Fishing Quota Markets

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Abstract

Fisheries worldwide continue to suffer greatly from the negative consequences of open access, despite numerous regulatory "solutions". In 1986, New Zealand responded by establishing the most comprehensive market-based Individual Transferable Quota (ITQ) system for fisheries management, resulting in the creation of over 150 fishing quota markets differentiated by geographic region and species. We assess the functioning of these quota markets from 1986-1999 in terms of the trends in market activity for selling and leasing quota; market entry and exit; the determinants of quota prices; and the interrelationship of quota lease prices, sale prices, and market interest rates. We find that there has typically been a sufficiently high level of market activity to support a competitive market. We also find evidence of economically rational behavior in these markets through the relationship between quota lease and sale prices and measures of fishing value, quota scarcity, ecological variability, and market rates of return. Moreover, after controlling for relevant factors, our results show a substantial increase in the value of quota prices over the history of the ITQ program, consistent with a significant increase in the profitability of the included fisheries. Overall, the evidence suggests a reasonably high level of economic sophistication in these markets, implying that market-based quota systems are potentially effective instruments for efficient fisheries management.

Key Words: tradable permits, individual transferable quota, fisheries, policy
JEL Classification Numbers: Q22, Q28, D40, L79, L10

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1. Introduction

Economists Gordon (1954) and Scott (1955) identified the "common pool" problem of fisheries almost 50 years ago, predicting that open access will lead to excess fishing effort, dissipation of rents, and inefficient depletion of fish populations. Unfortunately, the prediction has been borne out and is still coming true today. For example, after two decades of rapid expansion of fishing effort, the New England groundfish fishery collapsed and has been essentially closed since 1994. This story is not unique. Throughout the world approximately 25% of the major fish stocks are currently in jeopardy of collapsing (FAO 2001).

Until the 1970s, most fisheries were either completely unmanaged or regulated under command-and-control regulations governing the size of vessels, type of nets and season length as well as simply closing areas to fishing. Such regulations fail to check the number of vessels or the level of fishing effort and encourage fishermen to work around equipment constraints. Under these regulations, fishermen have no sense of ownership over the fish until they are caught. This creates a race to fish, and the historical record shows that the race will continue until fish stocks are depleted and the number and types of vessels in a fishery exceed its viable capacity.

Individual transferable quota (ITQ) systems are a promising means to correct this market failure. ITQ programs are directly analogous with other "cap and trade" programs, such as the

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U.S. tradable permit program for reducing sulfur dioxide emissions from power plants. Since the late seventies when countries began to "enclose the commons" by establishing Exclusive Economic Zones in the ocean off of their coasts, more than 15 countries have followed New Zealand and Iceland's lead in establishing rights-based fishing programs. These programs cover some 60 species, including 4 in the United States (OECD 1997).

ITQ systems limit fishing operations by setting a total allowable catch (TAC) which is then allocated to fishing participants, typically based on historical catch. Because fishermen have access to a guaranteed share of the TAC, this approach significantly reduces the incentives to engage in a race to fish.[1] In addition, when transferability of the shares is permitted, the least efficient vessels will find it more profitable to sell their quota rather than fish it. Over time, this will result in both reductions in excess capacity and more efficient vessels operating in the fishery. Furthermore, fishermen gain a financial stake in the resource. The share is an asset whose value is directly related to the health of the fish stock, and owners therefore will have an incentive to take into account how fishing today will impact future catch levels.

Even so, in order for ITQs to deliver an efficient solution to the common pool problem in practice, it is critical that quota markets function reasonably well. As described further below, competitive quota prices will equal the expected present value of future rents in the fishery. Price signals sent through the quota market are therefore an essential source of information on the expected profitability of fishing, and a key criterion for decisions to enter, exit, expand, or contract individual fishing activity. Quota prices also send signals to policymakers about

[1] Several benefits arise from reducing the race to fish, including an increase in season length and the ability of fishermen to move from maximizing quantity to quality. For example, the Alaskan Halibut fishery, which is closed when the total allowable catch was reached, had been reduced to seasons consisting of two 24-hour openings by the early nineties. Since the introduction of an ITQ system in 1994, the season length has grown to over 245 days. The flexibility to time fishing trips when port prices are higher and the elimination of large supply gluts of fresh product has resulted in per pound price increases over 40 percent (Casey et al. 1995). The focus on quality is also evident in New Zealand where fishermen have switched catching methods in the red snapper fishery in order to sell their catch on the highly profitable Japanese live fish market (Boyd and Dewees 1992).

whether the economic and biological health of a fishery is improving over time. Some have suggested quota prices could therefore be used as a measurement tool for the dynamic adjustment of TACs to optimize policy outcomes (Arnason 1990).

Despite its clear significance, there has yet to be a systematic analysis of the performance of fishing quota markets in operation.[2] Establishing an empirical record of how well "created markets" are working is important not only for fisheries policy, but across many resource areas where the advantages of market-based policies hinge on market performance. Assessments of the U.S. sulfur dioxide tradable permit system (Joskow et al. 1998, Carlson et al. 2000) are significant contributions in this regard. This is especially true since economists frequently recommend market-based quantity instruments and building the institutions necessary to implement them can require significant political and economic costs.[3] Even though the current set of ITQ programs are generally getting positive reviews (NRC 1999), their future is unclear. In 1996, the U.S. Congress established a four-year moratorium against fishing quotas to allow time for the establishment of national standards. The moratorium was extended to October 2002, because questions still remain about whether shares should be transferable, whether shares should have limited duration, and whether shareholders must remain active in the fishery, among other things.

Although recent experience with the sulfur dioxide trading program has changed many perceptions, there remains a considerable body of skeptics who question whether tradable permit

[2] There are a smaller number of studies that have looked at market performance shortly after an ITQ system was implemented. Lindner et al (1992) attempt to measure economic rents in the New Zealand fisheries using two years of data on annual profitability and quota and lease prices, but conclude that a more thorough analysis of the determinants of quota prices is needed to properly assess these rents. Using three years of data from the Alaskan Halibut fishery, Dinneford et al. (1999) present statistics on the number of trades and leases and also predict quota and lease prices based on regional and vessel characteristics along with size of the transaction variables. In addition, Batstone and Sharp (1999) present descriptive analysis of quota and lease prices for the New Zealand orange roughy and red snapper fishery.

[3] We do not assess the distributional effects of ITQs in this paper, although this is clearly an important political issue.

systems and other economic incentive-based policies can work in practice. Potential concerns include the degree of liquidity and transaction costs in such markets and information problems related to uncertainty and decision-making complexity.[4] For example, some argue that there might be few, if any, potential benefits of using created markets to address common property externalities in fisheries where multiple species are caught simultaneously (Copes 1986, Squires et al 1998). The fact that some fish populations cannot be directly targeted without incidental catch of other stocks means that not only is the level of catch on any trip uncertain but so is its composition. Thus, fishermen operating under a quota management system will likely need to rebalance their portfolio of quota holdings to match catch levels—a task that some argue is simply too complex.

Such skepticism is in part warranted by the limited number of opportunities for careful research on this issue. New Zealand's ITQ market is very rare in this regard, in terms of its long history, the shear size and comprehensiveness of the program, and importantly, in terms of access to rarely available data. The existing literature on experience with ITQ programs, although extensive, is dominated by description and anecdotal evidence of their effects (NRC 1999).[5] Some studies have quantitatively assessed the efficiency implications of the programs (Arnason 1993, Wang 1995, Weninger 1998, Grafton et al. 2000).[6] Such predictions are based

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[4] Another important issue is whether there exists potential for market power and strategic manipulation of market prices (Hahn 1984, Anderson 1991). We leave this question to further research; however, given that the output market is perfectly competitive it is not clear under what conditions this would amount to a significant problem in New Zealand.

[5] Other relevant literature includes Karpoff (1984, 1985), who investigates economic information embedded in limited-entry license prices of the Alaskan Salmon fishery, research on whether farm land prices reflect agricultural rents (e.g., Burt 1986, Alston 1986), asset pricing models of residential housing and art (e.g., Poterba, 1984, Psendao 1993, Geotzmann 1993), analysis of oil field unitization and rents (e.g., Wiggins and Libecap 1985), information embedded in oil lease and U.S. Forest Service auctions (e.g., Porter 1995, Athey and Levin 2001), and the large literature on asset prices and market efficiency (e.g., Fama 1991).

[6] For the U.S. Mid-Atlantic Surf Clam fishery, for example, studies predict estimated savings in total harvesting costs greater than 40 percent annually and a reduction in the number of fishing vessels between 35-50 percent (Wang 1995, Weninger 1998).

on the assumption that the market for fishing rights is efficient, but whether that is likely to hold in practice remains an open question.

To establish such an empirical record, we use the most comprehensive data set on ITQ markets gathered to date to evaluate the operation of New Zealand's market for fishing quota, the largest system of its kind in the world. The panel data set from New Zealand covers 15 years of transactions across 33 species and over 150 fish stock markets (see Table 1 and appendix). A unique aspect of our data is the breadth of markets and the cross-sectional heterogeneity, as the market characteristics are diverse across both economic and ecological dimensions. For example, average life spans range from one year for squid (*Nototodarus gouldi*) to over 145 years for orange roughy (*Hoplostethus atlanticus*). Some species occupy inshore and shallow habitat such as red snapper (*Pagrus auratus*) and are targeted with trawl gear, set netting, and long lining. Others such as orange roughy are found offshore in depths over 1000m and require large vessels and very specialized trawling gear. The quota markets also include shellfish and crustacean fisheries (e.g., abalone, rock lobster (*Jasus edwardsii*)) where potting, diving and dredging are the most common harvesting techniques. The export value of these species currently ranges from about NZ$700 per ton for jack mackerel to about NZ$40,000 per ton for rock lobster.

We assess the operation of these fishing quota markets from 1986-1999 in terms of the trends in market activity for selling and leasing quota; indicators of market entry and exit; the determinants of quota prices; and the interrelationship of quota lease prices, sale prices, and market interest rates. We find that there has typically been a sufficiently high and increasing level of market activity suggesting there is adequate support for a competitive market. Nonetheless, some specific markets are thin, but they tend to be economically unimportant. We also find evidence of economically rational behavior in these markets through the relationship between quota lease and sale prices and measures of fishing value, quota scarcity, ecological variability, and market rates of return. Moreover, after controlling for relevant factors, our results show a substantial increase in the value of quota prices over the history of the ITQ program, consistent with a significant increase in the profitability of the included fisheries. Overall, the evidence suggests these markets are operating reasonably well, implying that market-based quota systems are potentially effective instruments for efficient fisheries management.

In section 2, we describe the forces behind the adoption of an ITQ system in New Zealand, the legislative history of this program, and basic program design elements. In section 3, we analyze of the development of the market for quota sales and derivative leases, trends in market activity, and number of quota holders. In section 4, we investigate econometrically the determinants of quota lease and sale prices, as well as the relationship between these two markets and the market interest rate. We conclude in Section 5 with a discussion of our findings and areas of further study.

2. New Zealand's Individual Transferable Quota (ITQ) System

While the New Zealand fishing industry accounts for less than one percent of the world's fishing output, it contributes 1.7 billion annually to the New Zealand GDP. Seafood is the fourth largest export earner and over 90% of fishing industry revenue is derived from exports. New Zealand is currently considered a world leader in fisheries management, in terms of both environmental and economic concerns. This was not the case, however, prior to the implementation of its ITQ system.[7]

Prior to 1976, New Zealand fishery policy focused primarily on the development of inshore fisheries, leaving offshore fisheries to Japanese, Soviet, and Korean factory trawlers.

[7] For further history and institutional detail, see the many descriptive assessments of New Zealand fishery management: Crothers, 1988, Clark, Major and Mollett, 1988, Pearse, 1991, Sissenwine and Mace 1992, Boyd and Dewees, 1992, Annala 1996, Dewees 1999, Batstone and Sharpe 1999, and Yandle 2001, Clement & Associates 1997, New Zealand Official Yearbook 2001, and SeaFic 2001.

This focus began to shift, however, after New Zealand extended their Exclusive Economic Zone (EEZ) to 200 miles in 1978, which had the effect of "nationalizing" the waters where the offshore fisheries reside. Subsidized loans, duty-free imports of large fishing vessels, and price supports were all used by the government as means to promote the offshore fishery. In 1983, after a series of joint venture programs with foreign and domestic fishing interests, the New Zealand government established a quota-based system for nine companies fishing seven offshore species. Quota were allocated to each company for a ten-year period based on investment in catch and processing capital, although as described below this program was absorbed three years later by a more comprehensive system. Trading and leasing of shares is reported to have occurred, but the system did not provide an adequate mechanism for the transfer of quota.

At the same time the government was encouraging the development of offshore fisheries, inshore fisheries were beginning to exhibit signs of overfishing (Crothers, 1988). The catch of red snapper, for instance—a commercially important inshore species—had peaked in 1978 and fallen by 43 percent by 1983. As far back as the early 1960s, the government had instituted programs to encourage the growth of the inshore fishing industry, which resulted in increases in fishing effort (Clark, Major, and Mollet 1988). These years of subsidies for an industry in a regulated open-access setting are cited as the main reasons why excess capacity and depleted fish populations plagued the inshore fisheries in the early 1980's (Crothers 1988).

Inshore fisheries depletion, the development of the quota-based program for offshore fisheries, and the general orientation of the government in the 1980's toward deregulation, combined to create an atmosphere conducive for fundamental change in New Zealand fishery management. After years of consultation with industry, the Fisheries Amendment Act of 1986 passed creating New Zealand's ITQ system. Modifying legislation has been passed several times since, but the basic structure of the system has remained intact.

The ITQ system initially covered 17 inshore species and 9 offshore species, growing to a total of 33 species by 1998. Under the system, the New Zealand EEZ was geographically delineated into distinct quota management regions for each species. Rights for catching fish were defined in terms of "fish stocks" that correspond to a specific species taken from a particular quota management region. In 1998, the total number of fishing quota markets stood at 187, ranging from 2 for the hoki fishery (*Macruronus novaezelandiae*) to 11 quota markets for abalone (*Haliotis iris*). As of 1996, the species managed under the ITQ system accounted for over 85% of the total commercial catch taken from New Zealand's EEZ.

Fishing quota are generally tradable only within the same fish stock, and not across regions or species or years, although there are some minor exceptions.[8] The quota right can be broken up and sold in smaller quantities and any amount may be leased and subleased. There is no restriction on the number of times quota can be leased, subleased, or sold. The New Zealand Ministry of Fisheries sets an annual total allowable catch (TAC) for each fish stock based on a biological assessment as well as any other relevant environmental, social and economic factors. The TACs are set with a goal of moving the fish population toward a level that will support the largest possible annual catch (i.e., maximum sustainable yield), after an allowance for recreational and other non-commercial fishing.[9] There are also legislative limits on aggregation for particular stocks and regions, and limitations on foreign quota holding.[10] In general, there is a

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[8] Given the uncertainty around quantity and composition of catch, additional flexibility was introduced into the system in five ways (Clement & Associates 1997). First, a "by-catch tradeoff" exemption allows fishermen who incidentally take non-target fish to offset the catch by using quota from a predetermined list of target species. Second, quota owners can carry forward to or borrow from the next year up to 10 percent of their quota; this right does not apply to leases. The third option is to enter into a non-monetary agreement to fish against another's quota. The other options are to either surrender the catch to the government or to pay a deemed value, which is set based on the nominal port price to discourage discarding of catch at sea and targeting stocks without sufficient quota (Annala 1996).

[9] Here we use the term TAC to refer to the total allowable *commercial* catch, which under the New Zealand system is referred to as the TACC. For many species (e.g., offshore fish stocks) there is no interest from recreational anglers and the entire TAC is allocated to the commercial sector.

[10] Initially, the aggregation limits were on holding quota. The limits applied to particular fish stocks (no more than 10% of the TAC of rock lobster in any quota management area and 35% of the TAC of packhorse lobster in any quota management area), to a species and area combination (no more than 20% of the total TAC for any QMA of any species) and to a set of species (no more than 35% of the combined TAC for HAK, HOK, LIN, ORH, OEO, SWA, SQU). Substantial changes were written into the 1996 Fisheries Act (Section 59) one of which was changing

sufficient amount of flexibility built into the system, suggesting transactions costs will be low and activity will be high.

The individual quota rights were initially allocated to fisherman as fixed annual tonnages in perpetuity based on their average catch level over two of the previous three years. To increase industry support for the plan, the government allocated the quota free of charge and allowed fishers to petition for a change to their initial allocation. The main reasons to introduce the system, however, were to rebuild the inshore fisheries and improve the economic conditions of the industry. By denominating quota as fixed tonnages, the government was counting on its ability to purchase quota on the open market if it wanted to reduce the total catch from a fishery. In practice, the government found it very expensive to purchase the quota needed to reduce total catches to levels sufficient to rebuild some of the fisheries. Such reductions were necessary because the initial allocations, which were based on past catch histories, in some cases resulted in a total allocation greater than the maximum sustainable yield. In 1986 alone, the government paid $NZ 45 million ($US 25 million) to buy back 15,000 tons of quota from the inshore fisheries, which was about 70% of the total necessary reductions in tons (Boyd and Dewees, 1992).

Faced with the prospect of spending another 100 million to further reduce TACs and after prolonged negotiations (Sissenwine and Mace 1992), the government switched from quota rights based on fixed tonnages to denominating the quota as a share of the TAC beginning with the 1990 fishing year. In doing so, the burden of risk associated with uncertainty over future TAC

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the limits on holdings to ownership levels. The 1996 legislation also relaxed the restrictions on species and area combinations by setting limits at 35% within species and across quota management areas, implemented species restrictions for Bluenose at 20% of the combined TAC, implemented area restrictions for paua at 10%, eliminated specific packhorse limits and incorporated them into the set of species restrictions, and finally increased both the set of species and the limit to 45% of the combined TAC for every stock of that species (BYX, BAR, WAR, SKI, HAK, HOK, JMA, LIN, ORH, OEO, PHC, RCO, SWA, SQU). While the limits are generally adhered to, there have been over 38 exemptions granted by the NEW ZEALAND Ministry of Fisheries since the start of the QMS (Yandle, 2001).

levels was moved from the government to the industry. At the same time, the industry received compensation payments over a period to 1994 for TAC reductions (see Annala (1996) for details).

The New Zealand ITQ system is a dynamic institution that has had many refinements since its beginnings over 15 years ago. Nonetheless, the basic tenets of the system, the setting of a total allowable catch and leaving the market to determine the most profitable allocation of fishing effort, have remained intact. As have the goals to manage the fisheries in a sustainable manner and improve the economic conditions of the fishing industry.

3. Market Participation and Activity

Whether market-based instruments are being applied to fish, pollution, land, or taxi medallions, the ability of firms to buy and sell quota in a well-functioning market is necessary for achieving efficiency gains. In this section we assess the operation of the New Zealand ITQ market along the quantity dimension, in terms of the number of market participants and the level of market activity. Thin markets with few participants can lead to high transaction costs as buyers and sellers have difficulty finding trading partners. With high transaction costs, transactions are less likely to occur, which could lead to noisy price signals and little or no efficiency gains (Noll 1982). A serious problem with some tradable permit programs, but certainly not all, has been an insufficient number of participants, a low level of market activity, and therefore minimal efficiency gains (Hahn and Hester 1989). We also briefly examine the entry and exit of market participants, as there is some concern that the need to purchase quota to enter the fishery can involve large fixed costs, which could create a barrier to entry that may not exist in other regulatory settings.[11]

[11] In addition to the efficiency reasons for an interest in entry the debate about whether to implement market-based approaches in fisheries has focused on the distributional implications of potential concentration and industrialization

3.1 Market Participation, Entry, and Exit

There are a large number of quota owners in the New Zealand ITQ system, averaging about 1,500 over the history of the program. There has been a median of 56 quota owners in individual quota markets over the history of the program, ranging from 332 down to just 1 owner in some small fisheries of low importance. To place these numbers in context, there are about 100 utilities with permit allocations under the U.S. sulfur dioxide permit market (U.S. EPA 2002), while the New York City taxi medallion market has approximately 5,000 medallion owners (Schaller 2001).[12] As we discuss in the next section, each of these cap and trade programs has had enough participants to generate ample liquidity in their respective markets.

As illustrated in Figure 1, the total number of owners increased from a minimum of about 1,300 in 1986 to 1,800 in 1990, falling since then to 1,400 as of 1998. To give some additional sense of the variation across fishing stocks, we also present ownership trends by grouping species according to whether they are inshore, offshore, or shellfish species (see Table 1). Note that the total number of owners is less than the sum of owners in the inshore, offshore, and shellfish fisheries because many owners participate in multiple fisheries. The increase in quota owners from 1987-1990 was due to the addition of several shellfish species to the ITQ program[13], while the subsequent 22 percent decline was due to the exit of about 32 percent of inshore owners and 19 percent of shellfish owners from their peaks in 1989-1990. Likewise, the median number of owners in individual fishing quota markets has fallen from 62 in 1986 to 54 in

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of the fishery. Advocates against quota management systems argue that implementing such a system will result in the loss of the small-scale fishermen, a claim that is analogous to those made for preservation of the family farm. While these distributional concerns may be important, especially in the political realm, we generally leave them for another paper. In fact, in 1998 the Icelandic Supreme court declared as unconstitutional existing fisheries laws on ITQs because the exclusionary aspects of the system violated the rule about the "right to work".

[12] New York City's taxi medallion system has operated on a free-market basis since just after World War II.

[13] Although over 800 shellfish quota owners were added in this period, the net increase in the total number of owners was only about 500 because many of these fishermen were already active in offshore and inshore ITQ markets.

1998. At the same time, the number of quota owners in offshore fisheries is virtually unchanged since program inception. As mentioned earlier, one argument against implementing a quota-based system has been that it creates a barrier to entry that does not exist under open-access systems. We find that although there has been net exit in New Zealand's ITQ system, there has been on average 90 new quota owners entering the system per year since 1990.

Why the difference in exit behavior between the offshore versus inshore and shellfish fisheries? As described in Section 2 above, prior to the adoption of the full ITQ system a subset of the offshore stocks were included in a quota-based system, which had the effect of limiting entry. At the same time, the inshore fisheries especially in region 1 were plagued with excess capacity prior to the implementation of ITQs.[14] One might therefore expect to find that rationalization in the form of exit from certain fisheries would be greater in the inshore and shellfish compared to the offshore fisheries all else equal. The magnitude of the various trends in Figure 1 show that reductions in any one fishing quota market do not generally correspond to fishermen leaving the industry altogether. Rather the data imply that the quota owners on average hold a portfolio of quota and while some might be exiting, others are divesting from some stocks and investing in others. For example, it is evident from Figure 1 that in 1986 almost all of the inshore quota owners also owned quota for the offshore stocks.

Over time the typical portfolio of quota for the median quota owner has essentially remained 3 fish stocks across 3 species of fish (1 fish stock for shellfish). This represents the large number of small fishing enterprises, which are geographically and species focused. The median quantity of quota owned in recent years is 5 metric tons, which is the minimum necessary to get a fishing permit. The largest quota owners, on the other hand, held a much more diversified portfolio, with the largest portfolio increasing from 120 fish stocks across 30 species

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[14] Exit occurred mainly in the first quota management area for snapper (53% decline), trevally (41% decline), and gurnard (37% decline).

in 1987 to 155 fish stocks for 33 species in the 1998 fishing year. The largest ownership portfolios represent a mix of most species across most of the geographical regions.

3.2 Market Activity

As has already been alluded to, there are markets for the sale of the perpetual right to fish a certain quota, as well as a derivative market to lease quota. In practice, virtually all leases are for a period of one year or less. While most of the transactions occurring in the New Zealand ITQ system are bilateral transactions between the two parties, there is also an active third-party brokering industry. For example, brokers advertise quota prices and quantities for sale or lease in trade magazines, newspapers, and on the internet. As describe above, the rules on exchange are very flexible and the number of participants is high, suggesting that transaction costs will be low and quota markets will be active.

The data do in fact reveal a very active market. Over 120,000 leases and 30,000 sales of quota had occurred under the ITQ program as of the end of the 1998 fishing year, an average of about 9,200 leases and 2,300 sales per year. This represents a complete sample of market activity over time, because all transactions of quota (sales and leases) must be recorded and submitted to the New Zealand government. The mean lease and sale quantity is approximately 40 and 50 tons respectively. In comparison, the sulfur dioxide permit market—considered to have robust and competitive activity (Joskow et al. 1998; Schmalensee et al. 1998; Stavins 1998)—has seen a total of about 9,600 transactions between economically distinct organizations since 1995, or about 1,400 per year on average (EPA 2002). On the same note, there have been an average of about 800 transfers per year of taxicab medallions in New York City since 1982 (Schaller 2001).

The total number of leases has risen considerably over time from 2,000 annually in 1986 to 16,000 in 1998. To get a sense not just of the aggregate market activity, but also of the activity at the individual fishing quota market level, Figure 2 illustrates the historical trends in both the quota lease and sale markets as measured by the annual median across fish stocks of the net percent leased and sold by fishing year.[15] The figure shows that the median percent of quota leased in these quota markets has risen consistently over time from 18% in 1987 to 41% in 1998.

The total number of quota sales has fluctuated over the history of the program, with highs of almost 3,500 sales in 1986 and 1990 to a low of 1,500 sales in 1998. The high activity years correspond to time periods of large initial quota allocations; for most species in 1986 and for rock lobster in 1990. The median quota market shows the same pattern, with the percentage sold being as high as 18% in years of initial allocation (1986 and 1990), gradually decreasing in subsequent years to around 4% of total outstanding quota per year in the late 1990s.[16] This pattern of sales is consistent with there being a period of rationalization and reallocation proximate to the initial allocation of quota, with sales activity decreasing after the less profitable vessels have exited various fisheries.

While the typical ITQ market exhibits a reasonably high degree of activity, there is quite a bit of variation and some individual quota markets are thin. In particular, the number of leases that have occurred in the individual ITQ markets from 1986-1998 ranges from about 30 to 2,400, the median being 640 leases. The number of sales ranges from 0 to 1,100, the median being 140 sales. Quota markets with low activity tend to be of low economic importance in terms of size and value of catch. In many cases, these markets where designed more for political and biological reasons than for maximizing economic gains (Boyd and Dewees 1992, Annala 1996).

[15] Fishing years run from October to September for all species except rock lobster and scallops, which run from April to March.

[16] In comparison, in recent years the sales volume in the New York City taxi medallion market has averaged about 3% of outstanding medallions annually, while the average rate over the last four decades has been about 6%.

4. Market Prices

A crucial question in gauging the efficiency of quota markets is whether market prices behave in an economically reasonable manner. We assess quota price behavior in several ways. We begin by econometrically estimating the relationship between quota lease prices and variables that theory would tell us should determine these prices. We also do the same for quota sale prices. Finally, we evaluate the relationship between quota lease and sale prices, which in an efficient market would be related to the market interest rate through arbitrage.

4.1 Model of Quota Price Determination

In a competitive quota market, each fishing enterprise has an incentive to lease or trade quota until it attains just enough quota to cover a level of catch that maximize its profits. The price of a one-year lease on the right to catch one ton of fish should therefore equal the marginal flow of profit or rent from that enterprise. More formally, let annual fishing profits for firm *k* be given by $\pi_k = pq_k - c_k(q_k)$, where p is the given price per ton received for fish at the dock, q_k is the tonnage of fish caught, and $c_k(q_k)$ is a function representing the cost of catching q_k tons. Maximizing profits with respect to q_k, subject to the constraint that the fisherman holds enough quota to cover his catch, he will be willing to pay (or accept) λ for a marginal unit of quota, where λ is equal to the marginal profit flow or rent:

(1) $$\lambda = p - c_k'(q_k)\,.$$

In a competitive equilibrium, λ would equal the quota lease price.[17] The price of holding that right in perpetuity (i.e., the quota sale price) should likewise equal the discounted rent. Thus, as we explore further below, the quota sale price should roughly equal the lease price divided by the market rate of interest, assuming expected lease prices are relatively constant. If lease prices are

[17] For a more detailed derivation of the market equilibrium see Clark (1990).

expected to rise or fall, due to changing economic or biological conditions, the quota sale price would be correspondingly higher or lower.

This stylized model of ITQ market equilibrium provides a useful starting point for our ultimate interest, which is empirical analysis of the determinants of quota lease and sale prices. Equation (1) demonstrates the intuitively sensible dependence of quota prices on the price of fish, the costs of fishing, and factors underlying the technical relationship between fishing effort and the amount of fish caught, such as species biological characteristics, climatic conditions, and gear types. The specific role played by these latter factors could be further modeled by specifying functional forms for the fishing production function and the biological relationship between catch and the population of fish. As we move toward an empirical specification, however, we face the harsh reality that this stylized model asks for both too much and too little. Data constraints, for instance, prohibit us from obtaining exactly the right type of cost and technical information. On the other hand, the inherent uncertainty surrounding fishing and the evolving availability of information on demand in an ITQ market are very difficult to capture in a fully structural manner, especially if the ultimate desire is a basis for empirical estimation across many species, geographic regions, and time. We therefore take a reduced form approach, employing a flexible functional form of key variables to approximate the relationship between quota prices and their determinants. After laying out the specification below, we further explain its rationale.

Specifically, the relationship we bring to the lease price data is:

$$
\begin{aligned}
\ln \lambda_{ijmy} = {} & \beta_1 \ln p_{imy} + \beta_2 \left(\ln p_{imy}\right)^2 + \beta_3 \frac{H_{ijy-1}}{Q_{ijy-1}} + \beta_4 \left(\frac{H_{ijy-1}}{Q_{ijy-1}}\right)^2 \\
& + \beta_5 \left(\frac{\sum_{n=1}^{m-1} h_{ijny}}{Q_{ijy}} - \frac{\sum_{n=1}^{m-1} h_{ijny-1}}{Q_{ijy-1}} \right) + \beta_6 \left(\frac{\sum_{n=1}^{m-1} h_{ijny}}{Q_{ijy}} - \frac{\sum_{n=1}^{m-1} h_{ijny-1}}{Q_{ijy-1}} \right)^2, \\
& + \beta_7 r_i + \beta_8 \ln s_{my} + \alpha_0 + \alpha_{1j} + \alpha_{2y} + \alpha_{3m}
\end{aligned} \qquad (2)
$$

where λ is the average lease price, p is the contemporaneous export price, H is the actual annual catch, Q is the total allowable catch (TAC), h is the actual monthly catch, r is the species mortality rate, s is the absolute value of the Southern Oscillation Index, α_0 is a constant term, α_1 are region dummies, α_2 are year dummies, and α_3 are dummies for successive months within each fishing year. Species are denoted by the subscript i and regions by j, so that each ij combination indexes a different fishing quota market. Time is indexed by month m of year y.

We would expect the export price[18] of fish to be positively associated with quota prices, a relationship that is clearly illustrated in Figure 3, which shows a roughly linear relationship in logs between both quota lease and sale prices and fish export prices. In principal, the relevant price of fish for decisions regarding the value of a lease of duration one year or less is the price of fish at the expected time of sale. Without any clearly preferable alternative for measuring this expected price, we simply employ the contemporaneous export price of fish at the time the transaction was made. In practice, given the short time period at issue (one year or less), we consider to be quite reasonable.

We also include two variables (and their squares) to measure the effect of quota scarcity, or the degree to which the supply of quota available for a given fish stock is a binding constraint on the aggregate demand for that quota. That is, these variables are based on the percentage of a given TAC that is actually caught. While in a deterministic world one might expect the quota price to be zero for a fish stock with a non-binding TAC constraint, this will not be the case in an uncertain world. Uncertainty in the future profitability of fishing (e.g., due to export price and ecological uncertainty) make it impossible for firms to know precisely how many quota they will want in aggregate over the course of the year. Nonetheless, a large portion of quota is leased at

[18] While we would ideally like to use dock or port prices for fish, rather than export prices, adequate port price data do not exist. In practice, however, we find that export prices are an excellent proxy for the port price. Using a New Zealand government survey of port prices for specific fish stocks in 1998, we find that there is a 95% correlation between export prices and port prices.

the beginning of the fish year—quota that may turn out to be unprofitable to catch against. In addition, uncertainty in fishing conditions in conjunction with government penalties for overfishing provide incentives for firms to keep their catch below their quota holdings. This phenomenon has also been evidenced in so-called “overcompliance” by firms facing pollution control standards (Oates, Portney, and McGartland 1989).

Because Q is set exogenously by the government and altered only rarely, these quota scarcity variables will largely capture the influence of variation in relative demand within and between fish stocks. As such, we believe that these variables will proxy to a degree for cost differences across fish stocks. For example, there are several fishing quota markets for red snapper, each corresponding to a different region. We would expect that in regions where the costs of red snapper fishing are higher—perhaps due to the geographic distance from market—the demand for red snapper quota in those regions will be lower, all else equal. In turn, we would expect that the lease price for these relatively undesirable quota would be correspondingly lower.

The first measure of quota scarcity is H_{ijy-1} / Q_{ijy-1}, the prior year's percent caught of the TAC. The second scarcity variable, $\sum_{n=1}^{m-1} h_{ijny} / Q_{ijy} - \sum_{n=1}^{m-1} h_{ijny-1} / Q_{ijy-1}$, updates the first by measuring the year-to-date percent caught of the TACC *relative* to the prior year. In other words, the second factor measures the additional scarcity information available at some point within the fishing year that is incremental to what was available at the start of the fishing year. Since both higher demand and lower supply are associated with higher prices, we would expect both of these variables to have a positive influence on quota prices.

Two additional variables are included to assess the effect of ecological uncertainty on quota prices, one being biological and the other climatic.[19] The biological variable is the

[19] We omitted squared terms for these variables because we found that they were both very small and statistically insignificant and did not alter the results.

mortality rate for each species, which gives the percentage of the fish population that dies annually of natural causes. Species with higher mortality rates have population sizes that are more variable, which leads to greater uncertainty in the amount of fish likely to be caught with a given level of effort.[20] As a consequence, there is greater uncertainty in the profits from fishing high mortality species and we would expect the mortality rate to have a negative effect on quota prices due to risk aversion. The climatic variable we include is the Southern Oscillation Index, a time-series measure of variability in water temperature and pressure.[21] Water temperature significantly influences fish ecology and location, and is an important variable used by the fishing industry when assessing the productivity of fisheries. We would expect that greater variation in the Southern Oscillation Index would be associated with more uncertain profitability of fishing, and thus would have a negative effect on quota prices.

We also include dummy variables indicating the region, year, and month of each observation to control for system-wide time-series and regional effects.[22] The regional effects should to a certain extent control for fishing cost differences, especially those related to transportation. We do not, however, place much interpretative emphasis on the individual regional dummies, rather viewing them as control variables.

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[20] In fact, the New Zealand Ministry of Fisheries uses the mortality rate to construct a measure of natural variability that is factored into the setting of the TAC (Annala 2000). The assumption is that a stock with higher natural mortality will have fewer age-classes, and therefore will suffer greater fluctuations in biomass.

[21] It has been found that the cyclic warming and cooling of the eastern and central Pacific leaves a distinctive fingerprint on sea level pressure. In particular, when the pressure measured at Darwin is compared with that measured at Tahiti, the difference between the two can be used to generate an index number called the Southern Oscillation Index, which generally ranges from –35 to 35. When there is a positive number, we have La-Niña (or ocean cooling), and when the number is negative we have an El-Niño (or ocean warming).

[22] With 136 fish stocks in the sample, we do not include fixed effects for each fish stock in the model presented because such fixed effects reduce the transparency of the results without changing their basic message. Importantly, we wanted a model that could be directly applied not only to species and fish stocks within our sample, but also to other fish stocks that could potentially be added to the system. In addition, the qualitative results and statistical significance of the estimation are robust to the inclusion of fixed effects by fish stock, although, unsurprisingly, the magnitude of the export price coefficient is reduced because much of the variation in export prices is between species.

If the tradable quota system actually delivers on its most important promise—increased profitability of the fisheries through stock rebuilding and cost rationalization—we would expect the annual time effects in our model to generally be positive, at least during an initial transition period. That is, once we have controlled for changes in fish prices and other important factors in our analysis, the residual effect of time on quota prices should be positive as the system provides incentives for increased profitability. Caution is always in order when interpreting time effects, however, and there are other unmeasured factors that could plausibly influence quota prices over time. In addition to increased profitability, there may also be an increase in the perceived security of quota assets over time, which could have a positive effect on quota sale prices, but would not necessarily influence quota lease prices. There have also been policy changes over the history of New Zealand's ITQ system that could affect prices in both positive and negative ways. We discuss these issues further in the results section.

We also estimate a preliminary equation for quota sale prices. Earlier we pointed out that the quota sale price should equal the discounted expected rent from fishing, or equivalently, the discounted flow of future expected lease prices. If lease prices are expected to remain relatively constant, then the sale price would simply equal the lease price divided by the relevant market rate of interest. If lease prices are expected to move up or down over time, however, due to changing export prices or other relevant factors such as costs, the relationship between lease and sale prices would be more complex as it would depend on expectations of future conditions.

A thorough analysis of the sale price determinants and the relationship between lease and sale prices would therefore require carefully modeling future expectations of prices and costs, an endeavor that is beyond the scope of the present paper. Nonetheless, we believe it is useful as a first cut to investigate the determinants of quota sale prices, as well as the relationship between sale and lease prices, assuming that recent conditions in the fishery are an adequate approximation of future expectations. Under these conditions, quota sale prices should be roughly equal to lease prices divided by the interest rate—which would be swept into time dummies after taking logs. We therefore estimate a quota sale price equation whose explanatory variables are identical to the lease price equation described above.

4.2 Data and Estimation

We estimate Equation (2) using a comprehensive database of information we constructed from New Zealand government agencies and other sources for the period 1986-1999. All monetary figures were adjusted for inflation to year 2000 New Zealand dollars. A detailed description of the variables included in the data set and their sources is included in the appendix. Table 2 gives descriptive statistics on the included variables, which exhibit a large degree of variation. Fish export prices range from \$418 to \$54,500 per ton, while quota lease and sale prices range up to \$45,000 and \$337,500 per ton, respectively. The TACs for different quota markets range from 1 to 251,883 tons per year, with an average TAC of 5,702 tons per year. The number of transactions underlying each monthly average observation is 7 leases and 3 sales on average, ranging from 1 to 162 leases and 1 to 66 sales.

Our choice of functional form was designed to allow for joint estimation of a range of fish stock markets with a wide range of scales (e.g., in terms of prices and catch levels), to provide a reasonable fit of the data, to allow relatively transparent interpretation of the parameter estimates, and to be parsimonious. We therefore enter all variables in a form that yields percentage relationships, which we accomplish by taking natural logarithms in some cases, but not in others where the variable is already a percentage or a rate. Due to the presence of quadratic terms in the estimated equation, we also normalize certain variables to ease interpretation of the parameter estimates.[23]

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[23] We normalize the export price so that its normalized mean equals unity, or zero after taking natural logarithms. We normalize the lagged annual percent caught by subtracting one, so that it equals zero when the TACC is fully binding (i.e., when H/Q = 100%). We also take the absolute value of the Southern Oscillation Index because we are interested not in the sign of the Index, but rather its magnitude as an indication of climatic variability.

We estimate separate equations for lease prices and sale prices using feasible generalized least squares (FGLS), wherein the covariance matrix of the disturbances is adjusted in three ways. First, we weight the disturbances by the number of transactions underlying each observation, which is a monthly average. Weighting in this manner will correct for heteroskedasticity owing to the fact that averages based on more observations will have lower variance. Second, we use the multiple observations for each fish stock to construct separate stock-specific variance estimates, allowing us to weight the lower variance fish stocks more heavily. Finally, we use the time-series structure of the observations to make separate stock-specific corrections for autocorrelation.[24] More restrictive error structures were rejected by likelihood ratio tests. Estimation uses a two-step procedure, where in the first step residuals from OLS (weighted using the number of transactions) are used to determine the sample variance and first-order serial correlation for each fish stock; these components together with the transaction weights yield the complete weighting matrix. In the second step the complete weighting matrix is used in FGLS estimation of the parameters.

4.3 Results

The estimation results for both quota lease and sale prices are presented in Table 3. Overall, the results are consistent with the economic expectations about the parameters. The estimated coefficients all have the expected signs and reasonable magnitudes, and are consistent across both the lease and sale price equations. The results confirm that quota prices increase with increasing prices for fish and increased quota scarcity, and decrease with increasing ecological uncertainty. The year dummies indicate a substantial increase in quota prices since the QMS was established, consistent with an increase in the profitability of the fisheries.

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[24] The overall sample autocorrelation for lease prices was 0.35, and for sale prices was 0.50, both of which were significant according to Durbin Watson and Breusch Godfrey tests and also differed substantially across panels.

The relationship between quota prices and fish prices is clearly illustrated in Figure 3, which plots each species' average lease price and average sale price against its average export price for the 1998/1999 fishing year. The coefficient on ln$p$ (β_1) in both equations measures the elasticity of the quota price with respect to the fish export price, at the mean of the data, after controlling for other important factors. The elasticity is positive and statistically significant for both lease and sale prices, as expected, indicating that species with higher export prices also tend to have higher quota prices. The magnitude of the export price elasticity is also consistent across the two quota price equations; a 1 percent increase in the fish export price is associated with a 0.94 percent increase in the lease price and a 0.89 percent increase in the quota sale price. The coefficient on the squared export price (β_2) in both equations is positive, indicating that export prices above the mean (about NZ$7,000) have a somewhat greater effect on the quota price than that given by β_1, while below average export prices have a somewhat lesser effect.

The coefficient on H_{ijy-1}/Q_{ijy-1} (β_3) gives the elasticity of the quota price with respect to the percent caught of the TAC in the previous year, a measure of quota scarcity. The elasticity is similar in magnitude across the two equations and is positive and economically and statistically significant, indicating that a 1 percent increase in percent caught last year is associated with a 0.59 percent increase in the quota lease price and a 0.68 percent increase in the quota sale price—near the point where the TAC is just binding (i.e., H/Q = 100%). For the rare cases where the catch exceeded the TAC, the negative coefficient on the squared percent caught (β_4) indicates that further increases in the percent caught above 100% have a significantly lesser effect on quota prices, while further decreases in the percent caught below 100% have an increasingly negative effect on quota prices. These results makes economic sense because catches above the TAC are rare and short-lived and should therefore have a lessened effect on quota prices. On the other hand, fish stocks where the TAC is not binding can persist for long periods, and very low percent catches are indicative of fish stocks with little expected quota scarcity, and thus quota prices which should move quickly toward zero. Our second measure of quota scarcity, $h_{ijm-1y}/Q_{ijy} - h_{ijm-1y-1}/Q_{ijy-1}$, which updates the first by measuring the year-to-date percent caught of the TACC *relative* to the prior year, also had the expected positive effect on quota prices. The relevant coefficient (β_5) indicates that a 1 percent increase in this measure is associated with a 0.37 percent increase in the quota lease price and a very similar 0.38 percent increase in the sale price. The squared terms for this variable (β_6) were statistically insignificant and inconsistent in sign.

Turning to our measures of ecological uncertainty, as expected we found that species with higher mortality rates had significantly lower quota prices, other things equal. The parameter estimate on r (β_7) measures the percent decrease in the quota price for a 1 percent increase in the mortality rate, which we estimated to be a 0.89 percent decrease in the quota lease price and a 54 percent decrease in the quota sale price. As described above, these results are consistent with the idea that species with higher mortality rates have more variability in their populations, which leads to greater profit uncertainty and in turn lower quota prices. Our other measure of ecological uncertainty, the Southern Oscillation Index, was estimated to have a negligible relationship with quota prices. Part of the problem with trying to identify an effect of this variable is that it is purely time series, and we already include in the estimation dummy variables for years and months.

There is also evidence of significantly increased profitability of the included fisheries since the establishment of the QMS, which is the primary economic benefit promised by a tradable quota system. The coefficients on the year dummies (α_{2y}) can be transformed to yield the percent increase in quota prices since the program began, controlling for changes in the other variables, where the percent increase equals $e^{\alpha_{2y}} - 1$. Recall that since we have controlled for changes in export prices over time, as well as other important factors, the residual effect of time should capture cost reductions and other efficiency improvements leading to increased profitability.

The estimates indicate that quota lease prices were 48 percent higher and quota sale prices were 105 percent higher in 1999 compared to the first year of the program, other things equal. These increases represent a deterioration in both quota prices since 1995, however, when quota lease prices reached their maximum at a 93 percent increase over 1986, as did quota sales prices which reached a maximum 184 percent increase before falling. The timing of this decrease in quota prices is coincident with the enactment and implementation of the Fisheries Act of 1996, which has faced opposition from industry due to some of its provisions. There has been particular concern over quota forfeiture provisions for offenses, the elimination of provisions allowing "carryover" of some quota from one year to the next, the broader application of minimum wage and worker safety laws, and technical difficulties with system administration (Yandle 2001).

The greater increase in quota sale prices compared to quota lease prices—by a factor of about 2—can be entirely attributed to decreases in the market interest rate, which fell by half from about 10 to 5 percent over the relevant period. The relationship between quota lease prices, sale prices, and the rate of interest is illustrated in Figure 4. The "implicit hurdle rate" plotted in the figure is the median (across fish stocks) of the annual average lease price divided by the annual average sale price. Recall that in a competitive market the lease price should measure the annual profit flow and the asset sale price should represent the present value of expected future profit flows. Assuming roughly constant expected future profit flows; the lease price divided by the sale price should therefore roughly equal the market interest rate. Figure 4 supports the presence of this arbitrage relationship, with the computed implicit hurdle rate closely tracking the market interest rate over the sample period. At the same time the implicit hurdle rate fell by about half from 13 to 7 percent, the real rate of interest as measured by New Zealand Treasury bills, fell from 10 to 5 percent. Because quota are riskier assets than Treasury bills, one would expect that the implicit hurdle rate for quota should be higher than the rate for Treasury bills, which it typically is.

As mentioned earlier, increases in quota sale prices could also be driven by the perception of increased security of quota assets, although such an effect should not be important for quota lease prices. The fact that differences in the quota lease and sale price increases can be fully explained by decreases in the interest rate, however, suggests that changes in security perceptions may not have been very important. Nonetheless, these results are subject to the earlier caveat that we have not thoroughly explored alternative assumptions about future expectations of rents. Rather we have focused on the simplest assumption about expectations—namely that they are given by recent conditions.

Finally, we note that the month and region dummies also had a jointly significant effect on quota lease and sale prices. The largest seasonal effect for lease prices came in the last month of the fishing year, when prices were estimated to be 21 percent lower than in the first month of the year. Such a decline may be due to the fact that quota cannot generally be carried over from one year to the next, and thus would cease to have value at the end of the last month. The same effect is not evident for quota sales, which is expected since usage in any one year is only a small part of the asset's value.

5. Conclusion

Fisheries throughout the world are biologically and economically threatened not because fishermen are irrational, as many conservationists would claim, but because they are rational. Under the current system of regulated open-access, it is in their best interest to catch as much as possible as fast as possible. ITQs are a promising means of ending the race to fish and as a way to rationalize fisheries. At the same time, ITQs provide a vehicle by which fishermen can realize the potential gains of resource stewardship.

In theory, ITQ programs are directly analogous with other "cap and trade" programs, such as the U.S. tradable permit program for reducing sulfur dioxide emissions from power plants. In practice, however, there may be important differences between the participants in pollution permit versus fishing quota markets associated, for example, with the degree ex-ante uncertainty in production levels and financial sophistication. In fact, many argue that because of these differences, the use of cap and trade policies in fisheries is not as likely to achieve the goals of meeting a policy constraint at least cost.

Whether market-based instruments are being applied to fish, pollution, or other resource problems, the ability of firms to buy and sell quota in a well-functioning market is necessary for achieving efficiency gains. Critics of market-based instruments point out that these markets can be thin and have high transaction costs, or may be plagued with information problems related to uncertainty and decision-making complexity. With very few empirical studies of "created" markets, it is often hard to counter these claims with anything more than anecdotal stories. To further establish an empirical record, we use the most comprehensive data set on ITQ markets gathered to date to evaluate the operation of New Zealand's market for fishing quota, the largest system of its kind in the world.

Regarding market liquidity, we observe both a sufficient numbers of market participants and levels of market activity to support a competitive quota and lease market. There has been an average of 1,500 quota owners over time, with about 60 owners in the typical individual quota market. There have been over 150,000 transactions since the program started, at an average rate of 9,200 leases and 2,300 quota sales annually. The level of activity has risen steadily over the years, consistent with the notion that the development of these markets takes time. Not all is rosy, however—some markets have relatively few transactions, although these tend to be economically unimportant fisheries. In addition, some of the New Zealand quota markets were designed more for political and biological reasons than for maximizing economic gains (Boyd and Dewees 1992, Annala 1996).

Another critical question in gauging the performance of quota markets is investigating whether market prices behave in an economically reasonable manner. In general, we find evidence of economically rational behavior in these markets through the relationship between quota lease and sale prices and measures of fishing value, quota scarcity, ecological variability, and market rates of return. Our analysis of the implicit hurdle rate between quota leases and sales, for example, finds that the implicit rate for quota follows closely the general historical level and pattern of New Zealand's real rate of interest. Moreover, after controlling for relevant factors, our results show a substantial increase in the value of quota prices over the history of the ITQ program, consistent with a significant increase in the profitability of the included fisheries.

Even though the current set of ITQ programs are generally getting positive reviews, their future is unclear as evident by the ongoing moratorium in the United States. The debate in the U.S. is focused on whether to lift the moratorium and whether shares should be transferable. We can infer from the revealed behavior in the New Zealand ITQ market that transferability of shares has high economic value. There are, however, additional concerns about the potential loss of the small-scale fisherman if trading is permitted. While not addressed specifically in this paper, we do observe some fisheries where there has been significant reductions in owners, but there still remains a large number of small quota owners today.

Overall, the evidence to date suggests a reasonable level of economic sophistication in these markets, implying that market-based quota systems are potentially effective instruments for efficient fisheries management. But important questions remain for future research. A more careful modeling of future expectations and variability of fish export prices, for example, might shed further light on the relationship between quota lease and sale prices; both in aggregate and as it pertains to individual fisheries. The implications of incidental catch of non-target species for quota prices and market activity also bears further scrutiny.

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7. Data Appendix

Using information obtained from New Zealand government agencies and other sources, we assembled a comprehensive panel database of information related to the New Zealand ITQ system over the period 1986-1999. The data include information on the name of each fish stock, quota transactions (i.e., prices and quantities of quota leases and sales), the export prices of fish species covered by the QMS, quota ownership, the total allowable commercial catch (TAC) and actual catch for each fish stock, biological information on fish species, climate variation, and interest rates. All monetary figures were adjusted for inflation to year 2000 New Zealand dollars using the Consumer Price Index from Statistics New Zealand. A description of the variables included in the data set and their sources follows.

A.1 Species and Regions

The New Zealand ITQ system included 26 species when it began in 1986, growing to 33 species by 1998. Where data allow, we include all 33 species in our analyses. Associated with these 33 species are 157 geographically distinct fish stock markets.[25] Table 1 shows the species names, abbreviations, when they entered the ITQ system, and the number of associated fish stocks. For the econometric analysis of lease and sale prices we can include only 29 species (136 fish stocks) because export price data are unavailable for HPB, OYS, SPO, and STA. For the econometric analysis we also include dummy variables for 17 geographic regions which we determined based on the geographic coverage of each fish stock (Paulin 1996, Clement & Associates 1997).

[25] We exclude region 10 from our analysis because this region is rarely if ever fished for any species.

A.2 Quota Transactions

We acquired data from the New Zealand Ministry of Fisheries on all individual transactions between quota holders occurring from when the program began in late 1986, through 1999. This represents over 200,000 transactions. In order to sell, purchase, lease or sublease quota, the individuals involved in the transaction must register a "Notification of Sale and Purchase of Individual Transferable Quota" or a "Notification of Lease or Sublease of Individual Transferable Quota" with the appropriate agency, which includes information about the quota holders as well as the quantity and price per ton of the quota sold or leased. To protect privacy, the data on quota prices are separated from any identifying information, resulting in two transactions datasets.

Transaction Quantities and Concentration Measures. One transactions dataset includes the quantity of quota transacted, an identifier called the quota registration number, names and addresses for both parties involved in each transaction, the type of transaction, and the date of the transaction. The following types of transactions are included: sales and purchases, leases and subleases, initial allocations of quota, bycatch trade-off leases, TAC reductions, forfeitures, ITQ deductions, memoranda of variation, and lease transfers. We use the transaction quantity data to measure the amount of quota that firms hold and/or own, related concentration indices, how much quota is being leased or sold, how many firms are active in the QMS, and related trends in firm entry and exit.

As a first step, we consolidated certain quota registration numbers (QRNs) so that they better represented economically distinct behavioral units. Many firms transact quota under a number of different QRNs (e.g., Abalone Quota Ltd. and Abalone Quota Holdings Ltd.), but the quota are in reality under common management. After carefully scrutinizing the names, addresses, and other information for all 5,697 QRNs that existed at some point in the sample period, we consolidated many of them, leaving a total of 4,729 distinct units, which we call "firms". This is an important step—one that few if any other analyses of these data have taken—

because it influences all of the market measures mentioned above (e.g., quantity of transfers, industry concentration, number of firms). Given our unique firm identifier, we used the transactions data to determine the year-end quantity of quota that each firm owned in each fish stock as well as the quantity it held (i.e., taking account of leases in and out). We use the quantity of quota owned by each firm in each fish stock to construct an annual Herfindahl Index and 4-firm concentration ratio for each fish stock.[26]

Transaction Prices. The second transaction dataset contains the price per ton and the quantity of quota sold or leased, the relevant fish stock, and the transaction date; prices were available for 131,396 leases and 29,172 sales. Some of the price data were unreliable because other assets (e.g,., boats) were reportedly included in the sale price, the transaction was not "arms length", or perhaps due simply to misreporting. After carefully inspecting the data by individual fish stocks, we omitted 6% of lease and 11% of sale observations which were unreasonably low or high.[27] After adjusting for inflation using the CPI, we calculated the monthly average lease and sale price for each fish stock.[28] We also counted the number of transactions used in the creation of each monthly average for use in our econometric estimation, which employs this number of underlying transactions as a statistical weight.

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[26] The Herfindahl Index equals the sum of the squared shares of each quota owner in each fish stock; the 4-firm concentration ratio equals the sum of the shares of the four largest owners in each fish stock.

[27] In general, our conservative approach was to omit prices that were many times lower or higher than comparable prices for the same fish stock. On the high end, the cutoff we used varied by fish stock, while on the low end a conservative approach was to omit lease prices less than $1 and sale prices less than $100 per ton. In any event, whether or not we omitted observations did not alter the qualitative results, and it changed the quantitative results only to a small degree.

[28] An alternative would be to calculate a weighted average price, using the quantity of each transaction as its weight. We found that this alternative price measure was not substantially different from the straight average, and had the disadvantage of not leading to a clear weighting procedure for our econometric analysis.

A.3 Other Variables

Export Prices. As a measure of the value of each fish species, we calculated its export price per greenweight ton using data from Statistics New Zealand over the period 1986-1999. After adjusting for inflation using the CPI, we created a monthly export price by dividing the FOB revenue for each species by the greenweight tonnage of product. We computed the greenweight tonnage by multiplying exported tonnages—by product type (e.g., whole, fillets, lobster tails)—by the official Ministry of Fisheries conversion factors (Clement 1997,1998), and then summing these for each species.

TAC and Actual Catch. Both the Total Allowable Commercial Catch (TAC) and actual catch for each fish stock over time are from the New Zealand Ministry of Fisheries.

Real Interest Rates. For comparison purposes in our analysis of implicit hurdle rates, we use the 90-day New Zealand Treasury bill rate from the Reserve Bank of New Zealand, deflated by the New Zealand CPI to create an annual forward-looking real interest rate.

Ecological Variables. Species mortality data is from a compilation by Froese and Pauly (2000). As a measure of climate variation, we obtained monthly values for the Southern Oscillation Index from the Australian Bureau of Meteorology (http: //www.bom.gov.au /climate /current /soihtm1.shtml).

Table 1: 33 Species Included in the New Zealand ITQ System as of 1998

Species Name	Abbreviation	Year Entered	# Fish Stocks	Species Type
Barracouta	BAR	1986	4	Offshore
Blue Cod	BCO	1986	7	Inshore
Bluenose	BNS	1986	5	Inshore
Alfonsino	BYX	1986	5	Inshore
Rock Lobster	CRA	1990	9	Shellfish
Elephant Fish	ELE	1986	5	Inshore
Flatfish	FLA	1986	4	Inshore
Grey Mullet	GMU	1986	4	Inshore
Red Gurnard	GUR	1986	5	Inshore
Hake	HAK	1986	3	Offshore
Hoki	HOK	1986	1	Offshore
Hapuku & Bass	HPB	1986	7	Inshore
John Dory	JDO	1986	4	Inshore
Jack Mackerel	JMA	1987	3	Offshore
Ling	LIN	1986	7	Offshore
Blue Moki	MOK	1986	4	Inshore
Oreo	OEO	1986	4	Offshore
Orange Roughy	ORH	1986	7	Offshore
Oyster	OYS	1996	2	Shellfish
Paua (Abalone)	PAU	1987	10	Shellfish
Packhorse Rock Lobster	PHC	1990	1	Shellfish
Red cod	RCO	1986	4	Inshore
Scallops	SCA	1992	2	Shellfish
School Shark	SCH	1986	7	Inshore
Gemfish	SKI	1986	4	Offshore
Snapper	SNA	1986	5	Inshore
Rig	SPO	1986	5	Inshore
Squid	SQU	1987	3	Offshore
Stargazer	STA	1986	7	Inshore
Silver Warehou	SWA	1986	3	Offshore
Tarakihi	TAR	1986	7	Inshore
Trevally	TRE	1986	4	Inshore
Blue Warehou	WAR	1986	5	Offshore

Table 2: Descriptive Statistics for Determinants of Fishing Quota Prices

Variable	Mean	Std. Dev.	Min.	Max.
Lease price ($NZ/ton)	1,401	3,674	1	45,000
Sale Price ($NZ/ton)	19,119	43,824	100	337,500
Export Price ($NZ/ton)	6,955	10,128	418	54,498
Catch (tons/year)	4,455	22,000	0	268,633
Total Allowable Commercial Catch (tons/year)	5,703	25,360	1	251,883
Percent Catch	0.77	0.34	0.00	2.73
Percent Cum. Catch Over Prior Year	0.01	0.14	-1.61	1.53
Mortality rate	0.31	0.23	0.05	1.00
Southern Oscillation Index	-3.3	11.5	-28.5	21.0
Number of Leases per Month	7	9	1	162
Number of Sales per Month	3	3	1	66

Note: Statistics are based on the 13,783 observation sample from the estimation of quota lease price determinants, with the exception of sale prices and the number of sales which are based on the 8,117 sample from the estimation of quota sale price determinants. Monetary figures are year 2000 NZ dollars, which are typically worth about half a US dollar. Tons are metric tons.

Table 3: Determinants of Fishing Quota Lease and Sale Prices

Variables	Lease prices	Sale prices
Final demand		
Log of fish export price	0.941 (0.009)	0.890 (0.017)
Log of fish export price, squared	0.101 (0.005)	0.138 (0.010)
Quota scarcity		
Prior year % caught of total allowable catch (TACC)	0.592 (0.027)	0.676 (0.045)
Prior year % caught of TACC, squared	-0.643 (0.036)	-0.232 (0.060)
Year-to-date % caught of TACC above prior year	0.372 (0.045)	0.385 (0.068)
Year-to-date % caught of TACC above prior year, squared	0.142 (0.097)	-0.214 (0.122)
Ecological uncertainty		
Fish mortality rate	-0.888 (0.029)	-0.540 (0.051)
Log of absolute value of Southern Oscillation Index	-0.029 (0.003)	0.018 (0.004)
Year dummies *(1987 omitted)*		
1988	0.073 (0.048)	0.066 (0.039)
1989	0.195 (0.051)	0.046 (0.042)
1990	0.312 (0.048)	0.157 (0.038)
1991	0.342 (0.045)	0.181 (0.036)
1992	0.455 (0.043)	0.238 (0.039)
1993	0.467 (0.043)	0.592 (0.040)
1994	0.619 (0.043)	0.769 (0.039)
1995	0.655 (0.043)	1.043 (0.040)
1996	0.550 (0.043)	0.957 (0.041)
1997	0.624 (0.043)	0.871 (0.043)
1998	0.530 (0.042)	0.814 (0.042)

Table 3: Determinants of Fishing Quota Lease and Sale Prices

Variables	Lease prices	Sale prices
1999	0.390 (0.043)	0.724 (0.044)
Month dummies	*jointly significant*	*jointly significant*
Region dummies	*jointly significant*	*jointly significant*
constant term	6.835 (0.057)	8.890 (0.045)
number of observations	13,783	8,117

Note: The dependent variables are the average monthly lease and sale prices. The sample data are a panel of observations for different species-region differentiated quota markets over 14 years. The R^2 for the comparable OLS estimates for the lease price equation is 0.84 and for the sale price equation is also 0.84. Estimation method is feasible generalized least squares (FGLS), including heteroskedastic errors with first-order serial correlation, differentiated by panel, and weighted using the number of transactions underlying each monthly average price. There are 136 panels for the lease price equation and 135 for the sale price equation. Dummy variables to control for seasonal effects (i.e., 12 months) and regional effects (i.e., 17 regions) are also included in the estimation. Some variables are normalized to ease interpretation. See data appendix for further detail.

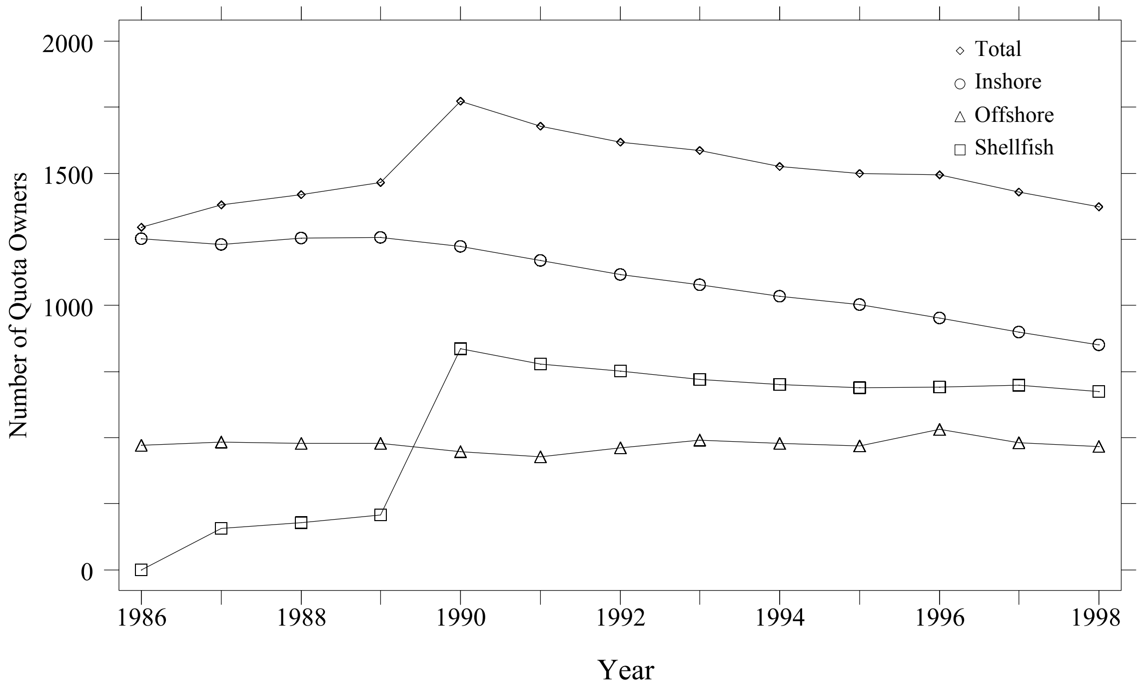

Figure 1: Trends in the Number of Quota Owners

Note: Number of quota owners, by fishing year. See Table 1 for species groupings.

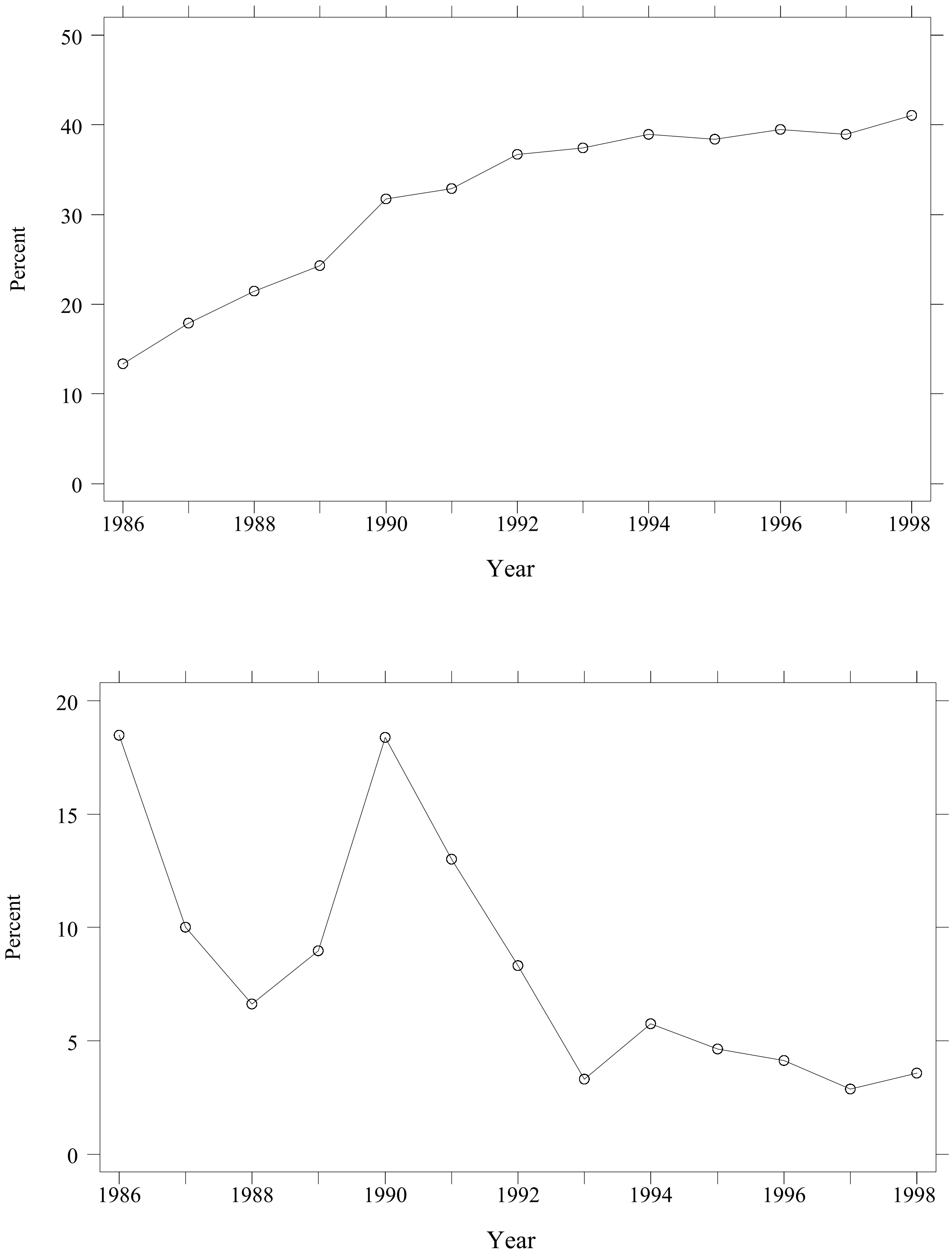

Figure 2. Trends in the Portion of Quota that are Leased and Sold

Note: Annual median across fish stocks of the net percent leased and sold by fishing year.

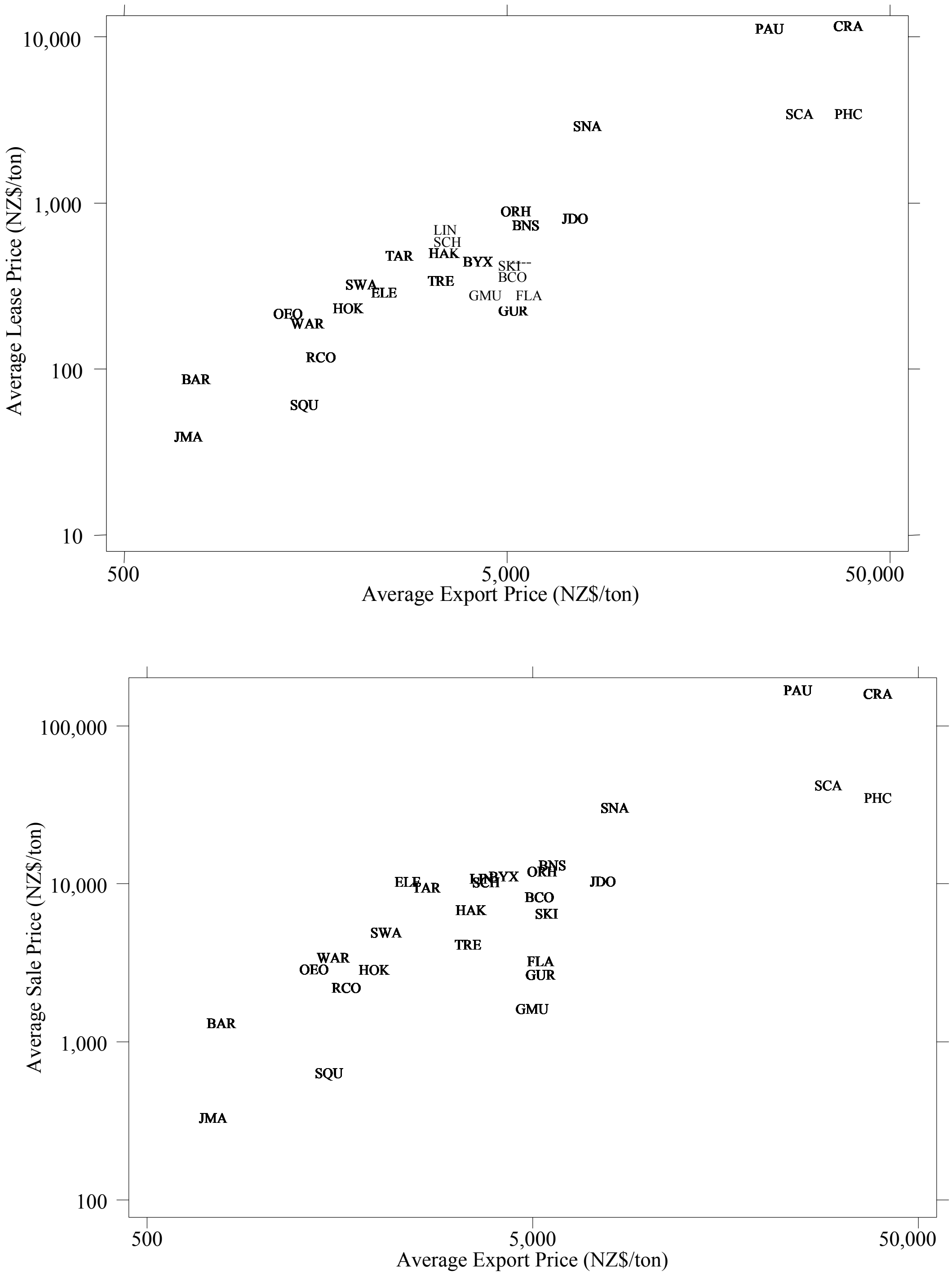

Figure 3. Quota Lease Prices, Quota Sale Prices, and Fish Export Prices

Note: Logarithmic scale. Averages by species for the 1998/1999 fishing year. Year 2000 NZ$. Data symbols are species abbreviations.

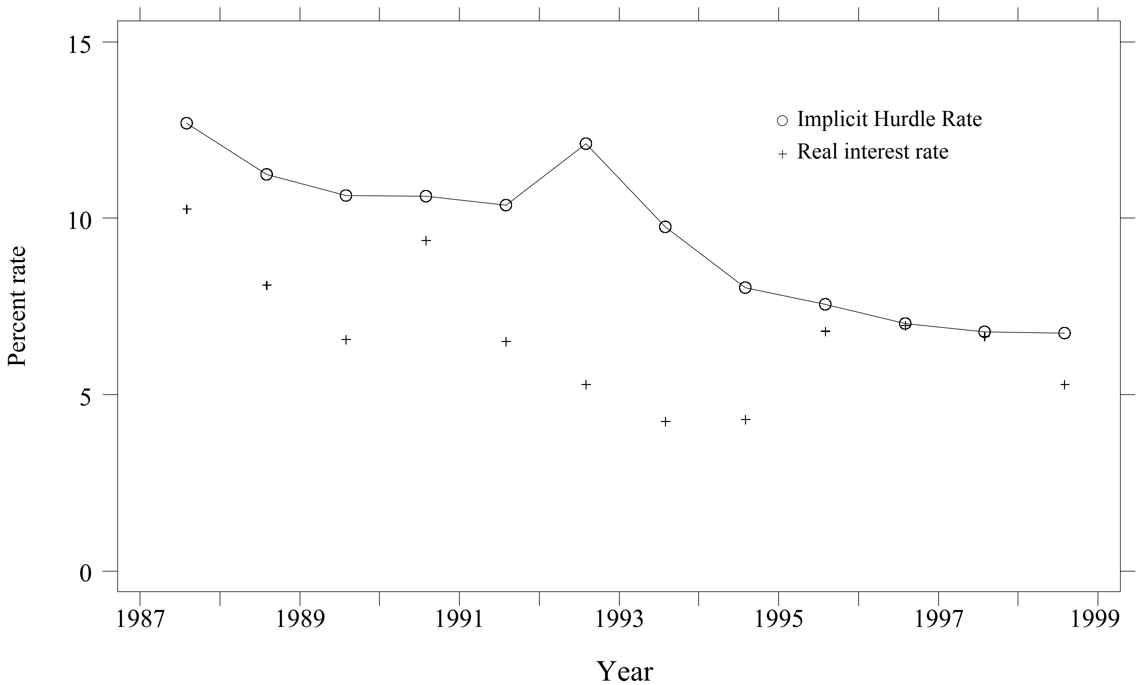

Figure 4. Implicit Hurdle Rate for Quota and Market Interest Rates

Note: Implicit hurdle rates are medians across fish stocks in each year. The real interest rate is based on New Zealand Treasury bills, deflated using the New Zealand consumer price index.