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Abstract

Fisheries worldwide continue to suffer from the negative consequences of open access. In 1986, New Zealand responded by establishing an individual transferable quota (ITQ) system that by 1998 included 33 species and more than 150 markets for fishing quotas. We assess these markets in terms of trends in market activity, price dispersion, and the fundamentals determining quota prices. We find that market activity is sufficiently high to support a competitive market and that price dispersion has decreased over time. Using a 15-year panel dataset, we also find evidence of economically rational behavior through the relationship between quota lease and sale prices and fishing output and input prices, ecological variability, and market interest rates. Controlling for these factors, our results show an increase in quota prices, consistent with increased profitability. Overall, the results suggest these markets are operating reasonably well, implying that ITQs can be 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 would lead to excess fishing effort, dissipation of rents, and inefficient depletion of fish populations. Unfortunately, the prediction has been borne out. To take just one example, after two decades of rapid expansion of fishing effort, the New England groundfish fishery collapsed and has been essentially closed since 1994. Throughout the world approximately 25% of the major fish stocks are currently in jeopardy of collapsing (FAO 2001).

Until the early 1980s, most fisheries were either completely unmanaged or managed under command-and-control regulations that governed the size of vessels, type of nets, season length, and which areas are open to fishing. Such regulations fail to check the number of vessels or the level of fishing effort, and they encourage fishermen to work around equipment constraints. Under these regulations, a fisherman has 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 exceeds its viable capacity.

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Individual transferable quota (ITQ) systems are a promising means to correct this market failure.[1] They limit fishing operations by setting a total allowable catch (TAC), which is typically allocated in perpetuity to fishing participants based on historical catch. Because fishermen have access to a guaranteed share of the TAC, this approach significantly reduces incentives to engage in a race to fish.[2] In addition, when transferability of the shares is permitted, the least efficient vessels will find it more profitable to sell their quotas rather than fish them. Over time, this should both reduce excess capacity and increase the efficiency of vessels operating in the fishery.

Since the late 1970s and early 1980s, when countries began to "enclose the commons" by establishing exclusive economic zones in the ocean off their coasts, more than 15 countries followed New Zealand's and Iceland's lead in establishing ITQ systems. To date, ITQs are used to manage over 60 species, including 4 in the United States (OECD 1997). Although assessments of these programs are generally positive, their future is unclear.[3] For example, a

[1] Landing fees or other price-based policies represent an alternative to quantity-based policies such as tradable quota. While either price or quantity instruments can attain equivalent outcomes in a deterministic setting, uncertainty leads to differences in the efficiency of these alternatives. Weitzman (2002), for example, offers one perspective on the instrument choice question, finding that price instruments are preferable when there is recurrent uncertainty in fish stocks. Other sources and forms of uncertainty—such as in economic variables—could favor quantity instruments, however, so that the net effect is theoretically unclear and case dependent.

[2] Several benefits arise from reducing the race to fish, including relaxing of controls on season length and the ability of fishermen to shift to quality from maximizing quantity. For example, since the introduction in 1994 of an ITQ system in the Alaskan halibut fishery, the season length has grown from two 24-hour openings to more than 200 days. The flexibility to time fishing trips when port prices are higher, and the elimination of large supply gluts of fresh product, have resulted in increases in price per pound of more than 40% (Casey et al. 1995). The focus on quality is also evident in New Zealand, where fishermen have changed catching methods in the red snapper fishery in order to sell their catch on the highly profitable Japanese live fish market (Dewees 1998).

[3] The existing literature on ITQ programs, although extensive, is dominated by description and anecdotal evidence of their effects (NRC 1999). There are, however, a few notable exceptions. Recent work by Grafton et al. (2000) uses firm-level data from the British Columbia halibut fishery spanning pre- and post-ITQ periods to estimate a stochastic production frontier. They find evidence of substantial gains in revenues and producer surplus and predict that the gains in producer surplus could be five times higher if restrictions on transferability were not in place. Other studies quantitatively assess ITQs using relationships estimated on either pre- or post-ITQ catch-effort data to predict changes in fleet restructuring, costs, and revenues (Squires et al. 1994; Wang 1995; Weninger 1998). Such predictions are based on the assumption that the market for fishing rights is operating efficiently, but whether that is likely to hold in practice remains an open question, which we address herein.

moratorium on implementing new ITQ systems has been in place in the U.S. since 1996 while policymakers have debated various design elements, including whether quota should be transferable.[4]

For ITQs to deliver an efficient solution to the common pool problem in practice, it is critical that fisherman can buy and sell quotas in a competitive market and that quota markets convey appropriate price signals. Assuming competitive markets, rational asset pricing theory suggests that quota prices should reflect the expected present value of future rents in the fishery.[5] Price signals sent through the quota market are therefore an essential source of information on the expected profitability of fishing and an important criterion for decisions to enter, exit, expand, or contract individual fishing activity. Quota prices also send signals to policymakers about the economic and biological health of a fishery. 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).

Establishing an empirical record of how well "created markets" work in practice is important not only for fisheries policy, but also in many other resource areas where the advantages of market-based policies hinge in part on market performance. 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. Assessments of the U.S. sulfur dioxide tradable permit system (Joskow et al. 1998; Carlson et al. 2000; Stavins 1998) are significant contributions in this regard.

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[4] In addition to the transferability question, other contentious issues include whether shares should have limited duration, whether shareholders must remain active in the fishery, and whether processors should be allowed to hold quota.

[5] See Cochrane (2001) for a survey of the large literature on asset pricing, and Karpoff (1989) and Stefanou and Wilen (1992) for conceptual application to fishing licenses.

In theory, ITQ programs are analogous to other cap and trade programs, such as the U.S. tradable permit program for reducing sulfur dioxide emissions from power plants. However, there may be important differences between pollution permit markets and fishing quota markets in practice. For instance, controlling and forecasting emissions from a power plant is arguably easier than predicting both the level of catch on any trip and its composition. This is especially true in multi-species fisheries where fish populations cannot be directly targeted without incidental catch of other stocks. Thus, fishermen operating under a quota management system will likely need to rebalance their portfolio of quota holdings throughout the year to match catch levels—a task that some argue is simply too complex (Copes 1986; Squires et al. 1998).

Although recent experience with the sulfur dioxide trading program has changed many perceptions, skeptics still question whether tradable permit systems and other economic incentive-based policies can work in practice. Potential concerns include the degree of liquidity and transaction costs in such markets as well as information problems related to uncertainty and decision-making complexity.[6] In fact, many detractors of ITQ systems claim that these concerns are more likely in a fishery setting, because of ex ante uncertainty in production levels and participants' supposed lack of financial sophistication.

Such skepticism is in part warranted by the limited number of opportunities for careful research on how well created markets have performed in general and particularly in fisheries.[7]

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[6] 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 future research. Nonetheless, given that the output market for fish in New Zealand trades at a world price, the ability of firms to exercise market power in the quota market would seem to be limited. In addition, there are distributional issues such as consolidation and aggregation of quota associated with trading that we do not assess in this paper, although these are clearly important political issues. We note that we do observe some fisheries with significant reductions in quota owners, yet there remains a large number of small quota owners today.

[7] A significant literature investigates aspects of market efficiency in a variety of markets, including those for financial assets (Fama 1998, Cochrane 2001), housing (Case and Shiller 1989), art (Geotzmann 1993, Psendao 1993), and natural resources. Within this large literature, the most closely related to our research is work on markets for lease and sale of land, oil fields, and forest tracts, which like fishing rights are valued primarily for the flow of rents from their productive use. For example, Burt (1986) found that rents (i.e., net revenues) are the fundamental

Several studies present descriptive statistics on annual quota prices and number of trades (Lindner et al. 1992, Arnason 1993, Batstone and Sharp 1999, Dinneford et al. 1999). For example, using two years of data on quota sale and lease prices from the New Zealand ITQ system, Lindner et al. (1992) attempt to measure economic rents, but conclude that a more thorough analysis of the determinants of quota prices is needed to properly assess market performance and rents.

To establish an empirical record on market performance for fishing quotas, we use the most comprehensive data set on ITQ markets gathered to date for the largest system of its kind in the world. The panel dataset from New Zealand covers 15 years of transactions across 33 species and includes price and quantity data on transactions in more than 150 fish stock markets (see Table 1 and Data Appendix). Markets exist in New Zealand both for selling the perpetual right to fish a certain quota stock and for leasing quotas. 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 145-plus years for orange roughy (*Hoplostethus atlanticus*). Some species, such as red snapper (*Pagrus auratus*), occupy inshore and shallow habitat and are targeted with trawl gear, set netting, and long lining. Others, such as orange roughy, are found offshore in depths over 1,000 meters and require large vessels and very specialized trawling gear. The quota markets also include abalone (*Haliotis iris*), rock lobster (*Jasus edwardsii*), and other shellfish and crustacean fisheries where potting, diving, and dredging are the most common harvesting techniques. The export value of these species

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driver of farmland prices, and that there is little evidence prices are driven by market speculation. The literature on offshore oil field leases and U.S. Forest Service timberland leases has focused mainly on the efficiency of auction mechanisms and the implications for bid prices (e.g., Paddock, Siegel, and Smith 1988; Porter 1995; Athey and Levin 2001). The work by Karpoff (1984, 1985) investigating the economic information embedded in limited-entry license prices of the Alaskan salmon fishery is also relevant, because these license prices in theory reflect the expected present value of future rents.

currently ranges from about NZ$700 per ton for jack mackerel to about NZ$40,000 per ton for rock lobster.[8]

We investigate how these markets have performed in a number of ways. First, by assessing the trends in market liquidity and participation across the markets, we establish whether the conditions necessary for well-functioning markets are satisfied. If these conditions are not met, noisy price signals might ensue reducing the expected efficiency gains. With active fishing quota markets and relatively low transactions costs, we should expect the law of one price to prevail—at least to the degree it does in typical well-functioning markets. We examine whether this proposition holds and how price dispersion has changed over the history of the program. Another aspect of well-functioning markets is that asset prices represent underlying fundamentals and behave in an economically rational way. If, as many claim, prices reported in these markets are fictitious and confounded by the inclusion of other assets (e.g., boats and gear), we should not find any meaningful relationship between quota prices and their underlying fundamentals (Lindner et al. 1992).[9] Finally, if quota prices reveal relevant asset arbitrage information, we should expect the rate of return to fish quotas to be comparable with other financial assets in the New Zealand economy. We test this proposition by investigating the relationship between the prices of perpetual quota sales and annual quota leases relative to measures of the market rate of interest.[10]

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. Although some specific

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[8] Throughout this paper, monetary figures are year 2000 New Zealand dollars, which are typically worth about half a U.S. dollar. Tons are metric tons.

[9] As noted in the data appendix, we do in fact observe a number of questionable price observations in the data. These observations are easily identified, however, amount to only a small fraction of the available data, and do not limit the ability of the remaining data to send meaningful market information.

[10] Due to a lack of information on the individual costs of fishing, we do not assess whether marginal fishing costs are being equalized under the ITQ system—another condition underlying efficient fishery management.

markets are thin, they tend to be economically and ecologically unimportant. The markets do not strictly conform to the law of one price, but the magnitude of price dispersion is comparable with typical findings in other markets, and the downward trend in dispersion is consistent with an adjustment period of learning and market development. We also find evidence of economically rational behavior in these markets through the relationship between quota lease and sale prices and fishing input and output prices, relative quota demand, ecological variability, and market rates of return. Moreover, after controlling for relevant factors, we see an increase in the value of quota prices over the history of the ITQ program, consistent with an increase in the profitability of the included fisheries. This is particularly true for fish stocks that faced significant catch reductions relative to historic levels. Overall, the results suggest these markets are operating reasonably well, implying that market-based quota systems are potentially effective instruments for efficient fisheries management. Nonetheless, the potential implications of incidental catch of non-target species and alternative expectations processes for quota prices remain fruitful areas for further research.

In section 2, we describe the forces behind the adoption of an ITQ system in New Zealand, the legislative history of this program, and its basic design. In section 3, we analyze the development of the market for quota sales and derivative leases, and trends in market activity and the number of quota owners. We also investigate the law of one price in both the lease and sale markets. 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

Although the New Zealand fishing industry accounts for less than 1% of the world's fishing output, it contributes NZ$1.7 billion annually to the New Zealand gross domestic product. Seafood is the fourth largest export earner, and more than 90% of fishing industry revenue is derived from exports. New Zealand is currently considered a world leader in fisheries management, in both environmental and economic terms. This was not the case, however, prior to the implementation of its ITQ system.[11]

Before 1976, New Zealand fishery policy focused primarily on the development of inshore fisheries, leaving offshore fisheries to Japanese, Soviet, and Korean factory trawlers. This focus began to shift, however, after New Zealand extended its 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 to promote domestic production in 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. Quotas 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 ITQ system. Trading and leasing of shares are reported to have occurred (Sissenwine and Mace 1992), but the system did not provide an adequate mechanism for the transfer of quotas.

While the government was encouraging the development of offshore fisheries, inshore fisheries were beginning to exhibit signs of overfishing. The catch of red snapper, for instance—a commercially important inshore species—had peaked in 1978 and fallen by 43% 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. These subsidies for an

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

industry in a regulated open-access setting are cited as the main reasons for excess capacity and depleted fish populations in the inshore fisheries in the early 1980s.

Inshore fisheries depletion, the development of the quota-based program for offshore fisheries, and the general orientation of the government in the 1980s toward deregulation, combined to create an atmosphere conducive for fundamental change in New Zealand fisheries management. After several 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, and expanded to a total of 33 species by 1998. Under the system, the New Zealand EEZ was geographically delineated into quota management regions for each species based on the location of major fish populations. 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 157, ranging from 1 for hoki (*Macruronus novaezelandiae*) to 10 for abalone.[12] As of 1996, the species managed under the ITQ system accounted for more than 85% of the total commercial catch taken from New Zealand's EEZ.

Fishing quotas are generally tradable only within the same fish stock, and not across regions or species or years, although there are some minor exceptions.[13] The quota rights can be

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

[13] 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 trade-off exemption allows fishermen who incidentally take nontarget 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% of their quota; this right does not apply to leases. A third option is to enter into a nonmonetary agreement to fish against another's quota. Or a fisherman can surrender the catch to the government or 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).

broken up and sold in smaller quantities and any amount may be leased and subleased.[14] There is no restriction on the number of times quotas can be leased, subleased, or sold. The New Zealand Ministry of Fisheries sets an annual total allowable catch for each fish stock based on a biological assessment as well as 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 noncommercial fishing.[15] There are also legislative limits on aggregation for particular stocks and regions, and limitations on foreign quota holdings.[16] The significant degree of flexibility built into the system suggests that transactions costs will be low and activity will potentially be high. Compliance and enforcement is undertaken through a detailed set of reporting procedures that track the flow of fish from a vessel to a licensed fish receiver (on land) to export records, along with an at-sea surveillance program including on-board observers (Boyd and Dewees 1992).[17]

Individual quotas were initially allocated to fishermen 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 quotas free of charge and allowed fishers to petition for a change in their initial allocation. The main reasons for introducing the

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[14] As of October 1, 2001, annual quota leases were supplanted by sales of "Annual Catch Entitlements" or ACEs, which are issued annually by the government equal to each quota owner's annual quota allocation. Thus there are currently two quota instruments: the ACE and the right to the perpetual stream of ACEs.

[15] 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.

[16] Initially, the aggregation limits were on *holding* quota. Substantial changes were written into the 1996 Fisheries Act, one of which was changing the limits on holdings to *ownership* levels. The 1996 legislation also relaxed the aggregation limits for particular species and region combinations.

[17] In a survey of fishermen operating under the New Zealand ITQ system in 1987, Dewees (1998) found that 40% thought enforcement and 66% thought highgrading were potential problems with an ITQ management system. Highgrading is the practice of maximizing the quality of the catch to be counted against ones quota by dumping less valauble fish over board. These numbers dropped to 21% and 25% respectively in 1995 (Dewees 1998).

system, however, were to rebuild the inshore fisheries and improve the economic conditions of the industry. By denominating quotas as fixed tonnages, the government was counting on its ability to purchase quotas 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 quotas for that purpose because in some fisheries the initial allocations—which were based on past catch histories—exceeded the maximum sustainable yield. In 1986 alone, the government paid NZ$45 million to buy back 15,000 tons of quotas from the inshore fisheries (Boyd and Dewees 1992).

Faced with the prospect of spending another NZ$100 million to further reduce TACs (Sissenwine and Mace 1992), after prolonged negotiations the government switched from quota rights based on fixed tonnages to denominating the quotas 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 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 (Annala 1996).

The New Zealand ITQ system is a dynamic institution that has had many refinements since its beginnings more than 15 years ago. Nonetheless, the basic tenets of the system—setting a total allowable catch and leaving the market to determine the most profitable allocation of fishing effort—have remained intact.

3. Trends in Market Liquidity

Whether market-based policy instruments are being applied to fish, pollution, land, or taxi medallions, the ability of firms to buy and sell quotas in a well-functioning market is necessary for achieving efficiency gains.[18] 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

[18] Of course if quota were auctioned off on a recurring basis there might be less need for a secondary quota market since there would be incentives in place for efficient initial allocation.

and the level of market activity. Thin markets with few participants can lead to high transaction costs because buyers and sellers may 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; Stavins 1995). Some tradable permit programs have in fact attracted an insufficient number of participants, resulting in a low level of market activity and minimal efficiency gains (Hahn and Hester 1989). In addition to looking at market participation, we investigate whether the law of one price is typically satisfied within these quota markets and whether any price dispersion has decreased over time as these markets developed.

3.1. Market Participation, Entry, and Exit

The number of quota owners in the New Zealand ITQ system has averaged about 1,500 over the history of the program. Individual markets have had a median of 56 quota owners, ranging from 332 to just 1 owner in some small fisheries of low importance. To place these numbers in context, there are about 250 utilities with permit allocations under the U.S. sulfur dioxide permit market (U.S. EPA 2002), and the New York City taxi market has approximately 5,000 medallion owners (Schaller 2001).[19] 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 in 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 (see Table 1). The increase in quota owners from 1987 to 1990 was due to the addition of several shellfish species to the ITQ

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

program,[20] and the subsequent 22% overall decline was due to the exit of about 32% of inshore owners and 19% of shellfish owners from their peaks in 1989–1990. The median number of owners in individual fishing quota markets has fallen from 62 in 1986 to 54 in 1998. One argument against implementing a quota-based system has been that the large fixed costs needed to purchase quotas to enter the fishery could create a barrier to entry that may not exist in other regulatory settings. We find that although there has been net exit in New Zealand's ITQ system, there have been on average 90 new quota owners entering the system per year since 1990.[21]

Why the difference in exit behavior between the offshore versus inshore and shellfish fisheries? As described in section 2, 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 had excess capacity, especially near Auckland.[22] 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 with the offshore fisheries, all else equal. Figure 1 also illustrates 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 quotas and while some might be exiting, others are divesting from

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[20] Although more than 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.

[21] 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 of the fishery. Critics of quota management systems argue that implementing such a system will result in the loss of the small-scale fishermen, a claim analogous to those made for preservation of the family farm. Although these distributional concerns may be important, especially in the political realm, we generally leave them for another paper.

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

some stocks and investing in others. For example, it is evident from Figure 1 that in 1986 almost all the inshore quota owners also owned quotas for the offshore stocks.[23]

3.2. Market Activity

Markets exist in New Zealand both for selling the perpetual right to fish a certain quota stock and for leasing quotas. In practice, virtually all leases are for a period of one year or less. Although there are no official statistics, the general belief among government officials and quota brokers is that a majority of the transactions between small and medium-sized quota owners are handled through brokers. Larger companies, on the other hand, typically have quota managers on staff and engage in bilateral trades with other large companies. Brokers advertise quota prices and quantities for sale or lease in trade magazines, newspapers, and on the Internet. A brokerage fee between 1% and 3% of the total value of the trade to be paid by the seller is standard. There is anecdotal evidence of speculative activity, but this practice is not widespread. In most transactions, brokers operate as matchmakers, not unlike real estate agents, whereby any spread between bid and ask prices accrues to the parties of the transaction. Thus, brokers tend to focus on repeat business and revenue from fees rather than profits from speculation.

As one would predict from the flexibility of the rules on exchange and the high number of participants, transaction costs are reasonably low and the quota markets are indeed very active. More than 120,000 leases and 30,000 sales of quotas had occurred under the ITQ program as of the end of the 1998 fishing year—an annual average of about 9,200 leases and 2,300 sales. This represents a complete sample because all transactions (sales and leases) must be recorded

[23] 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 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 regions.

and submitted to the New Zealand government. The mean lease and sale quantities are approximately 40 and 50 tons, respectively.[24]

The total number of leases has risen considerably, from 2,000 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 the quota lease and sale markets as measured by the annual median across fish stocks of the net percentage leased and sold by fishing year.[25] The figure shows that the median percentage of quota leased in these markets has risen consistently, from 18% in 1987 to 41% in 1998.

The total number of quota sales has fluctuated, from highs of almost 3,500 sales in 1986 and 1990 to a low of 1,500 sales in 1998. The high years correspond to the 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 quotas per year in the late 1990s. This pattern of sales is consistent with a period of rationalization and reallocation proximate to the initial allocation of quotas, with sales activity decreasing after the less profitable producers have exited.

Although the typical ITQ market exhibits a reasonably high degree of activity, some individual quota markets are thin. The number of leases in the individual ITQ markets from 1986 to 1998 ranges from about 30 to 2,400, the median being 640 leases. The number of sales ranges from 0 to 1,100 across quota markets, the median being 140 sales. Quota markets with low

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[24] We note that the sulfur dioxide permit market—considered robust and competitive (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 (U.S. EPA 2002), and the average annual number of transfers of taxicab medallions in New York City since 1982 is about 800 (Schaller 2001). 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%.

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

activity tend to be of low economic importance in the size and value of the catch. In many cases, these minor markets were designed more for political and biological reasons than for maximizing economic gains (Boyd and Dewees 1992; Annala 1996).

3.3. Law of One Price

Although we find evidence suggesting that there are ample participants and liquidity over the history of the ITQ system to support a competitive market, this does not rule out the possibility that significant price variation still exists. In theory, if the quota markets are competitive with low transaction costs, buyers have incentives to bid away any differences in prices. In practice, however, the law of one price is routinely violated, with commonplace commodities, such as concrete, calculators, and fuel oil having price dispersion on the order of 5% to 30% or more (Pratt et al. 1979). Pesando (1993) reported that the art print market has price variation ranging from 18% to 59%. Unlike more conventional assets and commodities, which will have existed for long periods of time, we would not necessarily expect to find fishing quota prices satisfying the law of one price initially. In addition, because quota transactions take place bilaterally or through a broker, differences in transaction costs, search costs, and bargaining power can lead to price variation. Nonetheless, the variation should go down over time as the market develops and fishermen and intermediaries learn how to operate in the newly created market.

When investigating price dispersion, one must first choose a time window within which to consider prices to be comparable. Taking a longer time step introduces more observations into each calculation; however, it also increases the chances of grouping observations that are not truly comparable. We focus on observations within one month blocks of time and measure price dispersion as the mean absolute percentage price difference between the individual trade prices and the monthly mean. The trends in price dispersion for both the lease and sale markets are illustrated in Figure 3, which shows the annual mean price dispersion across fish stock markets.

We find that on average, deviations of about 40% around the mean existed in 1987 for both the sale and lease markets, but that this variation has decreased over time. By 2000, the average sale price dispersion had fallen to 15% while the average lease price dispersion fell to 27%. The relatively larger dispersion in the lease market is possibly due to intraseason variability in fishing conditions or other short-term fluctuations that would not affect the sale price.

It is difficult to conclude whether the dispersion we observe is noteworthy relative to other created markets because data on individual trade prices typically do not exist for these markets. However, our results regarding the magnitude of the price dispersion, which falls within the range reported in the literature for more traditional commodities and assets, suggests that the precision of the price signal sent in these markets is on par with markets that are typically thought to be well-functioning. The downward trend in price dispersion is also reassuring and suggests learning in these markets.

4. Analysis of Fundamentals Determining Market Prices

A crucial question in gauging the performance 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 underlying fundamentals that theory would tell us should determine these prices. We 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. Empirical Specification of Quota Prices

In a competitive quota market, each fishing enterprise has an incentive to lease or trade quotas until it attains just enough quotas to cover a catch level that maximizes its expected 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, that is, the price of fish minus the marginal cost of fishing.[26] 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 expected to rise or fall because of changing economic or biological conditions, the quota sale price would be correspondingly higher or lower.

In a deterministic setting, quota prices would therefore depend on fish prices, factor prices, and factors underlying the technical relationship between fishing effort and the amount of fish caught, such as gear types, species biological characteristics, and climatic conditions. The specific role played by these factors could be modeled by specifying functional forms for the fishing production function and the biological relationship between catch and the population of fish. In practice, however, the inherent uncertainty surrounding fishing activities, biological populations, 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, 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. 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

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[26] 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, $\lambda = p - c_k'(q_k)$. In a competitive equilibrium, λ would equal the quota lease price. For a more detailed derivation of the market equilibrium, see Clark (1990).

reasonable fit of the data, to allow relatively transparent interpretation of the parameter estimates, and to be parsimonious.[27] 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 those where the variable is already a percentage or a rate.[28] After laying out the specification below, we further explain its rationale.

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

$$\begin{aligned}\ln\lambda_{ijmy} &= \beta_1 \ln p_{imy} + \beta_2\left(\ln p_{imy}\right)^2 + \beta_3 \ln c_{my} + \beta_4 \frac{H_{ijy-1}}{Q_{ijy-1}} + \beta_5\left(\frac{H_{ijy-1}}{Q_{ijy-1}}\right)^2 \\ &+\beta_6\left(\frac{\sum_{n=1}^{m-1} h_{ijny}}{Q_{ijy}} - \frac{\sum_{n=1}^{m-1} h_{ijny-1}}{Q_{ijy-1}}\right) + \beta_7\left(\frac{\sum_{n=1}^{m-1} h_{ijny}}{Q_{ijy}} - \frac{\sum_{n=1}^{m-1} h_{ijny-1}}{Q_{ijy-1}}\right)^2 \\ &+\beta_8 \ln p_{imy}\left(\frac{H_{ijy-1}}{Q_{ijy-1}}\right) + \beta_9 \ln s_{my} + \beta_{10} g_{my} + \beta_{11} R_{ij} t_y + \beta_{12} \tilde{R}_{ij} t_y + \alpha_0 + \alpha_{1ij} + \alpha_{2m}\end{aligned} \quad (1)$$

where λ is the quarterly average lease price, p is the contemporaneous export price, c is an index of fishing costs, H is the actual annual catch, Q is the annual total allowable catch (TAC), h is the actual quarterly catch, s is the absolute value of the Southern Oscillation Index, g is the New Zealand real GDP growth rate, t is an annual time index, R indicates if the fish stock faced significant reductions upon implementation of the ITQ program ($\tilde{R}$ indicates the opposite), α_0 is a constant term, α_1 are individual fish stock market fixed effects, and α_2 are fixed effects for successive quarters 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 quarter m of year y. We also estimate a model without individual fixed effects, where we instead

[27] While we believe it is appropriate to take an aggregate pooled approach in this initial investigation of quota price determinants, there is clear value in future work that explores differences in relationships at a more dissagregated species or fishing stock level.

[28] Box-cox estimation supported the use of a logarithmic specification. We did not include quadratic terms for several variables where they were estimated to be small and statistically insignificant and where there was no clear theoretical rationale for their inclusion.

include fixed effects for each geographic region as well as a measure of each species mortality rate.

We would expect the export price[29] of fish to be positively associated with quota prices, a relationship that is clearly illustrated in Figure 4, 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 landing. 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.[30] In practice, given the short time period for leases (one year or less), we consider this quite reasonable.

For fishing costs we include an input price index for New Zealand fishing over time, including labor, fuel, and material costs. These costs fell by about 20 percent over the late 1980s and early 1990s, but rose again by about half that in the late 1990s due largely to fuel price increases. The individual fixed effects we include will control for much of the cross-sectional factors that affect costs, including differences in fishing techniques for different species (e.g., gear) and regional costs differences (e.g., transportation costs).[31] In addition, we include variables that capture differences in relative quota demand within and between fish stocks over

[29] Although 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.

[30] Orazem and Miranowski (1986), for example, provide an empirical strategy for testing competing hypotheses of expectations regimes when direct measures of expectations are unavailable. Applied to farm acreage allocation decisions as a function of expected commodity prices, it yielded little evidence for favoring any of the three regimes they tested. Another issue raised by the use of the contemporaneous fish export price is potential for endogeneity. We believe it is reasonable to treat the fish export prices as given world prices because New Zealand exports about 90% of its commercial catch and is less than 1% of world fishing output. Even in the small number of cases where individual New Zealand species may comprise a more sizeable fraction of the world catch of those species, these species have many near-perfect substitutes in the form of other “white fish.”

[31] In an ideal scenario, we would have direct measures of firm-specific marginal costs of fishing over time, but the data unfortunately do not exist.

time. Because the supply of quotas is fixed, this variation will be driven largely by differences in costs. 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 because of the geographic distance from port to the fishing grounds—the demand for red snapper quotas in those regions will be lower, all else equal. In turn, we would expect that the lease price for these relatively undesirable quotas would be correspondingly lower.

The first measure of quota demand is the prior year's percentage caught of the TAC (H_{ijy-1}/Q_{ijy-1}). Although in a deterministic world one might expect the quota price to be zero for a fish stock with a nonbinding TAC constraint, this will not be the case where uncertainty gives rise to option value.[32] Uncertainty in the future profitability of fishing (e.g., because of export price and ecological uncertainty) makes it impossible for firms to know precisely how many quotas they will need in aggregate over the course of the year. Over half of the quotas are leased and sold in the first quarter of the fishing year—quotas that may turn out to be unprofitable to catch against. In addition, uncertainty in fishing conditions and 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 et al. 1989).

The second measure of quota demand updates the first by measuring the year-to-date percentage caught of the TAC *relative* to the prior year ($\sum_{n=1}^{m-1} h_{ijny}/Q_{ijy} - \sum_{n=1}^{m-1} h_{ijny-1}/Q_{ijy-1}$). In other words, the second factor measures the additional information available at some point within the fishing year that is incremental to what was available at the start of the fishing year.

[32] In this respect quota have option-like characteristics. The quota do not entitle the owner to a specific amount of fish, but rather to the option to catch and keep a specific amount of fish if it should prove profitable. Anderson (1987) develops the theoretical underpinnings of "quotas as options" within an international trade context, showing among other things how even non-binding quota can have positive prices.

Since both higher demand (H) and lower supply (Q) are associated with greater scarcity and higher prices, we would expect both of these variables to have a positive influence on quota prices.

We also include an interaction effect between H_{ijy-1}/Q_{ijy-1} and $\ln p_{imy}$ to allow the relationship between the quota price and the export price to vary based on the degree to which the TAC is binding. When the percentage caught of the TAC is higher, we would expect the relationship between quota prices and export prices to be stronger, suggesting a positive sign for the parameter estimate on this variable.

Additional variables are included, depending on the specification, to assess the effect of ecological uncertainty on quota prices; one is biological and the other climatic. The biological variable is the mortality rate for each species, which gives the percentage of the fish population that dies annually of natural causes. It is included only in the specification without individual fixed effects because it is not identified in the other specification. 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.[33] 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 curvature in the profit function[34] and risk aversion. The climatic variable we include is the Southern Oscillation Index, a time-series measure of variability in water temperature and pressure.[35] Water temperature significantly

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[33] 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.

[34] If there is a "stock effect" in the cost function for fishing, stock uncertainty will lead not only to variation in the profit function—which lowers the expected utility of profits in the presence of risk aversion—but also to a lower expected value of profits.

[35] It has been found that the cyclic warming and cooling of the eastern and central Pacific leave a distinctive fingerprint on sea level pressure. In particular, the difference between the pressure measured at Darwin and that measured at Tahiti can be used to generate an index number called the Southern Oscillation Index, which generally

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 fixed effects for each individual fish stock, as well as seasonal effects (by quarter). We also estimate a model without individual fixed effects, instead including regional effects which should to a certain extent control for fishing cost differences, especially those related to transportation. This alternative specification may be of particular interest if one is interested in prediction beyond the sample population, as well as better understanding the source of cross-sectional differences in quota prices. In addition, we include New Zealand's real GDP growth rate to control for changes in the general state of the New Zealand economy, which could affect corporate profitability, including that of the fishing industry.

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 time effects in our model to be generally positive and increasing. That is, once we have controlled for changes in fish prices, fishing input 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 catch per unit effort and increased profitability. [36] This should be particularly evident for fisheries that were the most depleted and faced significant reductions in allowable catch at the outset of the ITQ program. Most of the fishing stocks included in the

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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).

[36] Caution is always in order when interpreting time effects, however, and there are other unmeasured factors that could plausibly influence quota prices over time. For example, 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.

program did not in fact face significant initial reductions in catch, but rather had TAC levels set based on historical levels. We therefore estimate separate time effects in our model for fishing stocks that faced significant initial reductions, versus those that did not. We would expect the time effect to be significantly larger for the former, as these stocks should experience greater increases in profitability and thus quota prices.

We also estimate an equation for quota sale prices. Earlier we pointed out that rational asset pricing theory suggests 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, because of changing export prices or costs, the relationship between lease and sale prices would be more complex, since it would depend on expectations of changing future conditions. If, for example, rents (and lease prices) were expected to increase at a constant rate, then the lease price divided by the sale price would equal the discount rate *minus* the expected lease growth rate.

A definitive analysis of quota sale price determinants and the relationship between lease and sale prices may 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 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 provide an adequate representation of future expectations. Under these conditions, quota sale prices should be roughly equal to lease prices divided by the interest rate (minus perhaps a constant growth rate for lease prices)—which would be swept into the constant term 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 (1) using a comprehensive panel dataset 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 in the dataset and their sources is provided in the Data Appendix. Table 2 gives descriptive statistics for the included variables, which exhibit a large degree of variation. The number of transactions underlying each quarterly average observation is 17 leases and 5 sales on average, ranging from 1 to 228 leases and 1 to 80 sales. Note that due to the presence of quadratic terms in the estimated equation, we also normalize certain variables to ease interpretation of the parameter estimates.[37]

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 quarterly average.[38] Weighting in this manner will correct for heteroskedasticity because 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; this allows 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.[39] More restrictive error structures were rejected by likelihood ratio tests.

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[37] 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 1, so that it equals zero when the TAC 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 in its magnitude as an indication of climatic variability.

[38] The results are robust to the use of other averaging periods (e.g., months) or the use of individual transactions. We chose to use an average rather than individual observations because it allowed us to more readily treat the covariance structure of the model. We chose to use quarterly averages because it represented a desirable balance between parsimony and avoiding the omission of useful variation.

[39] The overall sample autocorrelation for lease prices was 0.22, and 0.37 for sale prices, both of which were significant according to Durbin Watson and Breusch Godfrey tests and also differed substantially across panels.

Estimation uses a two-step procedure, in which 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, and Table 4 for the model without individual fixed effects. Overall, the results are consistent with economic expectations about the parameters. The estimated coefficients all have the expected signs and reasonable magnitudes and are consistent across both the lease and the sale price equations. The results confirm that quota prices increase with increasing prices for fish and increased quota demand, and decrease with increasing costs and ecological uncertainty. The time effects indicate a substantial increase in quota prices since the ITQ system was established, consistent with an increase in the profitability of the fisheries. These quota price increases have been significantly greater for stocks that faced significant reductions in allowable catch levels. The qualitative results are robust to changes in the functional form and the error structure employed.[40]

These results are compelling for a number of reasons. First, with an equivalent OLS estimation of our model, we explain 95% of the variation in lease prices and 93% in sale prices. While one always has to be careful not to place too much emphasis on R^2 values, the model's

[40] We also explored whether the option of paying "deemed values" in lieu of holding quota to cover catches resulted in any bias to our results (see footnote 13). In principle the deemed value can censor the quota lease price by acting as a price ceiling if conditions would otherwise lead the lease price to exceed the deemed value. This could lead to the usual bias in means and variances that gave rise to the Tobit and other models for handling censored data. In practice, we found that only around 1 percent of our lease price observations approached the level of the deemed value. Furthermore, the results were not sensitive to treating these observations as censored.

explanatory power appears quite high. Second, the parameter estimates are largely consistent across the lease and sale price equations. Finally, contrary to the prevailing wisdom that these reported prices are of dubious quality and value, we find that prices do reflect underlying fundamentals, suggesting that the price signals from these markets contain valuable information for managers and fishermen.

After controlling for other important factors, we find that the elasticity of the quota price with respect to the fish export price is positive and statistically significant in both lease and sale prices equations. As expected, species with higher export prices also tend to have proportionately higher quota prices. The magnitude of the export price elasticity is also consistent across the two quota price equations ($\beta_1 = 0.2$ at the mean export price). It is much less than the elasticity of about 1 evident from Figure 4 and Table 4, indicating that quota prices are much more sensitive to long-term cross-sectional differences in export prices between different species than they are to fluctuations in export prices within species over time.

Changes in fishing costs had the expected effect on quota prices, with higher costs being associated with lower quota values. The effect was substantially lower for sale prices, and statistically insignificant in the individual fixed effects model for sale prices. This is possibly attributable to the perception that input price fluctuations may be short-lived, since they are due in part to changing fuel prices.

The coefficient β_4 gives the elasticity of the quota price with respect to the percent caught of the TAC in the previous year, a measure of relative quota demand.[41] The elasticity is similar in magnitude across the two equations and is positive and economically and statistically

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[41] We measure these variables as capturing quota demand and therefore, we expect a positive sign. The interpretation that these variables capture differences in costs would require us to measure the quota demand variables inversely yielding, as expected, a negative correlation with lease prices.

significant; $\beta_4 = 0.4$ at the point where the TAC is binding (i.e., $H/Q = 100\%$). For the rare cases where the catch exceeded the TAC, the negative coefficient on the squared percentage caught (β_5) indicates that further increases in the percentage caught above 100% have a significantly lesser effect on quota prices, but further decreases in the percentage caught below 100% have an increasingly negative effect on quota prices. These results make 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. Very low percentage catches are indicative of fish stocks with little expected quota demand (e.g., due to high costs), and thus quota prices should move quickly toward zero. As expected, the coefficient on the interaction of this variable with the logged export price (β_8) is positive. Our second measure of quota demand—which updates the first by measuring the year-to-date percentage caught of the TAC *relative* to the prior year—also had the expected positive effect on quota prices and is statistically significant.

One measure of ecological uncertainty, the Southern Oscillation Index (SOI), had a negligible relationship with quota prices. A complexity with measuring the influence of the SOI is that each species is expected to respond differently and over different time frames to this index. This requires a more disaggregated approach and careful treatment of the relationship between individual species abundance and oceanographic variables—an analysis that is beyond the current exploration. We found that species with higher mortality rates had significantly lower quota prices, other things equal, although we could only estimate this effect in the model without individual effects. The elasticity was –1.2 for lease prices and –0.7 for sale prices. These results are consistent with the idea that species with higher mortality rates have more variability in their populations, which leads to greater profit variability and in turn lower quota prices.

Higher quota prices were also significantly associated with periods of higher GDP growth. Controlling for the above factors, there is also evidence of significantly increased profitability of the included fisheries since the establishment of the ITQ system. Recall that since we have controlled for changes in export prices and fishing input prices over time, as well as other important factors, the residual effect of time should capture stock rebuilding and other efficiency improvements leading to increased profitability. That is, positive time effects indicate rising quota prices, controlling for other factors. For stocks that faced significant initial reductions in allowable catch, we estimate that lease prices rose at an average rate of 6% and sale prices by 12% annually since the program started. For other stocks, we estimate that lease prices rose a more modest 1% annually and sale prices by 6% annually.

Regardless of the specification employed, we found that quota sale prices have risen to a greater degree than quota leases prices. The greater increase in quota sale than lease prices can be at least partly attributed to decreases in the market interest rate, which fell from about 11% to 3% real over the relevant period.   As mentioned earlier, increases in quota sale prices could also be driven in part by the perception of increased security of quota assets, although such an effect should not be important for quota lease prices.

The relationship between quota lease prices, sale prices, and the rate of interest is illustrated in Figure 5. 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 be close to the market interest rate. Figure 5 supports the presence of this arbitrage relationship, with the computed implicit hurdle rate tracking both the level and the trend in the market interest rate over the sample period. At the same time the implicit hurdle rate fell by about half from 14% to 7%, the interest rate as measured by New Zealand Treasury bills fell from 11% to 3% real. Because quotas are riskier assets than Treasury bills, one would expect that the implicit hurdle rate for quotas should be higher than the real rate for Treasury bills, which it typically is. If quota market participants were factoring in expected growth in lease prices, the actual hurdle rate would be higher than we have estimated ignoring such increases.

Nonetheless, note that the results regarding quota sale prices and quota lease-sale relationships are subject to the earlier caveat that we have not thoroughly explored alternative assumptions about future expectations of rents. Rather, we have focused on a relatively simple assumption about expectations—that they are given by contemporaneous conditions. Having said that, the consistent results across both the lease and sale markets suggests that our current approach is not unreasonable.

5. Conclusion

Fisheries throughout the world are biologically and economically threatened not because fishermen are irrational, as many would contend, 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 to ending the race to fish and rationalizing fisheries. At the same time, ITQs provide a vehicle by which fishermen can realize the potential gains of resource stewardship.

Whether market-based instruments are being applied to fish, pollution, or other resource problems, the ability of firms to buy and sell quotas in a well-functioning market is necessary for achieving efficiency gains. In practice, one might worry that these markets may be thin or plagued with information problems. With very few empirical studies of created markets, it is often hard to counter these worries with anything more than anecdotal evidence. To further the empirical record, we evaluate the operation of New Zealand's market for fishing quotas, the largest system of its kind in the world.

We typically observe both a sufficient number of market participants and high enough levels of market activity to support a competitive quota market. 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 and ecologically unimportant fisheries. Market thinness could be addressed through policy by aggregating illiquid quota markets into other quota markets. The advantages of such aggregation would of course have to be considered along with any positive or negative biological implications.

We find that there has been substantial price dispersion within individual quota markets, but that the magnitude of this dispersion has gone down over time and is comparable to that found in other well-functioning markets. The trends are consistent with a period of market development where participants learn how to operate in the newly created market, and traders and brokers begin to set-up shop.

Overall, we find that prices in these markets are related in an expected manner with underlying economic fundamentals, including measures of fishing value, relative quota demand, ecological variability, and market rates of return. Our analysis of the market arbitrage relationship between quota lease and sale prices, for example, shows that the implicit hurdle rate for quotas follows the general historical level and trend 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. This is particularly true for fishing stocks that have faced significant catch reductions from historic levels.

The results are also relevant for ongoing policy developments in the United States, where the debate focuses in part on 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.

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 nontarget species and market concentration levels for quota prices and market activity also bear further scrutiny.

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Data Appendix

Using information obtained from New Zealand government agencies and other sources, we assembled a comprehensive panel database of information on the New Zealand individual transferable quota (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 ITQ system, quota ownership, the total allowable commercial catch (TAC) and actual catch for each fish stock, biological information on fish species, climatic variation, and interest rates. All monetary figures were adjusted for inflation to year 2000 New Zealand dollars using the producer price index (PPI) from Statistics New Zealand. A description of the variables included in the dataset and their sources follows.

A.1 Species and Regions

The New Zealand ITQ system covered 26 species when it began in 1986 and expanded 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.[42] 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 30 species (141 fish stocks) because export price data are unavailable for HPB, OYS, and STA. For the econometric analysis, we also include dummy variables for 8 regions, based on the geographic coverage of each fish stock (Paulin 1996; Clement & Associates 1997).

[42] 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 leases and sales between quota holders from when the program began in late 1986 through 2001—more than 170,000 transactions altogether. To sell, purchase, lease, or sublease quotas, 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 quotas sold or leased.

Transaction Quantities. The transactions dataset includes the price and quantity of quotas transacted, the name and an identifier called the quota registration number for each party to the transaction, and the date of the transaction. We use the transaction quantity data to measure the number of quotas that firms hold or own, how many quotas are being leased or sold, how many firms are active in the ITQ system, 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 quotas under several different QRNs (e.g., Abalone Quota Ltd. and Abalone Quota Holdings Ltd.), but the quotas 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, for a total of 4,729 distinct units. This is an important step—one that few if any other analyses of these data have taken—because it influences all 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 quotas that each firm owned in each fish stock as well as the quantity it held (i.e., taking account of leases in and out).

Transaction Prices. The transactions dataset also contains the price per ton of quotas sold or leased, the relevant fish stock, and the transaction date; prices were available for 151,835 leases and 25,210 sales. Some of the price data were unreliable because other assets (e.g., boats) were reportedly included in the sale price, or the transaction was not arms-length or was misreported. In all, we omitted 31% of lease and 11% of sale observations which did not represent true market transactions.[43] After adjusting for inflation using the PPI, we calculated the quarterly average lease and sale price for each fish stock.[44] We also counted the number of transactions used in the creation of each quarterly average for use in our econometric estimation, which employs this number of underlying transactions as a statistical weight.

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 PPI, we created a quarterly 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 official Ministry of Fisheries conversion factors (Clement & Associates 1997, 1998), and then summing these for each species.

Fishing Costs. Using data from Statistics New Zealand, we constructed an index of New Zealand fishing costs over time using the rates of change in real (PPI-deflated) labor and material

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[43] We omitted all prices for transactions that were not between economically distinct parties, for leases from the government early in the program, and for leases from the Treaty of Waitangi Fisheries Commission (which are deliberately discounted). We also omitted lease prices less than $1 per ton, sale prices less than $20 per ton, as well as a small number of prices that were unreasonably high (which likely contain other assets). We also omitted prices for bundled transactions involving multiple types of quota, where the reported price was simply a constant average value for all quota. In any event, whether or not we omitted observations did not alter the qualitative results, and it changed the quantitative magnitudes only to a small degree.

[44] 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.

(including fuel) costs for fishing, weighted by their shares in total variable costs (25% labor and 75% materials (including fuel), according to New Zealand fishing industry contacts).

TAC and Actual Catch. Both the total allowable commercial catch and the actual catch for each fish stock over time are from the New Zealand Ministry of Fisheries.

Real Interest Rates and GDP. 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, adjusted using the New Zealand CPI to create an annual real interest rate. The real GDP growth rate for New Zealand is from Statistics New Zealand.

Ecological Variables. Species mortality data are from a compilation by Froese and Pauly (2000) and Annala et. al.(2000). As a measure of climate variation, we obtained monthly values for the Southern Oscillation Index from the Australian Bureau of Meteorology, from which we computed quarterly averages (http://www.bom.gov.au/climate/current/soihtm1.shtml). We classified fish stocks as to whether they faced significant initial catch reductions under ITQs by using historical information on catch rates, TAC levels, and references in the literature (Annala 2000, Major 1999). The following 18 fish stocks were so classified: CRA1-7, CRA7-8, ELE3, ELE5, ORH3A, ORH2B, SCH1, SCH2, SCH7, SCH8, SNA1, SNA2, SNA8.

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

Species	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 and 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 ($/ton)	1,758	4,350	1	43,663
Sale price ($/ton)	21,498	48,903	22	358,586
Export price ($/ton)	7,655	11,321	569	60,263
Catch (tons/year)	4,023	20,972	0	268,633
Total allowable commercial catch (tons/year)	5,154	23,584	1	251,883
Percentage catch	0.76	0.35	0.00	5.09
Percentage cumulative catch over prior year	0.01	0.14	-1.07	3.11
Mortality rate	0.30	0.22	0.05	1.00
Southern Oscillation Index	-2.7	10.2	-23.7	15.47
Fishing cost index (index = 1 in Jan. 1986)	0.85	0.04	0.79	1.00
GDP annual growth rate	0.02	0.02	-0.02	0.07
Number of leases per quarter	14	171	1	192
Number of sales per quarter	4	5	1	75

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

Table 3. Determinants of Fishing Quota Lease and Sale Prices

Variables	Lease prices	Sale prices
Price of fish		
Log of fish export price	0.237 (0.020)	0.201 (0.017)
Log of fish export price, squared	0.064 (0.009)	0.051 (0.008)
Cost of fishing (Log of fishing cost index)	-0.786 (0.125)	-0.010 (0.124)
Quota demand		
Prior year % caught of total allowable catch (TAC)	0.362 (0.035)	0.388 (0.045)
Prior year % caught of TAC, squared	-0.232 (0.031)	-0.178 (0.037)
Year-to-date % caught of TAC above prior year	0.071 (0.037)	0.203 (0.050)
Year-to-date % caught of TAC above prior year, squared	0.080 (0.079)	-0.056 (0.033)
(Log of fish export price)*(prior year % caught of TAC)	0.191 (0.029)	0.204 (0.036)
Ecological uncertainty		
Log of absolute value of Southern Oscillation Index	-0.011 (0.004)	0.006 (0.004)
Quota price trends		
Recovering fisheries (annual trend interacted with recover)	0.060 (0.003)	0.122 (0.005)
Other fisheries (annual trend interacted with recover=0)	0.010 (0.002)	0.060 (0.003)
GDP growth rate	1.345 (0.182)	2.455 (0.244)
Seasonal effects	*jointly significant*	*jointly significant*
Fish stock fixed effects	*jointly significant*	*jointly significant*
Constant term	5.544 (0.129)	7.693 (0.131)
Number of quarterly observations	5,913	4,161

Note: The dependent variables are the average quarterly lease and sale prices. The sample data are a panel of observations for species- and region-differentiated quota markets over 15 years. The R^2 for the comparable OLS estimates for the lease price equation is 0.95 and for the sale price equation is 0.93. 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 quarterly average price. There are 141 panels for the lease price equation and 139 for the sale price equation. Fixed effects are included for seasons (i.e., 4 quarters) and individual fish stock markets (i.e., 141 different markets). Some variables are normalized to ease interpretation. See Data Appendix for further detail.

Table 4. Determinants of Fishing Quota Lease and Sale Prices

Variables	Lease prices	Sale prices
Price of fish		
Log of fish export price	1.012 (0.012)	0.851 (0.014)
Log of fish export price, squared	0.028 (0.006)	0.009 (0.007)
Cost of fishing (Log of fishing cost index)	-1.695 (0.196)	-0.517 (0.168)
Quota demand		
Prior year % caught of total allowable catch (TAC)	0.807 (0.042)	0.804 (0.048)
Prior year % caught of TAC, squared	-0.465 (0.032)	-0.476 (0.041)
Year-to-date % caught of TAC above prior year	0.312 (0.049)	0.363 (0.062)
Year-to-date % caught of TAC above prior year, squared	-0.070 (0.092)	-0.078 (0.037)
(Log of fish export price)*(prior year % caught of TAC)	0.351 (0.034)	0.497 (0.038)
Ecological uncertainty		
Fish mortality rate	-1.210 (0.035)	-0.746 (0.064)
Log of absolute value of Southern Oscillation Index	-0.003 (0.005)	-0.008 (0.005)
Quota price trends		
Recovering fisheries (annual trend interacted with recover)	0.037 (0.007)	0.100 (0.006)
Other fisheries (annual trend interacted with recover=0)	-0.004 (0.003)	0.044 (0.004)
Recover (dummy indicating fishery had reductions)	-0.113 (0.076)	0.051 (0.057)
GDP growth rate	1.049 (0.283)	2.934 (0.323)
Seasonal effects	*jointly significant*	*jointly significant*
Regional effects	*jointly significant*	*jointly significant*
Constant term	7.304 (0.050)	9.017 (0.047)
Number of quarterly observations	5,913	4,161

Note: See note above. The R^2 for the comparable OLS estimates for the lease price equation is 0.88 and for the sale price equation is 0.85. Fixed effects are included for seasons (i.e., 4 quarters) and geographic region (i.e., 8 regions).

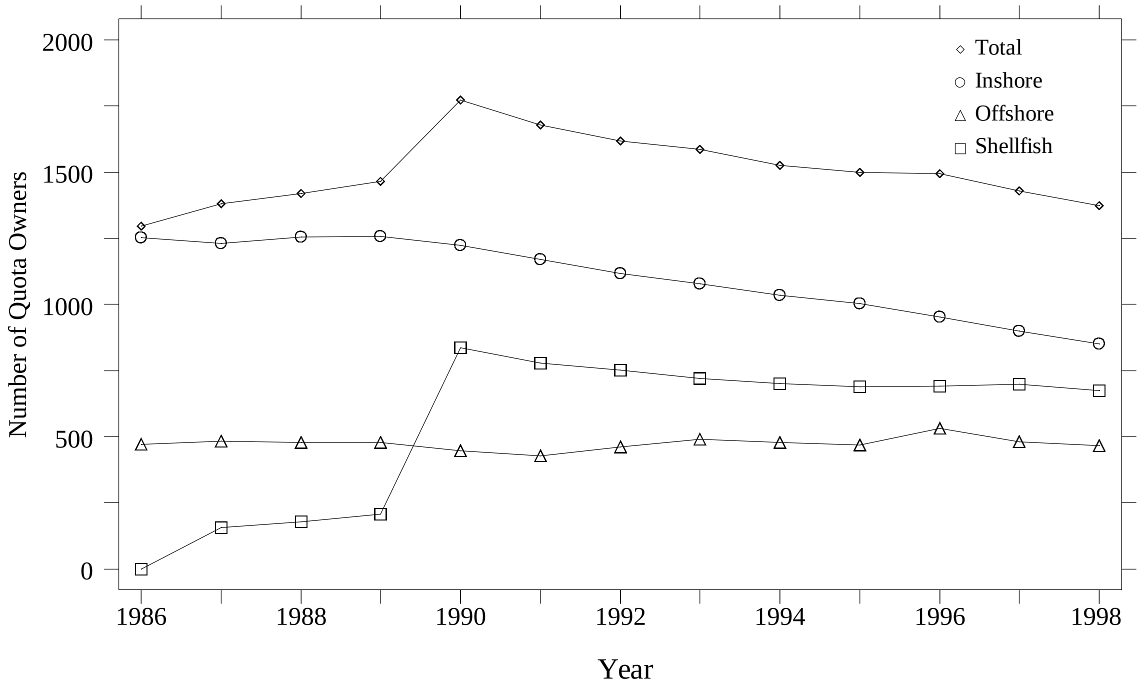

Figure 1: Trends in the Number of Quota Owners

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

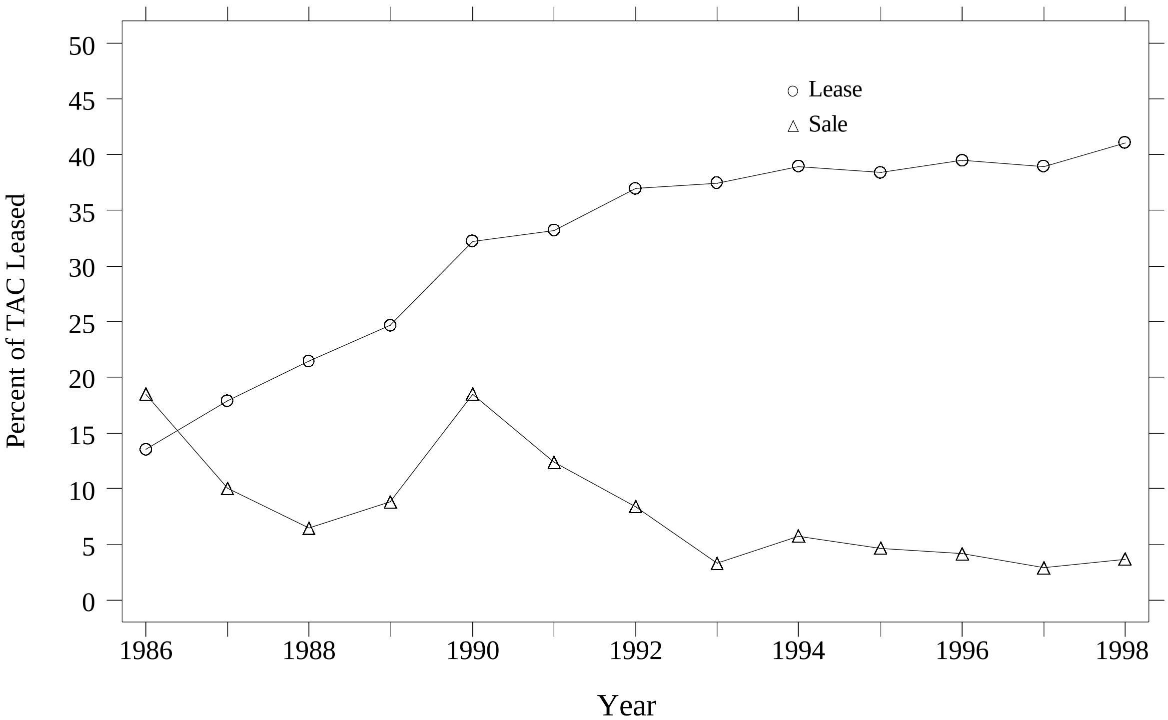

Figure 2. Trends in the Portion of Quota that are Leased and Sold

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

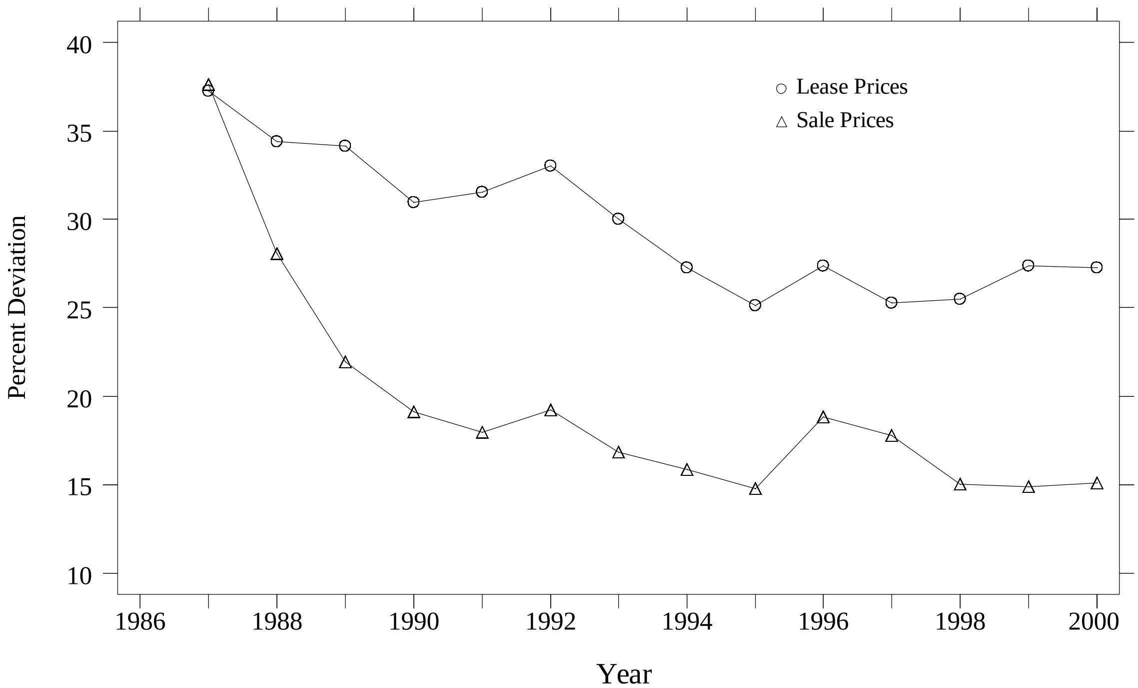

Figure 3: Trends in Lease and Sale Price Dispersion

Note: Price dispersion is measured as the annual average across the fish stocks of the percent absolute deviation from the monthly mean price.

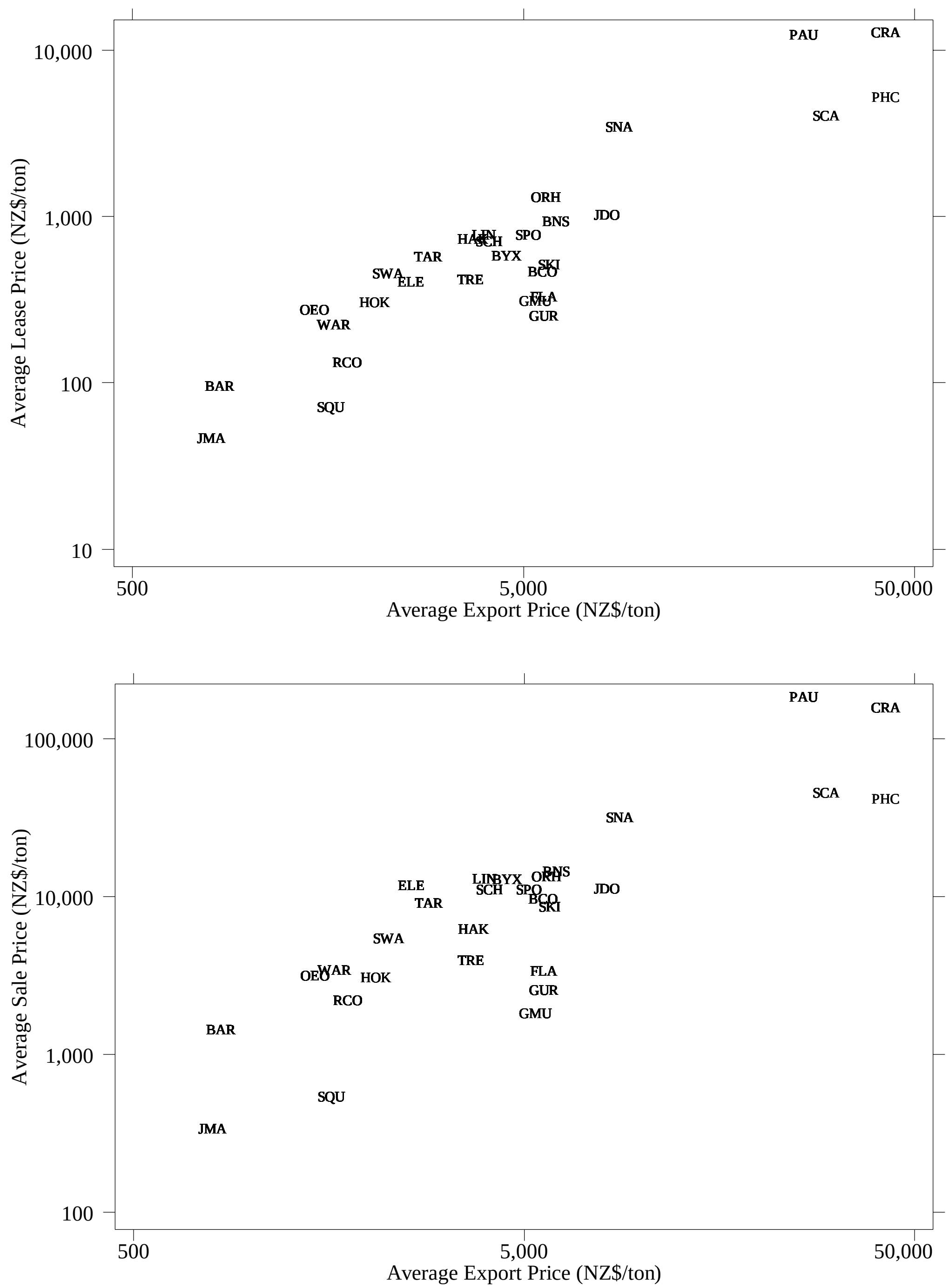

Figure 4. Quota Lease Prices, Quota Sale Prices, and Fish Export Prices

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

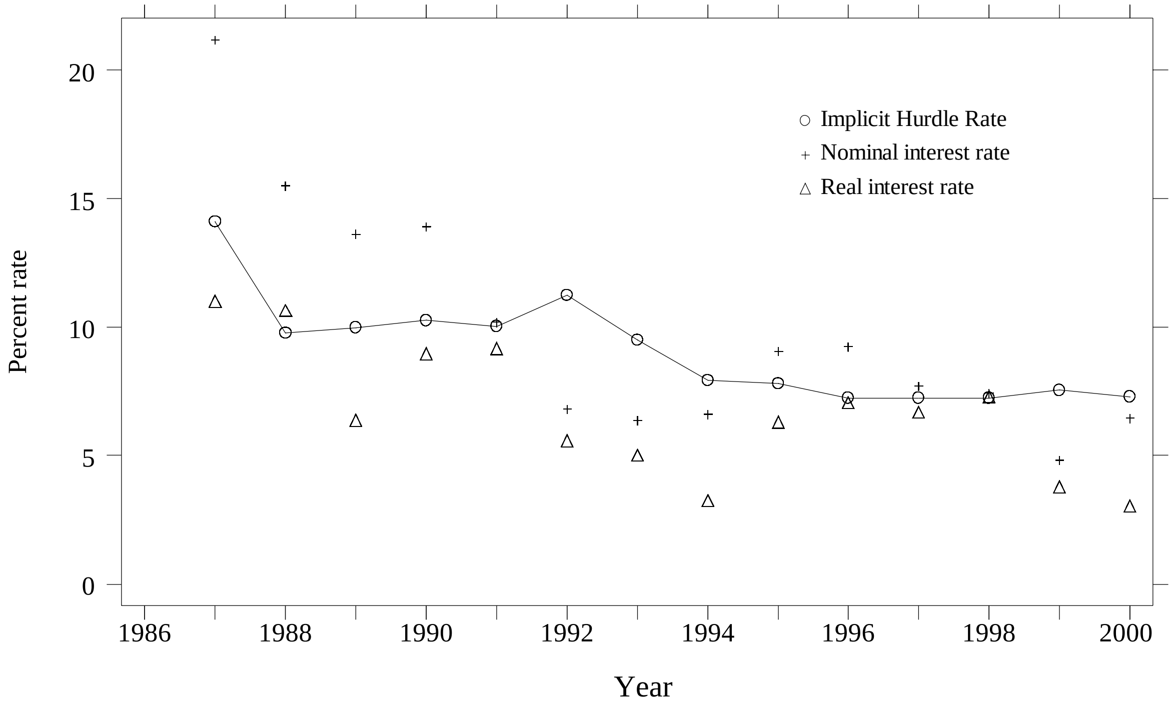

Figure 5. Implicit Hurdle Rate for Quota and Market Interest Rates

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