic efficiency of tradable allowance systems. In an experiment designed to parallel the most common rules for trading allowances, we find that allowance prices are only weakly associated with the value of the fishing right it provides. Instead, we find a high degree of price variability, consistent with field experiences. In the lab, this variability hampers convergence and supports speculation, leading to average prices much higher than the equilibrium value of allowances. During this protracted price discovery, allowances are misallocated and efficiency falls. Modifications to the market institutions used in most tradable allowance systems to improve price discovery and enhance efficiency are discussed.*

Key words Fishery management, ITQs, tradable fishing rights, transferable allowances, experiments, asset markets.

JEL Classification Codes Q22, Q28, G12.

Introduction

Tradable allowance systems are being increasingly applied to address numerous environmental and natural resource management problems, including water use, pollution, and overfishing (Tietenberg 2002). In a typical application of tradable allowances, a management authority sets an allowable level of activity, allocates allowances to that level among users, and permits users to trade, or otherwise transfer, their allocations. This establishes a market for an entirely new asset, which can be extremely valuable and constitute a significant portion of the wealth or assets of the stakeholders, particularly in water and fishing applications where stakeholders are often small or family businesses. Research on the design of institutions for trad-

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ing water and pollution rights has greatly improved the performance of these institutions. However, there is no published research on the design of the institutions that are used for trading fishing allowances. This paper aims to begin to fill this gap in knowledge.

In fishery management, tradable allowance management includes tradable crab and lobster traps, tradable days-at-sea, and the most common, individual transferable quotas (ITQs). Like other cap-and-trade systems, in each of these tradable allowance systems, fishery managers determine a total amount of effort (traps or days-at-sea) or landings (quota) allowed, allocate it among fishery participants, and permit them to trade their allocations. According to the most recent review of experiences with tradable fishing allowance programs, ITQ programs have been applied to manage hundreds of fish stocks globally (Arnason 2002). At least seven major fishing countries use ITQs as a principal component of their fisheries management systems.[1] Arnason (2002) estimates that "over 10% of the global ocean fish harvest is currently taken under ITQs."

The spread of tradable fishing allowance programs, which began with the adoption of 200-mile exclusive economic zones in the 1970s, is due in large part to the comparative advantages of these rights-based systems. Relative to traditional management measures, ITQs have a proven record of more effectively constraining exploitation within set limits, mitigating the race-to-fish, reducing overcapacity and gear conflicts, while improving product quality and availability. Producers and consumers benefit from ITQs, and, when the resource rent is used to pay for the cost of management, the general public benefits (Arnason 2002; NRC 1999; OECD 1997; Squires, Kirkley, and Tisdell 1995; Sutinen and Soboil 2003).

There are other appealing attributes of ITQs as well. Quota markets relieve managers of most allocation decisions and allow them to devote their time and resources to conservation decisions. ITQs provide fishers with the flexibility to scale their operations to a level that best suits them. Another appealing feature is that quota markets value the right to fish, which provides fishers with greater security for retirement than currently exists. The approach creates an incentive to leave the fishery and to sell quota to new entrants. Fishers also appreciate the opportunity to value explicitly their fishing skills, and the liberation from command-and-control regulation, which can be unpredictable. Some environmental groups support ITQs because of the environmental and ecosystem benefits that result from the reduction in fishing effort.

Despite the many advantages of ITQs, there are numerous concerns about the overall merits of these tradable allowance programs. One principal concern is concentration of ownership; that a few large operators will control the quota (or other allowance) and small operators will be pushed out of the fishery. Another concern is that ITQs will harm the coastal communities that depend on numerous small-scale fishing operations (NRC 1999). Some fishers and managers find such programs threatening and risky because of previous experiences with high levels of price volatility (Newell, Sanchirico, and Kerr forthcoming; Larkin and Milon 2000). They are anxious about how they and their fisheries will be affected by unfamiliar market institutions. They tend to prefer to rely on the management methods with which they are familiar, such as size and gear restrictions. In addition, some simply believe it is wrong to allow a market to determine who can fish and the quantity of fish any one

[1] The seven countries are Australia, Canada, Chile, Iceland, Namibia, the Netherlands, and New Zealand. In addition, at least five other countries (Greenland, Mexico, Mozambique, Portugal, and the United States) use ITQs in some of their fisheries; and other important fishing countries, such as Argentina, Morocco, and Peru are planning to introduce ITQs in some of their fisheries.

individual can catch; wrong to 'privatize' our public resources; and wrong to allow some fishers to reap windfall profits from initial quota allocations (Macinko and Bromley 2002).

These concerns about the effects of ITQs have resulted in programs that place several restrictions on transferability. Arnason (2002) notes that there are restrictions on both quota trades and quota holdings. Trades commonly are restricted by setting a minimum or maximum volume of the quota traded, restricting times when trades may be made, and allowing trades only among specific subgroups of the fishery. Holdings commonly are restricted by who can hold quota and how much can be owned by any one party.

The concerns about the effects of ITQs prompted the US Congress to include in the 1996 Sustainable Fisheries Act a moratorium on the introduction of new ITQ programs. The moratorium lasted six years and expired in the fall of 2003. Recent reports by the National Research Council (NRC 1999) and the Pew Oceans Commission (2003) have encouraged many managers and stakeholders to consider making tradable allowances part of their management programs. They are hoping that ITQs and other types of tradable allowance programs can be designed to address a wide range of fishery-specific social and economic objectives.

Since the extent to which these objectives can be achieved varies from fishery to fishery, it is common for regional management bodies to have responsibility for designing new tradable allowance systems. Unfortunately, these regional management bodies have little experience—and less systematic analysis of those experiences—on which to draw when designing new trading institutions. First, there is limited experience worldwide with tradable allowance programs, and second, there is little variation in the institutional designs of tradable allowance programs, as programs within and across countries share many basic design features.

One way to inform the design of tradable rights systems is through controlled economic experiments, in which human subjects play the role of fishers in a simulated environment that represents the key incentives of alternative allowance trading institutions. By comparing institutions in the laboratory, they can be evaluated for the degree to which they achieve management program objectives, and flaws can be identified and addressed before serious or irreversible consequences arise in the field. Laboratory testbedding, which has proven useful in developing high-value centralized auctions, like those used by the FCC to sell spectrum rights, and in designing tradable rights systems for water use and pollution emissions can be a vital tool for designing these new institutions. Implementing rules of regulation, enforcement, and trade in the laboratory will allow policymakers to compare—at relatively low cost—the complex interactions of incentives and disequilibrium properties that are not well understood theoretically.

We demonstrate an application of laboratory testbedding to tradable allowance fishery management, using the Rhode Island inshore lobster fishery as the context for the study. In 2001, a group of Rhode Island lobstermen and fishery managers considered applying a tradable trap program to the southern New England American lobster fishery (modeled on the tradable trap certificate program in the Florida spiny lobster fishery). The Atlantic States Marine Fisheries Commission, which manages American lobster in northeastern US, recently approved a version of the tradable trap program for the fishery. The details of the trap trading arrangements have not yet been determined. Our research efforts are aimed to inform managers on how to design the market institution for this program.

The next section of the paper provides some background on previous applications of experimental methods to policy analysis. We then present the general equilibrium model of tradable allowance systems on which our experimental hypotheses are based. This is followed by a description of the laboratory representation of a common allowance trading institution that we used to test our primary hypothesis, that allowance trading achieves stable, predictable equilibrium prices and the corresponding efficient allocations of fishing effort. The results presented are not supportive of this hypothesis, instead reflecting a high degree of price variance and showing prominent features of disequilibrium trading in other experimental asset markets. Many of these features are consistent with field data on tradable allowance prices. Because experimental techniques allow knowledge of the equilibrium value of allowances, we can determine that this price variance facilitates formation of a price bubble and significantly inhibits price convergence and efficiency. We conclude with a discussion of modifications to our tested institution, which mirrors prominent features of field institutions, which might improve initial and long-term outcomes.

Use of Experimental Methods in Policy Analysis

Experimental economics can contribute to the analysis of market-based policies in two ways. First, it can provide a carefully controlled test of a theoretical model. Many of the reasons cited for using tradable allowances rely on the ability of the market to accurately price allowances. When the market price is based on supply and demand derived from the marginal profit an additional allowance unit provides fishers, the post-trading allocation of allowances maximizes the profitability of the fishery. In addition, allowance costs can be covered with earnings from the additional allowances, and price changes will be predictable based on expected changes in the stock, harvesting costs, and market demand. However, realizing these efficient allocations requires equilibration. An empirical question that can be addressed in the laboratory is whether quota markets equilibrate, or instead exhibit unstable or non-equilibrium tendencies that are due to features of the underlying derived demand functions, the asset-like properties of permanent quota, or particular rules of trade which facilitate speculation or other disequilibrium behavior.

A second way experimental techniques can contribute to analyzing market-based policies is by comparing different ways of structuring the market (Plott 1994; 1997). While we might accept an equilibrium theory as true if predicted outcomes eventually obtain, the convergence process—about which very little is known theoretically—has important policy consequences (Banks *et al.* 2003). Different definitions of the property right, rules for trading it, and complementary institutions affect the speed and nature of price discovery, and thus ultimately determine the outcome. When theory offers little guidance, experiments can be used to testbed trading institutions or evaluate the merits of alternative trading policy proposals to determine those that appear best suited for a particular application. Flaws in proposed designs can be uncovered and corrected before implementation in the field, where such adjustments may be impossible or require much greater expense.

Experimental testbedding has been successful in a number of high-profile, high-value applications which are closely related to tradable allowances, including the auction NASA uses to determine space shuttle payload priorities (Ledyard, Porter, and Wessen 2000) and the auction the FCC has used raise more than $9 billion selling licenses to bandwidth used by cellular telephones (Banks *et al.* 2003; Salant 2000; Plott 1997). Cellular licenses are challenging to auction efficiently because there are complementarities in owning adjacent licenses; owning both south and central Florida is more valuable than the sum of owning just south and just central, because fees do not need to be paid to the owner of the other to carry calls to the other zone. In a sequential auction, bidders on south Florida would need to adjust their price strategically, not knowing whether they would be able to afford central

Florida, auctioned later. Experiments helped design an auction institution that improves efficiency and maximizes revenue by allowing participants to bid on all licenses simultaneously, so the synergies of owning adjacent licenses can be priced in the auction. Experiments also addressed practical questions about the efficiency impacts of minimum bid increments, which considerably speed this complex auction.

Most closely related to tradable fishing allowances are a number of applications in water rights trading (*e.g.*, Murphy *et al.* 2000; Murphy *et al.* 2003; Cummings, Holt, and Laury 2004), and tradable pollution rights (Franciosi *et al.* 1993) (see Shogren and Hurley 1999 for a survey). Specific cases include the market mechanism for trading sulfur dioxide and nitrous oxide in southern California (Ishikida *et al.* 2000; Carlson *et al.* 1993) and that used by the Environmental Protection Agency to trade pollution permits for sulfur dioxide under the Clean Air Act (Cason 1995; Cason and Plott 1996). In the latter case, the EPA implemented a discriminative auction for trading permits in which buyers and sellers each submit sealed bids and low-asking sellers were matched with high-bidding buyers; buyers paid their bid price to their matched sellers. Experiments demonstrated that this institution's incentives led sellers to underreport the true costs of emissions control in hopes of being matched with lower-bidding buyers, resulting in inefficient trades. These experimental results subsequently led to a change in the auction design for pollution permits. This is an example of how investing in laboratory testbed research before implementing a rights-trading system can improve the outcomes of tradable allowance markets.

A General Equilibrium Model of Tradable Allowances

Whether it is optimal for each fisher to buy or sell allowances depends on the price, suggesting it is easiest to think about allowance trading in a general equilibrium framework. Consider a fishery of $i = \{1,\ldots,I\}$ fishers. Each fisher has nonnegative amounts of two goods; allowances, x_i; and numeraire, μ_i. Each fisher has an endowment of allowances, ω_{xi}, and an endowment of a numeraire good, $\omega_{\mu i}$. He earns a profit from fishing, $\pi_i(x_i)$, based on the quantity of allowances he holds. In a fishery in steady state, the fisher's problem is to select a level of allowances, x_i, which maximizes his total utility from fishing and holding the numeraire:

$$\text{Max}_{xi}\ U = \pi_i(x_i) + \mu_i$$
$$\text{s.t. } p \cdot x_i + \mu_i = p \cdot \omega_{xi} + \omega_{\mu i},$$

where $\pi_i(x_i)$ is the monetized profit the fisher earns from fishing with x_i allowance units. We allow the profit functions to vary from fisher to fisher based on skill, the cost structure of each operation, individual discount rates, and the utility from fishing. We impose the restriction that the profit function is convex from below, $\partial\pi_i(x_i)/\partial x_i > 0$ and $\partial^2\pi_i(x_i)/\partial x_i^2 \leq 0$.

The quantity of allowances demanded by fisher i is given by the level of x_i^* which satisfies:

$$\left.\frac{\partial\pi_i(x_i)}{\partial x_i}\right|_{x_i^*} = p.$$

This induces a demand function, $x_i(p)$, which indicates x_i^* for all prices, and an excess demand function $z_i(p) = x_i(p) - \omega_{xi}$, which indicates the quantity of allowances demanded in excess of endowment; negative values indicate a willingness to supply at price p.

A Walrasian equilibrium of this economy is a nonnegative price for allowances p^* and a vector of allocations $(x^*, \mu^*) = \{\{x_1^*,\ldots,x_I^*\},\{\mu_1^*,\ldots, \mu_I^*\}\}$ such that:

$$\sum_i p^* \quad z_i(p^*) = 0 \quad \text{and} \quad \sum_i x_i^* \leq \sum_i \omega_{xi} \quad \text{and} \quad \sum_i \mu_i^* = \sum_i \omega_{\mu i}.$$

If the regulatory input or output restriction is binding, p^* will be strictly positive. This is an equilibrium in the sense that at the given price, no fisher wishes to sell another allowance unit, for it would cost more than p^* in foregone profit, and no fisher wishes to purchase another allowances unit, for it would gain less than p^* in additional profit.

This equilibrium has two properties that are often cited as reasons to use a market to allocate allowances. First, the First Welfare Theorem implies that no Pareto improvements are possible, which means that allowances will be traded from fishers who value them less to the fishers who value them more, maximizing the profit value of landed catch. Second, equilibrium prices are tied to a fundamental value, the marginal profit-value of the additional harvest they provide to the marginal purchaser. This means that any changes in allowance prices should reflect changes in the cost structure of the fishery, stock health, and the market price for landings rather than fluctuate without apparent cause. Therefore, prices should be predictable given the state of the fishery, and there should be few opportunities for market speculation.[2]

Hypotheses

The hypothesis to be tested is that the prices and allocations predicted by the general equilibrium model obtain. That the experiment is testing a model is significant because economic theory provides the key to the generalizability of the results: testing the predictions of a model implies the results of the experiment will extend to other situations that can be represented by the same model.

There are at least two alternative hypotheses which may help explain deviations from equilibrium. The first is price discovery failure. While markets are generally good at converging to equilibrium prices, equilibrium need not always obtain. Inelastic supply and demand curves allow a wide range of prices at which mutually profitable trades can take place. In this environment where supply and demand curves are based on profit functions with decreasing marginal returns, each buyer must first purchase his highest-value unit from a seller, who must first sell his lowest value unit. Therefore, early prices may range widely and result in slow price discovery.

A second reason outcomes may deviate from equilibrium is speculative bubbles. Because an allowance is an asset which can be bought and sold in each period, when deciding whether to purchase allowances, a fisher may consider her beliefs about what others will pay for it in the future, as well as the profit from fishing which can be obtained with the additional allowances. In experimental markets where assets pay a random dividend at the end of each period, bubbles—in which prices exceed the expected total dividend, and even the maximum possible total dividend—have been widely and consistently observed (*e.g.*, Smith, Suchanek, and Williams 1988; Fisher and Kelly 2000; see Sunder 1995 for a survey). If many people believe others will pay a high price in the future, they may bid up the price of allowances.[3] The

[2] The model is stated and tested with perfect information. In the field, market participants have imperfect and asymmetric information about stock levels, harvesting costs, and future market demand. However, if equilibrium outcomes do not obtain with perfect information, there is little chance the model will apply in the more complex field environment.

[3] Lei, Noussair, and Plott (2001) show that bubbles occur even when resale is prohibited, suggesting that bubbles may occur for reasons other than speculation.

likelihood of such bubbles may increase when higher-than-equilibrium prices observed in the high-variance early stages of price discovery reinforce the belief that others will be willing to pay high prices in the future.

Experimental Design

To test whether the general equilibrium predictions obtain, we use a controlled laboratory experiment in which subjects play the role of fishers in a tradable allowance market modeled on trading rules commonly used in the field. In the experiment, subjects trade in a market for allowances, and their profit from fishing is determined by the quantity of allowances they hold. At any available market price for allowances, they must decide whether to buy more allowances and fish more, sell some allowances and fish less, or fish their current holdings of allowances. As in a naturally occurring fishery with an allowance market, subjects who better balance fishing and trading allowances to maximize their total profit from both activities earn more profit in the experiment and are paid more money for participating.

A round of the experiment consists of four periods, or fishing years. At the beginning of the round, subjects are endowed with a quantity of allowances and cash. Each period has two parts, a trading phase and a fishing phase. During the trading phase, the market opens for subjects to trade allowances with one another. The first trading period of each round is five minutes long, the second period is four minutes long, and the third and fourth are three minutes long. After the trading market closes, subjects earn profit from fishing. Profit is determined from a table based on the amount of allowances the subject holds after trading. Four periods have been shown to be sufficient time for markets to converge (Davis and Holt 1993; Smith and Williams 1983). Each experimental session consists of three rounds, where initial endowments are restored between rounds, so subjects may repeat the exercise with the benefit of experience, and we may assess how experience affects outcomes.

Allowances are structured as an asset which provides the opportunity to earn profit in each period until the end of the round. Allowances purchased in the first of four periods provide profit in each of the four periods, while allowances purchased in the last period provide profit only in the final period. Therefore, the predicted equilibrium price of allowances decreases from period to period by the amount of profit the inframarginal demander earns from holding the marginal allowance unit in one period.

The allowance market is structured as a double auction, in which any fisher can make both buy and sell offers in the market. The market consists of a centralized price board (the "Current Market" in figure 1) which lists the prices at which buyers are willing to buy and sellers are willing to sell. At any time, a subject can buy (sell) by accepting the best lowest sell (highest buy) price advertised. If he does not like the best prices advertised, he can also advertise his own price buy (sell) price and quantity through the market, hoping someone will accept it. Once an offered price is accepted, the trade is immediately executed at that price, so different trades can take place at different prices.

The double auction is a robust market institution originally developed to address shortcomings of decentralized bilateral markets (Chamberlain 1948; Smith 1962).[4]

[4] Most allowance systems use a decentralized auction, where participants may trade at different prices but price information is imperfectly distributed. This system closely resembles Chamberlain's (1948) market experiments, where competitive equilibrium did not obtain. The primary features of the field market we are replicating are the opportunity for different trades to take place at different prices and the opportunity for resale. To the extent that the double auction is more centralized than many field institutions, it biases our results toward price convergence.

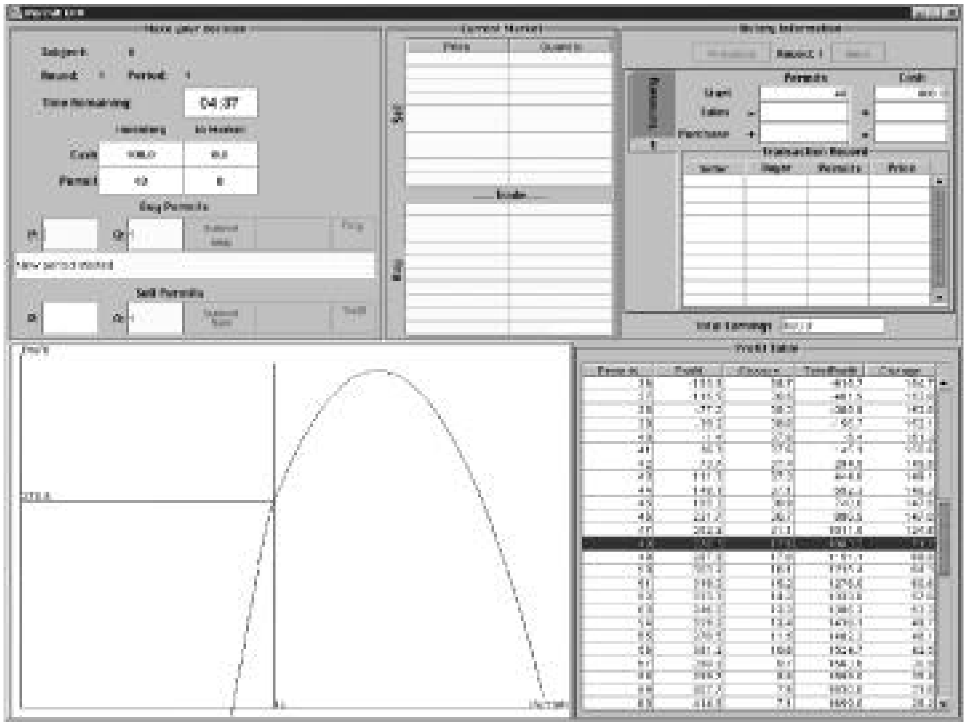

Figure 1. Subject's Experimental Software Interface

Since then, it has been widely used in experiments in single markets (see Kagel 1995 for a survey), multiple-market systems (*e.g.*, Noussair, Plott, and Reizman 1995; Anderson *et al.* 2004), and asset markets (*e.g.*, Smith, Suchanek, and Williams 1988). In standard commodity markets, its convergence properties are so well established that it is frequently used to teach undergraduates about competitive equilibrium theory (Bergstrom and Miller 1999).

Subjects earn profit from fishing based on the amount of allowances they hold when the market closes. Profit functions are presented to subjects both as a graph of the period-profit function, shown in the lower-left of figure 1, and as a table, in the lower right of figure 1. For each number of allowance units, the table shows the subject her total profit for the period; the marginal profit provided by the last allowance unit; the total profit (from fishing) if she holds exactly that quantity of allowances at the end of each period remaining in the round; and the marginal total profit provided by the last allowance unit. This is the least she should be willing to accept to sell one unit; the marginal total profit in the next row is the most she should be willing to pay to purchase another allowance unit.

The profit functions are based on those of medium-large operators in the Rhode Island inshore lobster fleet, derived from 2001 logbook data (collected by the RI Department of Environmental Management). The medium-large classification is a cluster of 33 licenses landing an average of 14,950 pounds per year, fishing 90 days a year at an average of 236 hauls per day. They average 1.68 crew members (including the captain), and soak for a median of 6.45 days.[5] For this group, we estimated an annual production function and multiplied it by the average ex-vessel price ($4.15) to obtain annual revenues.[6] We obtained variable and fixed cost estimates from local lobstermen assisting with the project.[7] Convexity is achieved by assuming that a larger number of traps increases soak time, which increases bait cost and decreases per-trap productivity. This profit function treats the market for catch as exogenous, eliminating a task that would otherwise have to be explained to subjects. It also simplifies the subjects' task by reducing the number of production variables (*e.g.*, different input costs) that would need to be explained, while still capturing the incentives represented in those costs.

In this experiment, the profit function of each of 14 subjects (12 in session E) is maximized at 67 allowance units, with a per-period profit of 440 experimental dollars. The total allocation of allowances among the 14 subjects is 770 units. Subjects were endowed with either 62 allowance units and 80 cash units (expected net sellers) or 48 allowance units and 400 cash units (expected net buyers). With these endowments, the allowance market equilibrium is for each subject to hold 55 allowance units and the market price to be between 41 and 46 experimental dollars in the first period.[8]

To simplify the design of initial experiments, and especially to reduce the complexity of the subjects' problem, this profit function is assumed to be the same in every period. This is equivalent to assuming the fishery is in steady state, and that the total allocation of allowances is such that recruitment exactly offsets harvest and mortality. Although few managed fisheries are in steady state, if the equilibrium of the tradable allowance model fails to obtain in this simpler environment, there is little hope it will be useful with a dynamic or stochastic stock.[9] A steady-state stock

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[5] Using a cluster analysis based on landings, hauls per day, days fished per year, crew, set time, and total traps fished, we classified the 287 licenses active in Area 2 during 2001 into five categories: Large (18 licenses), landing an average of 27,104 pounds per year; Medium-large (33 licenses), landing 14,950 pounds; Medium (18 licenses), landing 8,169 pounds; Medium-small (44 licenses), landing 3,600 pounds; and Small (174 licenses), landing 464 pounds. We will use this data for subsequent experiments with heterogeneous fishers representative of the local fishery.

[6] The production function is of the form:

$$Landings = Days\ Fished * [Constant * (Traps)^b].$$

The *Constant* was estimated to be 0.609 and the exponent *b* to be 0.7931.

[7] Since these are the estimates of a few lobstermen, the cost parameters are not necessarily representative of the industry. We note, however, that the experiment is testing hypotheses of the model described in the previous section, which makes only very general restrictions on the profit function. Therefore, the hypothesis tests are meaningful even if this unscientific parameter benchmarking is inaccurate; the calibration is illustrative only.

[8] With discrete-unit supply and demand curves, we must select between a price tunnel (multiple equilibrium prices) and a quantity tunnel (multiple equilibrium quantities). In experiments with quantity tunnels, trading commissions are often offered to provide incentive to make the inframarginal trade at the equilibrium price. In environments where resale is allowed, commissions cannot be offered, so we elected to use a price tunnel, where the market provides the incentive to trade the inframarginal unit.

[9] Previous experiments on repeated common pool resources with contemporaneous externalities have broadly supported rent dissipation models (*e.g.*, Walker, Gardner, and Ostrom 1990; see Ledyard 1995 for a survey). The effects of simple management measures in the contemporaneous externality game are examined in Walker *et al.* (2000). Moxnes (1998b) examines the behavior of different subject pools, including fishermen, in an unmanaged contemporaneous externality game. Walker and Gardner (1992) add a dynamic element by tying the probability of repetition to the level of resource remaining at the end of each stage-game, and find similar results. Moore, Gardner, and Walker (1998) and Gardner, Moore, and Walker (1997) study a dynamic resource problem with intertemporal externalities. In these experiments, subjects allocate effort to harvest a common pool resource in each of several periods. At the end of each period, the remaining resource reproduces itself before the subjects' next period harvest decision. As in the naturally occurring fishery, without regulation, subjects tend to overexploit the laboratory common pool resource. Hey, Neugebauer, and Sadrieh (2001) examine a sole-owner fishery.

also controls for systematic errors in perception of dynamic problems which lead to inefficient resource exploitation (Hey, Neugebauer, and Sadrieh 2001; Moxnes 1998a).

Although explained here in a fisheries context, the task was presented to subjects in neutral terms, consistent with standard experimental practice. Subjects traded “permits” to produce “bings” (a “fictitious product”), from which they earned profit in each period. This decontextualization is necessary because the external validity of the experiment relies on subjects “playing the role” of fishers, given the preferences induced by the experimenters. Participants who better respond to these induced preferences are paid more, in cash, at the end of the experiment for their participation (Smith 1976; Davis and Holt 1993). It is axiomatic in economics that people make decisions that maximize their utility, and since money earned in the laboratory can be used to increase utility outside the lab, participants will make decisions during the experiment that earn them the most money. If the incentives of the economic environment being simulated have been properly represented in the experiment, then participants acting to maximize their laboratory earnings will make the same decisions as agents trying to maximize their utilities in the natural environment. However, if the induced preferences are colored by, or replaced by, an individual’s own preferences, experimental control is lost. Such a loss of control might result in principled responses that provide neither an accurate test of the model (because subjects are not responding to presented incentives) nor an accurate prediction of the outcome in the naturally occurring environment being modeled (because experimental payoffs are not scaled so that subjects may trade off their monetary and non-monetary preferences).

For an experimental session, subjects were recruited to appear at the Policy Simulation Laboratory at an appointed time. They were told they would receive a five dollar participation fee, and would have the opportunity to earn “considerably more” during the experiment. If there were extra subjects (we designed the experiment to accommodate 10, 12, or 14 subjects), volunteers, then randomly selected subjects, were paid their participation fee and dismissed. After signing consent forms, subjects were shown into the laboratory and seated at individual computer terminals, with barriers to discourage talking and impair visibility of others’ terminals. The experimenter then read aloud the instructions (available from the authors) as subjects followed along on their computer screens, explained how to use the experimental software, and led subjects through a two-period practice round. After answering any questions, the experiment began. Following the experiment, subjects’ earnings were converted to US dollars and they were paid privately as they left the lab. Earnings averaged $23.82 with a standard deviation of $3.95 (range of $6.25 to $32.50) for sessions which lasted approximately 1 hour and 45 minutes each.

Although this experiment was designed to achieve a high scientific standard, the policy objectives influenced some design decisions. First, the initial endowments and profit functions lead to a high level of initial efficiency (the endowment is 94% efficient). These functions and endowments were chosen to mirror the fishery, to help fishers and policymakers relate the results of the experiments to the field; while experimental economists might devise a much lower efficiency endowment to generate a stronger test of equilibration, the stronger result would be more difficult for its intended audience to interpret. Second, experimental economists might add more rounds, possibly even bringing back experienced subjects for a second or third session, to determine whether additional experience leads to equilibrium. However, from a policy perspective, this treatment is uninteresting: in the field, there is only one round, so one objective of the experimental testbed is to identify an institution which performs well the first time. Third, experimentalists may also argue that the allowance should have a longer life to be more directly comparable to previous experiments, many of which use 15-period assets. With shorter-lived allowances, we can still effectively test the hypothesis that observed allowance prices equal fundamental values while determining the effect of limited experience with and training on the market institution.

Subjects

Subjects in our experiments were undergraduate students at the University of Rhode Island, recruited from a variety of courses in the College of the Environment and Life Sciences and from a list of students who had participated in previous unrelated experiments. Experimentalists' use of undergraduate student subjects is ultimately a practical consideration, as undergraduates are available by the thousands at most experimental labs, are computer literate, and are willing to participate and make considered decisions for relatively small average payments, making possible collection of statistically valid samples within budgets that funding agencies are willing to supply. Using such a specific subset of the population is not considered to bias results because most experiments do not measure preferences, but rather assess what happens in complex systems when people respond to induced preferences. Since any individual would attempt to maximize their earnings given the induced preferences, the argument goes, no subject population is preferred over any other, since all will respond to the same incentives in the same way.

In policy experiments, however, it is often thought that subjects who are expert in the naturally occurring institutions being modeled might behave differently from properly incentivized non-expert subjects (usually students); therefore, such expert subjects are a preferred subject pool. The common intuition is that experts have well-developed strategies which differ from those of inexperienced subjects that enable them to better respond, or more realistically respond, to the incentives provided. However, expert subjects may have developed habits rather than strategies, and thus not be responsive to features of the experimental environment—such as the potential policies being evaluated—which differ from those presently used. The scale of experimental payoffs may not be sufficient to motivate reevaluating a habitual response in the same way as would a change in the natural environment. In addition, in policy experiments in particular, expert subjects may have opinions about the best policy and may attempt to manipulate the experimental outcome to provide evidence for their position, forgoing some experimental earnings in hopes of a favorable policy. These reasons suggest the opposite intuition, that inexperienced, disinterested non-expert subjects will have greater external validity than a pool of experts.

Based both on previous research and features of our experiment, we expect there would be little systematic difference between fisher and student subject pools attributable to fisher experience. An experiment by Moxnes (1998b) found no differences in the behavior of Norwegian cod fishers, fisheries managers, and non-experts in managing a single-owner laboratory fish stock.[10] In addition, neither subject pool has significant experience with centralized auction markets. Smith, Suchanek, and Williams (1988) found little difference between student and professional bond trader subjects in laboratory asset markets. However, whether, how, and why fisher subjects may differ from students subjects is an interesting avenue for future research.

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[10] Cardenas (2003) documents a relationship between Columbian rural villagers' behavior in a forestry-based common pool resource experiment and their degree of dependence on the forest surrounding the village.

Results

Figure 2 shows the time series of trade prices from one of our five experimental sessions, designated A through E. The heavy vertical lines divide the rounds, and the lighter vertical lines indicate periods. The width of each period's band represents the number of trades that were executed during that period. The thin horizontal lines forming a step function within each round indicate the upper bound of the predicted equilibrium price. Within each round, the equilibrium price of allowances decreases because there are fewer periods remaining in which to earn profit from fishing with them. The gray line connects consecutive contract prices.

The time series reveals several phenomena which indicate the market may not be functioning well. First, there is a tremendous amount of price variance, especially in the first round. Throughout the first period, some subjects are selling for prices below 20, while other are buying at prices above 60, in some cases in (nearly) consecutive trades. While some of this spread may be the result of subjects' focusing too intently on only one side of the market, it presents significant arbitrage opportunities that should inspire corrective action and reduce variance quickly. Instead, this variance establishes a precedent for being able to sell at high prices and buy at low prices, affecting subjects' beliefs about the prices at which they should trade, hampering convergence. Worse, it may support price bubbles as subjects demand units for resale, expecting to be able to resell them at prices like those observed in initial trading.

Second, trading volume is very high. The minimum number of trades necessary in each round to achieve equilibrium is 49 (42 in session E), in which each of seven (six in session E) prospective buyers buys seven units. Because profit functions do not change between periods, these trades should all occur in the first period, and there need not be any trades in the other periods. In figure 2, there were a total of 927 units traded; in each

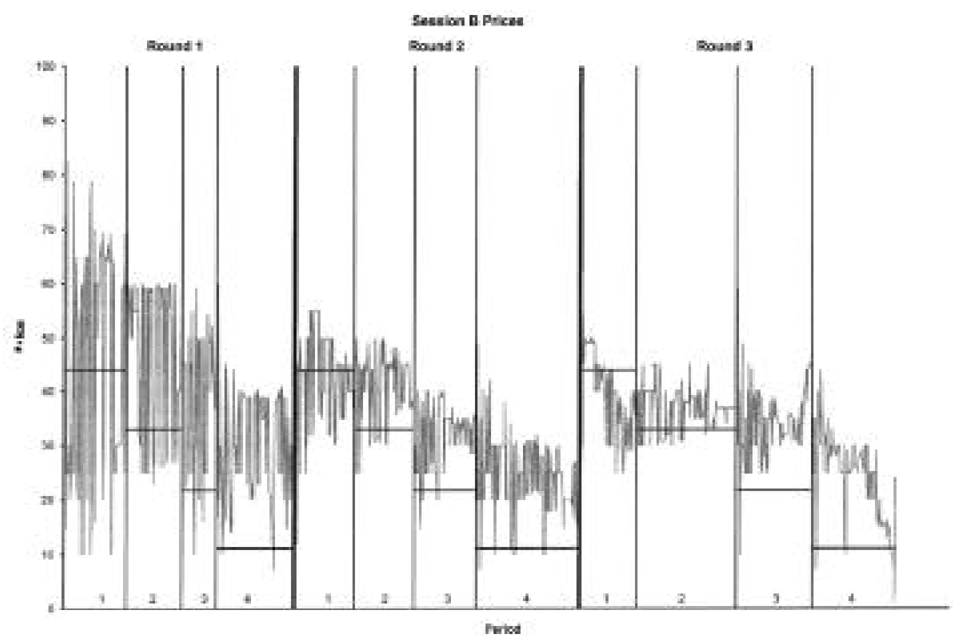

Figure 2. Time Series of Allowance Trade Prices from an Experimental Session

round, there were more than five times the minimum number of transactions necessary to achieve an efficient allocation. This volume of trading suggests that trades are not being driven only by differences in the value of allowances between the buyer and seller, and that prices may, therefore, not reflect fundamental values.[11]

Third, prices within rounds do not decrease across periods as the fundamental value of the allowance asset falls. Instead, average prices stay roughly the same—or even increase—between periods 1 and 2, decrease less than the fundamental value between periods 2 and 3, and decrease more than the fundamental value between periods 3 and 4. Since prices are not reflecting or moving with fundamental value, the market may not achieve its promised efficiency levels.

The following sections more formally characterize the patterns observed in figure 2 across all five experimental sessions. In general, high price variance and high volume dominate the early rounds of trading. Average prices are higher than predicted in equilibrium in all rounds, suggesting trade is not based only on differences in fundamental value between buyers and sellers. Together, these factors lead to a reduction in economic efficiency over the initial allocation.

Average Prices

Patterns in the prices, especially across periods, are most easily seen by examining trends in each period's average price. Figure 3 graphs the average contract price of allowances in each period of each round for each experimental session.[12] The dashed

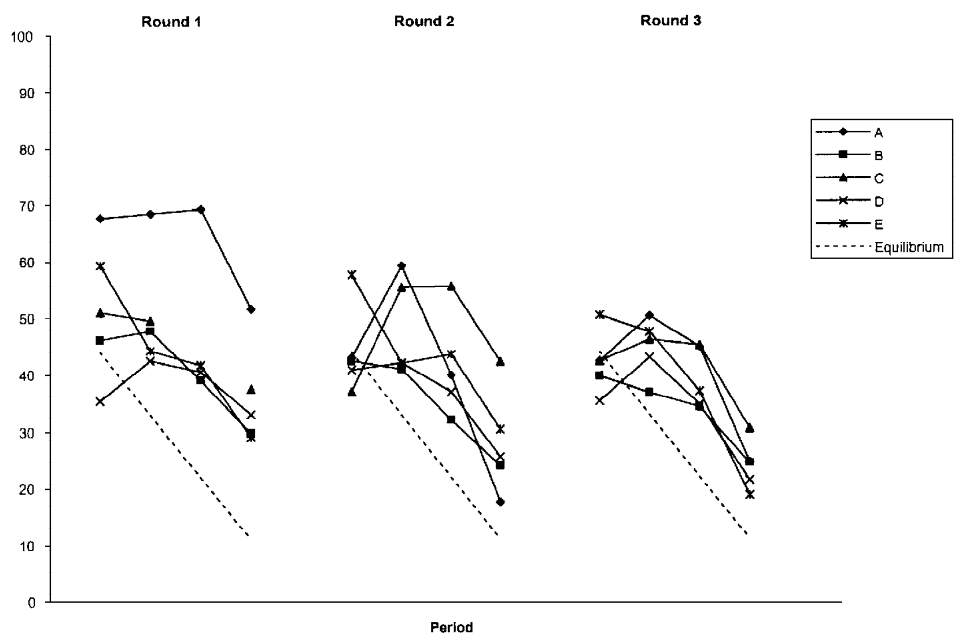

Figure 3. Average Allowance Prices

[11] Lei, Noussair, and Plott (2001) find that a second, "distractor" market reduces excess volume and helps suppress bubbles, but this does not explain why "boredom trading" occurs at disequilibrium prices.
[12] Due to a software glitch, the third period of round one of session C was zero seconds long.

line represents the predicted equilibrium price. The across-session variation is smaller in later rounds, suggesting learning about the process or others' price expectations occurs with repetition. The feature of primary interest, the price levels in each period, exhibit a consistent pattern within each round. Except perhaps in round 1, where there is considerable variance, first period prices are near the equilibrium level. In the second period, they remain approximately level or increase, as the predicted equilibrium price falls away. In the third period, prices fall, but more slowly than the fundamental value, increasing the distance between equilibrium and observed prices. In the fourth period, prices again fall, faster than the fundamental value, but not enough to reach equilibrium.

The dominant feature of the data in figure 3 is that average prices are higher than their predicted equilibrium values. Table 1 presents the median allowance trade price in each period, along with a sign test that the median price is greater than the predicted equilibrium. The pattern in prices across periods is consistent across rounds. In the first period, prices are at or slightly below the upper bound of the equilibrium price tunnel of $46. Except in session A round 1 and session E rounds 1 and 2, first period median prices are not significantly different than equilibrium at conventional levels. After the first period, however, the median trade price in every period of every session is significantly higher than the predicted equilibrium value, with *p*-values of 0.016 or better.

This pattern of below- or at-equilibrium prices in the first period leading to above-equilibrium prices in subsequent periods is consistent with the price paths observed in other experimental asset markets (*e.g.*, Smith, Suchanek, and Williams 1988; Noussair, Robin, and Ruffieux 2001). Lei, Noussair, and Plott (2001) characterize price paths in experimental asset markets as "bubbles" when the following are observed: "(*a*) prices lower than the fundamental value at the beginning …, (*b*) booms …, and (*c*) crashes in some sessions" (p. 856). Prices in our experimental allowance markets are lower in the beginning, and then experience a boom of higher than equilibrium prices in later periods.

To understand the extent of the booms and whether or not crashes occur in some sessions, it is necessary to look at changes in prices between periods. Because the number of times allowances can be fished before expiring decreases as periods elapse, the observed market price of allowances should fall by the equilibrium marginal value of between $10.25 and $11.50 each period. Table 2 presents the change in average prices between subsequent periods. The overall pattern presented by the table is summarized in the Overall row, which computes statistics based on aggregated data. Overall changes between periods 1 and 2 and 2 and 3 of each round are significantly smaller ($p < 10^{-7}$ or better) than the predicted change. In many sessions, there is very little price change between the first and second periods. In others, such as sessions A ($p < 10^{-8}$) and C ($p = 0.003$) and D ($p = 0.007$) in round 2, and A ($p < 10^{-4}$) and D ($p < 10^{-8}$) in round 3, there are actually significant increases in price between the first and second periods. These are consistent with the boom cycles that are often seen in experimental asset markets.

While prices do not decrease with the fundamental value of the asset, there is a consistent pattern of decrease in the final period of each round. In the first two rounds, the average decrease is not significantly different from the equilibrium prediction of –$11.50, but in round 3, it becomes statistically larger than equilibrium predicts. Considering the decreases session-by-session, there are decreases in price larger than the change in fundamental value in sessions A ($p < 10^{-9}$) and E ($p = 0.066$) in round 2 and in all but session B in round 3. These significant decreases represent the "crashes" observed by Lei, Noussair, and Plott (2001) and Smith, Suchanek, and Williams (1988). In each case, the price in the previous period is significantly higher than the equilibrium value, so crashes represent markets correcting

Table 1
Median Price in Each Period of Each Round

	Round 1				Round 2				Round 3			
	1	2	3	4	1	2	3	4	1	2	3	4
A	65.5	70.0	70.0	63.0	40.0	60.0	36.0	16.0	37.0	50.0	39.0	22.5
	97%	100%	100%	98%	20%	97%	100%	96%	26%	100%	100%	100%
	10^{-9}	10^{-8}	10^{-7}	10^{-12}	*1.000*	10^{-8}	10^{-12}	10^{-7}	*0.998*	10^{-9}	10^{-8}	10^{-8}
B	55.0	55.0	45.0	30.0	44.0	44.0	34.0	25.0	40.0	37.0	35.0	25.0
	58%	73%	89%	97%	35%	86%	96%	94%	22%	74%	98%	93%
	0.093	10^{-4}	10^{-7}	10^{-16}	*0.993*	10^{-9}	10^{-14}	10^{-16}	*1.000*	10^{-7}	10^{-16}	10^{-16}
C	50.0	60.0		40.0	30.0	55.0	57.0	40.0	38.5	43.0	50.0	39.0
	55%	81%		77%	27%	79%	100%	100%	42%	82%	97%	71%
	0.223	10^{-4}		10^{-4}	*0.991*	*0.016*	10^{-5}	10^{-8}	*0.793*	10^{-6}	10^{-9}	*0.005*
D	40.0	40.0	44.0	30.0	40.0	45.0	35.0	25.0	35.0	45.0	35.0	18.0
	8%	87%	98%	100%	22%	88%	100%	100%	14%	91%	100%	100%
	1.000	10^{-9}	10^{-14}	10^{-13}	*1.000*	10^{-8}	10^{-11}	10^{-13}	*1.000*	10^{-9}	10^{-9}	10^{-14}
E	60.0	50.0	44.0	30.0	58.0	45.0	35.0	30.0	49.0	47.0	34.5	16.8
	82%	65%	95%	100%	80%	79%	100%	100%	52%	92%	100%	100%
	10^{-8}	*0.016*	10^{-8}	10^{-13}	10^{-9}	10^{-8}	10^{-16}	10^{-14}	*0.375*	10^{-11}	10^{-13}	10^{-13}
Overall	50.0	50.0	45.0	30.0	44.0	45.0	35.0	25.0	40.0	40.0	35.0	24.5
	55%	80%	96%	95%	41%	85%	99%	97%	31%	85%	99%	93%
	0.042	10^{-16}	10^{-16}	10^{-16}	*1.000*	10^{-16}	10^{-16}	10^{-16}	*1.000*	10^{-16}	10^{-16}	10^{-16}

Notes: The second row for each session is the percentage of trades that took place at prices above the upper limit of the equilibrium price tunnel. The italicized numbers are the p-values of one-tailed (upper) sign tests that trade prices are equal to their equilibrium value.

Table 2
Change in Average Prices between Periods

	Round 1			Round 2			Round 3		
	1–2	2–3	3–4	1–2	2–3	3–4	1–2	2–3	3–4
A	0.7	0.8	–17.8	16.9	–19.3	–22.3	7.9	–5.4	–20.3
	10^{-5}	*10^{-5}*	*0.195*	*10^{-11}*	*10^{-7}*	*10^{-9}*	*10^{-8}*	*0.055*	*0.003*
B	1.5	–8.7	–9.3	–1.4	–8.9	–8.1	–3.0	–2.4	–9.9
	10^{-6}	*0.052*	*0.079*	*10^{-11}*	*10^{-4}*	*10^{-4}*	*10^{-14}*	*0*	*0.005*
C	–1.5			18.5	0.1	–13.3	3.8	–1.0	–14.6
	0.009			*10^{-4}*	*0.062*	*0.232*	*10^{-6}*	*10^{-4}*	*0.031*
D	7.1	–1.8	–7.5	1.3	–5.1	–11.4	7.6	–8.3	–13.3
	0	*10^{-8}*	*0.002*	*10^{-16}*	*10^{-8}*	*0.144*	*0*	*0.007*	*0.018*
E	–14.5	–2.6	–12.6	–15.7	1.6	–13.2	–3.0	–11.2	–17.7
	0.144	*10^{-4}*	*0.071*	*10^{-4}*	*10^{-6}*	*0.066*	*10^{-5}*	*0.090*	*10^{-5}*
Overall	–1.3	–3.1	–10.1	–1.2	–5.2	–12.5	0.8	–5.0	–14.3
	10^{-11}	*10^{-7}*	*0.117*	*0*	*10^{-9}*	*0.171*	*0*	*10^{-15}*	*0.003*

Notes: Numbers in italics are two-tailed *p*-values of Wilcoxon rank-sum test that the difference is equal to the change in the equilibrium fundamental value of the allowance, –11.5.

toward fundamental value, perhaps due to the absence of future opportunity to re-sell.

It is notable that we do not observe strong crashing behavior in the first round, whereas most previous experiments with inexperienced subjects observe strong crashing. This could be because the life of allowances is only four periods, much shorter than the fifteen period assets used in other designs. With only four periods in which to gain experience with the market, it is possible that—despite instructions and a demonstration round—not all subjects were comfortable enough with the market dynamics to identify that the only value of allowances purchased in the last period of a round is that of the marginal profit from holding an additional unit of allowances. Alternatively, in many rounds, the within-period standard deviation of contract prices is larger than the single-period change in fundamental value. Price variance of this scale could prevent subjects from effectively observing how prices change from one period to the next.

Volume and Price Variance

That period-average prices do not respond to changes in the fundamental value of allowances is symptomatic of price discovery difficulties which can be better understood by examining the dynamic of within-period trades. In equilibrium, each net buyer-net seller pair should exchange 7 units, leading to an equilibrium volume of 49 trades in the first period of each round in all but session E, where 42 trades are predicted. Table 3 shows the number of trades that occurred in each period of each round. In all but four of the 15 first periods (session A rounds 1 and 3 and session C rounds 2 and 3), the number of trades exceeds that predicted by equilibrium. The critical value for rejecting the hypothesis that the observed number of trades is generated from a Poisson distribution with a mean of 49 at the 5% level is 61 (53 for a mean of 42), so in 11 of the 15 first periods, the number of trades is significantly

Table 3
Number of Trades Observed in Each Period

	Round 1				Round 2				Round 3			
	1	2	3	4	1	2	3	4	1	2	3	4
A	36	30	27	49	70	33	47	27	35	35	31	30
B	69	63	37	86	66	66	70	116	63	112	84	95
C	62	31	—	43	26	14	16	31	24	45	39	38
D	80	63	59	54	78	56	44	53	90	54	34	57
E	74	49	37	52	93	90	90	56	89	63	53	50
Average	64.2	47.2	40.0	56.8	66.6	51.8	53.4	56.6	60.2	61.8	48.2	54.0

more than would be expected under the equilibrium model. In addition, large numbers of trades occur in each period following the first, while equilibrium predicts all trades should occur in the first period.

Such high volume is supported by subjects' belief that they can make money by buying and reselling allowances within periods. This belief is justified by the high price variances shown in table 4. Although it is difficult to establish a baseline against which to compare the level of price variance to that in other markets, we can compare the price variance to observed and predicted changes in prices within this market. In moving between consecutive periods, the standard deviation of prices exceeds the corresponding change in the fundamental value of the allowance. The time series of prices in figure 2 is typical, where, especially in the first round, the range of prices exceeds the change in running average price level or period-to-period price level, and, therefore, obscures changes in price. This variance hinders price discovery and supports speculation.

Efficiency

In equilibrium, the market will allocate allowances to those who value them most and can fish them most profitably, maximizing the surplus from the fishery. However, the previous analysis suggests that the market had difficulty identifying an

Table 4
Standard Deviation of Trade Prices Observed in Each Period

	Round 1				Round 2				Round 3			
	1	2	3	4	1	2	3	4	1	2	3	4
A	13.3	11.5	12.6	18.6	15.8	9.9	12.7	5.9	13.0	6.6	14.5	9.2
B	21.3	13.9	12.8	10.1	9.2	6.2	5.5	7.0	7.4	3.9	6.9	8.0
C	24.7	21.6	—	20.8	19.8	24.1	11.0	7.9	12.0	12.5	15.1	17.3
D	9.5	8.9	8.3	5.5	6.0	7.4	3.2	9.1	9.8	6.8	4.5	6.7
E	16.2	13.2	11.9	9.9	12.4	12.0	17.0	11.2	11.7	12.4	10.5	6.5
Overall	20.6	15.8	15.4	15.5	14.3	12.4	13.3	10.5	12.1	9.9	11.3	10.1

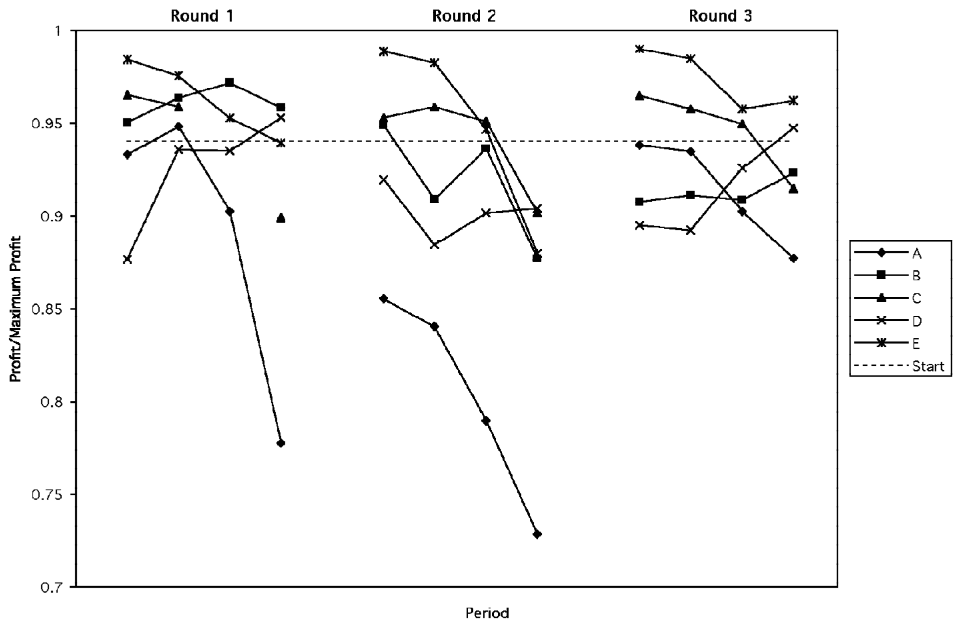

Figure 4. Efficiency of Allowance Allocations

equilibrium price during the experiments. Without an accurate price signal, fishers may not be able to determine their optimal effort levels, and trades may not lead to an efficient allocation of allowances and fishing effort.

Figure 4 graphs the ratio of realized profit from fishing to the maximum profit possible (*i.e.*, profit at the equilibrium allocation) across periods in each round. The dashed horizontal line indicates the efficiency level of the initial endowments; observations above the line indicate an increase in efficiency due to trading. From the graph, there is little tendency for efficiency to improve through trading. In only two observed rounds, session B round 1 and session E round 3, are observed efficiencies higher than those of the initial allocation in all four periods.

Decreasing efficiency suggests that in many of the observed trades either the seller sold for less than the marginal profit foregone by selling allowances, or the buyer bought for more than the marginal profit earned from holding allowances. The latter is more common because most transaction prices exceed equilibrium values. In fact, most trades are not mutually beneficial based on the profit functions. Overall, only 19.4% of trades were mutually beneficial, with 36.6% of trades benefiting the buyer and 67.5% of trades benefiting the seller. This pattern further supports persistent volatility as buyers are willing to pay more than their marginal profit for allowances in hopes they could resell for more money later.

Discussion

This experiment was designed to test the equilibrium model on which the economic arguments supporting the use of tradable allowances to manage fisheries are based. In our environment, with exchange of multi-period allowances taking place through a double auction that allows different transaction prices, the experimental data deviate from the prediction of competitive equilibrium in two ways. First, average prices are systematically higher than the equilibrium price suggested by fundamental value. Second, large disequilibrium price fluctuations persist in the data. Although all markets experience disequilibrium trading during price discovery, price discovery in this market is protracted, and the price variance is quite dramatic, swamping changes in the underlying value of allowances. This price fluctuation demonstrates that many trades take place for reasons other than differences in marginal harvest value between the buyer and seller. Therefore, the resulting allocations do not always improve economic efficiency. Under our experimental conditions, allowance trading resulted in lower efficiency than if allowance trading had been prohibited.

The implications of our experimental outcome for real tradable allowance markets depend on how closely the important economic features of our market correspond to those of real markets. One way to assess this is to look for the prominent features of our laboratory data in trade prices in existing tradable allowance programs. The dominant feature of our data, a prolonged price discovery characterized by widely fluctuating prices, is also the dominant feature of many field markets. For example, Newell, Sanchirico, and Kerr (forthcoming) identify price dispersion as a prominent feature of the first four years in a 30-species study of the New Zealand quota management system. During this period, dispersion levels were close to 30% of the average price level; the level of dispersion over the last five years is closer to 10%.[13] In the Florida spiny lobster fishery, Larkin and Milon (2000) find price ranges spanning from one to four times the average price in each of the first five years of the tradable trap certificate program. Thus, while equilibrium does not obtain in our experiment, our data replicate prominent features of field markets, including those which have led to dissatisfaction with tradable allowance systems.

While dispersion is a natural part of price discovery, the high degree of dispersion over several periods in laboratory allowance markets, and several years in field markets, has important policy implications. Even for a fisher who buys or sells allowances only when it increases her profit, prices which are not based on fundamental values pose significant pitfalls. In a fundamental-revealing market, price changes are predictable based on changes in demand and the cost of harvesting. In a market not based on fundamentals, price changes are not predictable. Arbitrary price fluctuations can significantly affect the value of allowance holdings, which may constitute a significant portion of a fisher's wealth or retirement savings. Such fluctuations complicate long-term business and capitalization decisions, including the decision to fish at all. In some fisheries, early sellers have found long-term prices higher than the price at which they sold out, leaving them to regret selling and too poor to buy back into the fishery. The risk associated with investment in volatile allowances could also provide an opportunity for consolidation as larger operators, especially those who are diversified across fisheries, may take on risk that smaller operators are not willing to accept. Finally, disequilibrium prices do not reflect the health of the stock, and thus cannot be used as a basis for management decisions (Arnason 1990; Batstone and Sharp 2003).

However, these negative initial results do not imply that effective transferable allowance programs cannot be designed. Many field experiences suggest that allowance market prices eventually become predictable, increasing satisfaction among participants. For example, Newell, Sanchirico, and Kerr (forthcoming) find recent quota prices in the New Zealand system to be correlated with export prices, indicat-

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[13] Newell, Sanchirico, and Kerr measure dispersion as the ratio of the absolute value of the difference between a trade's price and the month's mean price, and the month's mean price.

ing a relationship between allowance prices and fundamental value. While our markets did not converge in the time allotted, our results suggest outcomes could be improved by expediting price discovery and reducing initial price variance. Although the convergence process is typically ignored in economic analysis, it is critically important for policy application because many people make significant business or life decisions based on prices observed during equilibration.

One of the important lessons of past applications of experimental methods to auctions and market-based management systems is that the economic institutions used affect outcomes. In particular, different trading rules have different price discovery properties. The design used in this experiment was chosen to reflect the incentives and institutions of typical established tradable allowance markets. Since the shortcomings of the tradable allowance field data mirror those in the laboratory, laboratory work can be directed at exploring alternative institutions that may reduce price variance and measures for reducing speculative opportunities. The laboratory is a critical tool in this analysis because, although it is a significant determinant of outcomes and drives the fear many fishers have of tradable allowance management, disequilibrium behavior is not well understood theoretically. In the laboratory, alternative institutions, proposed to address specific challenges in particular applications or drawn from experience with other tradable allowance systems, can be assessed based on economic and social performance measures. Institution "tournaments" can be used to select and refine sets of rules of trade for different applications before implementation in the field leads to outcomes which are irreversible or very costly to restore. With this refined institution, managers and stakeholders will know the potential of market-based management in their fishery, and can compare expected outcomes with other forms of management to determine whether the fishery is best managed by tradable allowances.

Ongoing work is assessing a promising alternative for addressing the high initial price variance which inhibits price discovery: an "initial lease period" in which only single-period allowances, not permanent allowances, may be traded in the first periods (or years) of the program. Phased-in transferability was used in the British Columbia halibut individual quota program (Casey *et al.* 1995).[14] This feature allows the market to address separately the problems of identifying the market value of single-year allowances and determining how that value is aggregated over time. Future work will increase the complexity of the experimental environment to study whether markets facilitate consolidation among heterogeneous fishers and the effects of concurrent allowance derivative and lease markets on permanent allowance markets.

While useful for assessing alternative institutions, future experimental work can help facilitate effective fishery management in another way. The experimental environments developed for scientific investigation can also be used to educate the fishers themselves about alternative management systems through hands-on workshops or training sessions. Although Cummings, Holt, and Laury (2004) invited farmers to participate in their water auctions, the auction design in theirs and all other previous applications of experiments was unilaterally determined by the regulatory agency. In fisheries, where stakeholder input is highly integrated into the management process, such simulations have the potential to allay fears, address questions, or raise new issues during, rather than after, the decision-making process.

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[14] The BC halibut individual vessel quota began in 1991, and during the first two years, no quota transfers (temporary or permanent) were allowed separate from fishing licenses. After two years, temporary (annual) transfers were permitted, which remained in effect until about three years ago. Both permanent and temporary transfers are now allowed in the fishery (Turris 2004).

This can improve the management of all fisheries by grounding stakeholder and manager arguments in information rather than conjecture, helping each fishery select the best management system for its specific bio- and socioeconomic goals.

When trades take place at or near the market equilibrium price, tradable allowance systems for managing fisheries have many desirable economic properties. However, in the early periods following the introduction of tradable allowances, outcomes are significantly influenced by disequilibrium behavior. Therefore, such systems cannot be implemented indiscriminately and without regard for the price discovery process. As our experimental data attest, undesirable outcomes can arise from disequilibrium trading. However, these adverse outcomes do not mean that transferable allowances cannot work or should not be used. Rather, they pose a challenge to managers and fisheries economists to identify institutions that facilitate trade and yield the most desirable outcomes on social and equity as well as economic dimensions. If experience in other complex markets is any indication, this research can drive advances in economic theory and institutional design, and significantly enhance the economic and social success of the management programs.

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