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Fishing quota markets

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Abstract

In 1986, New Zealand responded to the open-access problem by establishing the world's largest individual transferable quota (ITQ) system. Using a 15-year panel dataset from New Zealand that covers 33 species and more than 150 markets for fishing quotas, we assess trends in market activity, price dispersion, and the fundamentals determining quota prices. We find that market activity is sufficiently high in the economically important markets and that price dispersion has decreased. 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 a greater increase in quota prices for fish stocks that faced significant reductions, consistent with increased profitability due to rationalization. Overall, this suggests that these markets are operating reasonably well, implying that ITQs can be effective instruments for efficient fisheries management.

Keywords: Tradable permits; Individual transferable quota; Fisheries; Policy

JEL classification: Q22; Q28; D40; L10

1. Introduction

Since the late 1970s, when countries began to enclose the ocean commons by establishing exclusive economic zones (EEZ), more than 15 countries followed New Zealand's and Iceland's

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lead in establishing individual transferable quotas (ITQs) to manage fisheries. ITQs are used to manage over 80 species, including four in the United States. Although assessments of these programs are generally positive, their future is unclear.[1] For example, a 6-year moratorium on implementing new ITQ systems in the US expired in September 2002, but policymakers continue to debate various design elements. Legislation introduced in 2001 by Senators Snowe (Maine) and McCain (Arizona), for example, prohibited the selling and leasing of quota shares (S.637 Section 2.6.a). Other contentious issues include whether shares should have limited duration, whether shareholders must remain active in the fishery, and whether the programs should have sunset provisions. Part of the debate also concerns the distributional implications of potential concentration and industrialization of the fishery after an ITQ system is in place.

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. 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. For example, Arnason [5] showed that under the assumption of perfectly competitive markets, monitoring the effect on quota prices of changing the total allowable cach (TAC) could be used to converge to the optimal TAC.

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.[2] This is especially true since economists frequently recommend tradable permits or quotas, and building the institutions necessary to implement them can require significant political and economic costs. Assessments of the US sulfur dioxide tradable permit system [11,23,42] are significant contributions in this regard.

In theory, ITQ programs are analogous to other cap and trade programs, such as the US 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

[1]The existing literature on ITQ programs, although extensive, is dominated by description and anecdotal evidence of their effects [28]. One notable exception is by Grafton et al. [20], which use 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 predict that the gains in producer surplus could be five times higher if restrictions on transferability were not in place. Other studies assess ITQs using relationships estimated on either pre- or post-ITQ catch-effort data to predict changes in fleet restructuring, costs, and revenues [39,44]. Such predictions assume that the market for fishing rights is operating efficiently, but whether that holds in practice remains an open question, which we address herein.

[2]There is a significant literature investigating aspects of market efficiency in a variety of markets, including those for financial assets [15,19], housing [12], art [32], orange juice concentrate [34], and natural resources (e.g., lease and sale of land, oil fields, and forest tracts). For example, Burt [10] found that rents (i.e., net revenues) are the fundamental driver of farmland prices.

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 [16,40].

Although recent experience with the sulfur dioxide trading program has changed many perceptions, skeptics still question whether tradable permit systems and other economic market-based policies can work in practice. Potential concerns include the level of activity and transaction costs in such markets as well as information problems related to uncertainty and decision-making complexity. 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 the fishery context, several studies present descriptive statistics on annual quota prices and number of trades [6–7,26].[3] For example, using 2 years of data on quota sale and lease prices from the New Zealand ITQ system, Lindner et al. [26] 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. Batstone and Sharp [8] investigate the relationship between fishing quota prices and changes in the TAC for the New Zealand red snapper fishery (region 1) and find support for the relationship proposed by Arnason [5] mentioned above.

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 the 33 species that were in the program as of 1998 and includes price and quantity data on transactions in more than 150 fishing quota markets (see Table 1 for a list of species included). Markets exist in New Zealand both for selling the perpetual right to fish a certain quota stock and for leasing quotas.[4] 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 1 year for squid (*Nototodarus gouldi*) to 125-plus years for orange roughy (*Hoplostethus atlanticus*). Some species, such as red snapper (*Pagrus auratus*), abalone (*Haliotis iris*), and rock lobster (*Jasus edwardsii*), occupy inshore and shallow habitat and are targeted with trawl gear and long lines, SCUBA gear, and lobster pots, respectively. Others, such as orange roughy, are found offshore in depths over 1000 m and require large vessels and very specialized trawling gear. The export value of these species currently ranges from about NZ$700/ton for jack mackerel to about NZ$40000/ton for rock lobster.[5]

We assess how these markets have performed in a number of ways. First, we find that the overall level and trends in market activity and participation across the markets suggest that there is adequate support for a competitive market for the economically important fish stocks. If these

[3]The work by Karpoff [24,25] investigating the economic information embedded in limited-entry license prices of the Alaskan salmon fishery is also relevant.

[4]After 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.

[5]Throughout this paper, monetary values are year 2000 New Zealand dollars, which are typically worth about half a US dollar. Tons are metric tons.

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

markets had few participants and transactions, noisy price signals could ensue reducing the expected efficiency gains. We measure price dispersion using quota lease and sale prices for individual transactions, finding that it has decreased over time. This is consistent with an adjustment period of learning and market development. Another aspect of well-functioning markets is that asset prices represent underlying fundamentals—a necessary condition for semi-strong market efficiency [19]. Contrary to the claim by Lindner et al. [26] that prices reported in these markets are fictitious and confounded by the inclusion of other assets (e.g., boats and gear), we find statistically and economically significant relationships between quota lease and sale prices and fishing input and output prices, relative quota demand, and ecological variability.[6] Finally, we find support for quota prices revealing relevant asset arbitrage information by investigating the relationship between the prices of perpetual quota sales and annual quota leases relative to measures of the NZ market rate of interest.[7]

Moreover, we exploit a natural experiment in our data—some fish stocks faced significant reductions in TAC relative to historic levels while others did not—to test whether fish stocks where more rationalization is occuring, experience greater increases in profitability over the course of the ITQ program. After controlling for relevant factors, we indeed find statistical evidence to support this prediction. Overall, the results suggest that market-based quota systems are potentially effective instruments for efficient fisheries management.[8]

In Section 2, we describe the design of the ITQ system in New Zealand. 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 price dispersion in 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 discuss our findings and areas for further study in Section 5.

2. New Zealand's ITQ system

Although the New Zealand fishing industry accounts for less than 2% 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.[9]

After several years of consultation with industry, the Fisheries Amendment Act of 1986 passed, creating New Zealand's ITQ system. The ITQ system initially covered 17 inshore species and nine offshore species, and expanded to over 70 species by 2004. 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 2000, the total number of fishing quota markets stood at 275, ranging from 1 for the species hoki (*Macruronus novaezelandiae*) to 11 for abalone. As of the mid-1990s, the species managed under the ITQ system accounted for more than 85% of the total commercial

[6]As noted in the supplementary material, we do in fact observe a number of questionable price observations in the data. These observations are easily identified, however, and based on our analysis with and without these observations, we conclude that these data do not appear to limit the ability of the remaining data to send meaningful market information.

[7]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.

[8]While we focus on market efficiency, there are other dimensions that ultimately must be examined to determine how well ITQ programs work. SeeYandle [45] and Sanchirico and Newell [35] for a discussion of the distributional, biological and administrative changes that have occurred in New Zealand since 1986.

[9]For further history and institutional detail, see [3,7,9,13,14,38,45].

catch taken from New Zealand's EEZ and from our calculations had an estimated market capitalization of NZ$3 billion.

The New Zealand Ministry of Fisheries sets an annual TAC for each fish stock based on an intertemporal biological assessment (including the prior year's catch level) 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 non-commercial fishing. Consequently, the TAC will likely differ from the economically efficient level that takes into account the intertemporal stock externalities inherent in common pool resource extraction. 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.[10]

Individual quotas were initially allocated to fishermen as fixed annual tonnages in perpetuity based on their average catch level over 2 of the years spanning 1982–1984. 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 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. Because the initial allocations—which were based on past catch histories—exceeded the maximum sustainable yield in some fisheries, the government bought back quota on two occasions prior to the implementation of the program. Purchasing these quotas turned out to be expensive, however, as the government paid NZ$45 million for 15,000 tons of quotas from the inshore fisheries [13].

Faced with the prospect of spending another NZ$100 million to further reduce TACs [38], 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 [3].

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 1 year or less. Given the uncertainty around quantity and composition of catch, a fisherman's quota holdings represent a mix of ex ante and ex post leases, purchases, and sales to cover actual catch. Whether ex ante or ex post transactions, 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.[11] The quota rights

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[10]In a survey of inshore fishermen based out of Auckland in 1987, Dewees [17] found that 40% thought enforcement and 66% thought maximizing the quality of the catch to be counted against one's quota by dumping less valuable fish over board were potential problems with ITQ management. These numbers dropped to 21% and 25%, respectively, by 1995.

[11]Over the time period of our study, prior to leaving the dock fishermen were required by law to hold quotas for their intended target fish stocks. In addition to the lease and sale markets, fishermen had a number of ways within a 30-day window after they landed their catch to balance their quota holdings and catches. First, a "by-catch trade-off exemption" allowed fishermen who incidentally took non-target fish to offset the catch by using quota from a predetermined list of target species. Second, quota owners could carry forward to or borrow from the next year up to

can be broken up and sold in smaller quantities and any amount may be leased and subleased any number of times. There are also legislative limits on aggregation for particular stocks and regions, and limitations on foreign quota holdings.[12]

The New Zealand ITQ system is a dynamic institution that has had many refinements since its beginnings more than 17 years ago. Nonetheless, the basic tenets of the system—setting a TAC and leaving the market to determine the most profitable allocation of fishing effort—have remained intact.

3. Trends in market activity

Regardless of whether market-based policy instruments are being applied to fish, pollution, land, or water, the efficiency gains of tradable rights markets rely on the ability of firms to buy and sell quotas in a well-functioning market. Thin markets with few participants can lead to high transaction costs, because buyers and sellers may have difficulty finding trading partners.[13] With high transaction costs, transactions are less likely to occur, which could lead to noisy price signals and little or no efficiency gains [22,29,41]. 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 [21]. In this section we assess the operation of the New Zealand ITQ market along the quantity dimension, in terms of the number of market participants and the level of market activity. In addition to looking at market participation, we investigate the degree of price dispersion in these markets, and whether such 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 1400 over the history of the program. Individual markets have had a median of 47 quota owners, ranging from 430 to just one owner in some small fisheries of low importance.[14] As illustrated in Fig. 1, the total

(*footnote continued*)
10% of their quota (although not leases). A third option was to enter into a non-monetary agreement to fish against another's quota. Or a fisherman could surrender the catch to the government or pay a ''deemed value'', set based on the nominal port price to discourage discarding of catch at sea and targeting stocks without sufficient quota [3]. These rules have changed since October 1, 2001.

[12]Initially, the aggregation limits were on holding quota. Substantial changes were written into the 1996 Fisheries Act, including changing the limits on holdings to ownership levels, and limits for particular species and region combinations.

[13]A related efficiency issue is whether concentration raises the potential for market power and strategic manipulation of market prices [2,21]. We find that while about one-quarter of NZ fishing quota markets are concentrated (i.e., Herfindahl index >0.18), these fisheries have always been concentrated with little change in concentration since the start of the ITQ program. Whether the observed concentration levels affect market performance is left for future research. Nonetheless, given that the output markets for fish in New Zealand trade at world prices, the ability of firms to exercise market power in the quota market would seem to be limited.

[14]To place these numbers in context, there are about 250 utilities with permit allocations under the US sulfur dioxide permit market [43], and about 375 registered facilities in the RECLAIM market for SO_2 and NO_x in southern California. New York City's taxi medallion system has operated on a free-market basis since just after World War II, currently with about 5000 medallion owners [36].

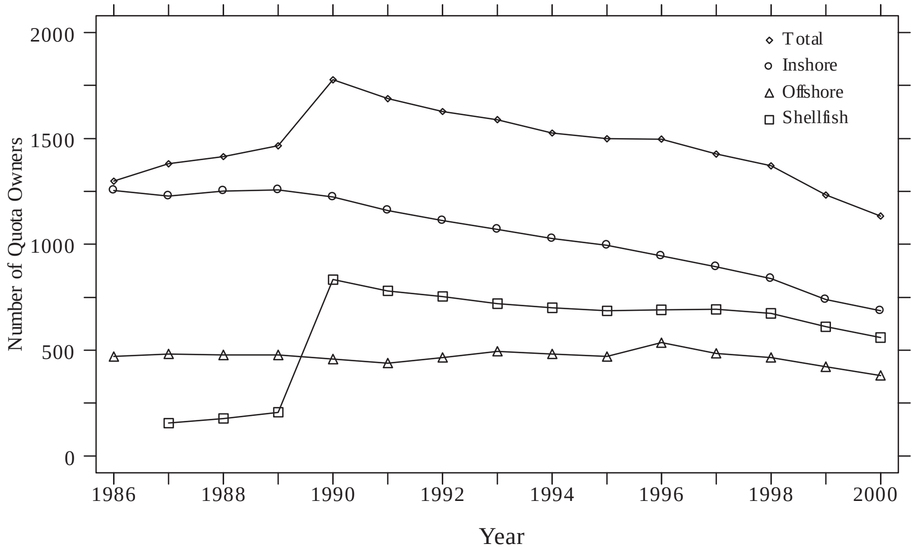

Fig. 1. Trends in the number of quota owners.

number of owners increased from a minimum of about 1300 in 1986 to 1,800 in 1990, falling since then to 1100 in 2000. 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 about 500 quota owners from 1987 to 1990 was due to the addition of several shellfish species to the ITQ program—this increase is less than the 800 shellfish quota owners that were added in this period because many of these fishermen were already active in the system. The 37% overall decline was due to the exit of about 46% of inshore owners, 33% of shellfish owners, and 19% of offshore owners from their peaks in 1989–1990. We find that although there has been net exit in New Zealand's ITQ system, there have been on average around 90 new quota owners in a variety of markets (including inshore species) entering the system per year since 1990.

Why the difference in exit behavior between the offshore versus inshore and shellfish fisheries? First, prior to the adoption of the full ITQ system, nine companies fishing for a subset of the offshore stocks were included in a quota-based system in 1983, which had the effect of limiting entry.[15] Second, and at the same time, the 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. 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.

Fig. 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

[15]Quotas were allocated to each company for a 10-year period based on investment in catch and processing capital. Trading and leasing of shares are reported to have occurred [38], but the system did not provide an adequate mechanism for the transfer of quotas.

divesting from some stocks and investing in others. For example, it is evident from Fig. 1 that in 1986 almost all the inshore quota owners also owned quotas for the offshore stocks.[16]

3.2. Market activity

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, which falls between the typical fees of 1% in the US national sulfur dioxide market and 6% in California's RECLAIM pollution market and US and New Zealand real estate markets. In most transactions brokers operate as matchmakers, whereby any spread between bid and ask prices accrues to the parties of the transaction. In this way, fishing quota brokers are similar to brokers in pollution and real estate markets.

As one would predict from the flexibility of the rules on exchange and the high number of participants, we find that the quota markets are indeed very active, implying that transaction costs are reasonably low. About 140,000 leases and 23,000 sales of quotas had occurred between economically distinct private entities under the ITQ program as of 2000—an annual average of about 9,300 leases and 1500 sales. This represents a complete sample because all transactions (sales and leases) must be recorded and submitted to the New Zealand government. The mean lease and sale quantities are approximately 24 and 16 tons, respectively.[17] We also find that about 22% of quota owners took part in a market transaction in the first full year of the program, increasing steadily to around 70% by 2000.

The annual number of leases has risen 10-fold, from about 1500 in 1986 to 15,000 in 2000. To get a sense not just of the aggregate market activity, but also of the activity at the individual fishing quota market level, Fig. 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. The figure shows that the median percentage of quota leased in these markets has risen consistently, from 9% in 1987 to 44% in 2000.

The total number of quota sales declined from a high of about 3200 sales in 1986 when initial quota allocations for most species took place, leveling off to around 1000 sales in the late 1990s.

[16]Over time the typical portfolio of quota for the median quota owner has essentially remained three fish stocks across 3 species of fish (one 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.

[17]The sulfur dioxide permit market—considered robust and competitive [23,37,42]—has seen a total of about 9600 transactions between economically distinct organizations since 1995, or about 1400 per year on average [43], and the average annual number of transfers of taxicab medallions in New York City since 1982 is about 800 [36]. 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%.

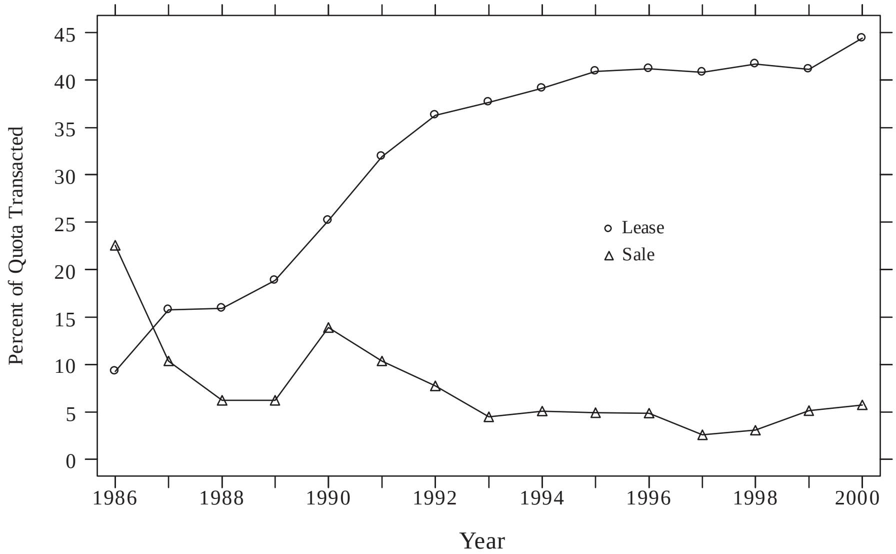

Fig. 2. Trends in the portion of quota that are leased and sold. *Note*: Annual median across fish stocks of the net percent of quota owned that is leased and sold by fishing year.

The upward movement in 1990 corresponds to a period of adjustment following the switch from denomination of quota in tons to shares of the TAC, as well as initial allocations for rock lobster. The median quota market shows a similar decline, with the percentage sold being as high as 23% at the start of the program, gradually decreasing in subsequent years to around 5% 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 median number of transactions in the individual ITQ markets was 760 leases and 110 sales, ranging from very few transactions up to almost 4000 leases and 1200 sales in the most active markets. Quota markets with low 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 [3,9].

3.3. Price dispersion

Although we find evidence suggesting that there are ample participants and activity 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 quota markets are competitive with zero transactions costs, buyers will arbitrage across competing sellers to equalize prices for identical quota at a point in time. More realistically, even if price dispersion is relatively high when a market is first initiated, any variation should go down over time as the market develops, fishermen

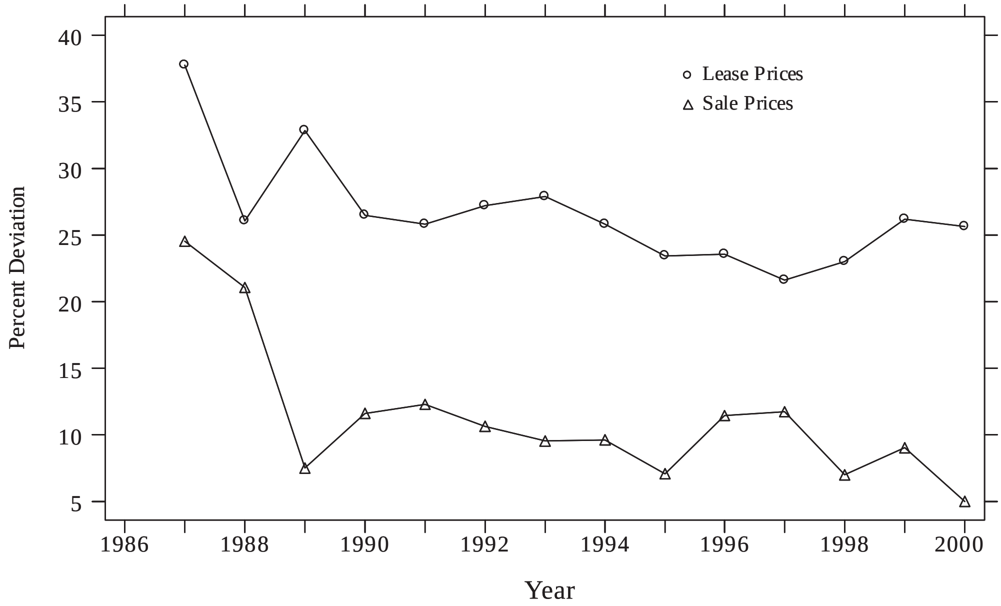

Fig. 3. Trends in lease and sale price dispersion. *Note*: Price dispersion is measured as the annual average of the percent absolute deviation of each transaction price from the monthly mean price of its fish stock.

and intermediaries learn how to operate in the newly created market, and transactions costs fall. Nonetheless, price variation could persist due in part to quota transactions taking place bilaterally or through a broker, leading to differences in transaction costs, search costs, and bargaining power.

When investigating price dispersion, one must be careful to ensure that the prices and products are comparable. One question is the time window to consider. Taking a longer time step introduces more observations into each calculation, but it also increases the number of transactions that may not be truly comparable. We measure price dispersion as the mean absolute percentage price difference between the individual trade prices within each month and the monthly mean for its fishing quota market. Since 2-day and 1-year leases are not comparable, we only include leases whose length is over 80% of the remaining days in the fish year. In both lease and sale markets, we also omitted transactions involving bundles of multiple quota, for which it is likely more difficult to assign individual quota prices.

The trends in price dispersion for both the lease and sale markets are illustrated in Fig. 3, which shows the annual mean price dispersion across fishing quota markets. We find that on average, deviations of quota prices around their mean were about 35% for leases and 25% for sales in 1987, falling to about 25% for leases and 5% for sales by 2000.[18] The higher

[18]When bundled transactions are not omitted, the qualitative patterns illustrated in Fig. 3 still hold, but overall the levels in both markets are higher; dispersion in both the lease and sale market fell from around 35% in 1987 to around 29% and 12% in 2000, respectively.

dispersion in lease prices is likely due to uncontrolled differences in lease characteristics. Lease contracts for quota cover many issues that could affect their price, including purchase requirements or guarantees for fish that are caught. Intraseason variability in fishing conditions or other short-term considerations could also lead to lease price dispersion within 1-month periods.

In general, it is difficult to interpret the magnitude of the dispersion, because there is no generally accepted metric for measuring whether dispersion is unusually large or not. The literature investigating whether markets conform to the "law of one price" reports price dispersion on the order of 5–30% for commonplace commodities, such as concrete, calculators, and fuel oil [33] and from 18% to 59% in the art print market [32]. Relative to these markets, it appears that price dispersion in the fishing quota markets might be considered "reasonable". Another relevant comparison to fishing quotas is other "created" markets designed to address environmental externalities, such as the US national sulfur dioxide (SO_2), nitrogen oxides (NO_x) trading in the northeastern United States, and California's RECLAIM program. We find that a sample of national SO_2 market prices exhibited average dispersion of 2% over 2001–2002, while the northeastern NO_x price dispersion averaged 5% over the same period (see supplementary material for details). RECLAIM price dispersion is much higher, averaging 27% over the period 1995–2002, and without a discernable trend.[19] We conclude, therefore, that the 5% price dispersion for recent quota sales suggests that the precision of the price signal sent in these markets is on par with others that are typically thought to be well functioning.

4. Analysis of fundamentals determining market prices

An important question in gauging the performance of quota markets is whether market prices are consistent with semi-strong market efficiency—with prices reflecting all of the currently available public information [19]. We assess quota price behavior 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. We also 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 1-year lease on the right to catch 1 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

[19]The much lower dispersion for national SO_2 and northeastern NO_x markets may be due in part to the fact that we did not have price data for the entirety of these markets as for the other cases. In general, it is difficult to isolate the causes of price dispersion, such as transactions costs or market power. For example, List [27] discusses how heterogeneity in the experience of market participants can affect dispersions in willingness to pay and accept.

cost of fishing.[20] According to rational asset pricing theory, the price of holding that right in perpetuity (i.e., 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.

In a deterministic setting, quota prices would 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, fishing locations, and time of year. 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 fishing quota markets with a wide range of scales (e.g., in terms of prices and catch levels), to provide a reasonable fit of the data, to allow relatively transparent interpretation of the parameter estimates, and to be parsimonious. We therefore enter all variables in a form that yields percentage relationships, which we accomplish by taking natural logarithms in some cases, but not in those where the variable is already a percentage or a rate.[21]

We also assume 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 any expected growth rate in 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 below. While we should see agreements in terms of the expected signs across the lease and sale price equations, we should also find that estimates for variables more susceptible to short-run fluctuations are larger in the lease than sale equation, everything else being equal.

[20]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.

[21]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.

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

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

where λ is the quarterly average lease price,[22] p is the contemporaneous export price, c is an index of fishing costs, H is the actual annual catch, Q is the annual TAC, h is the actual quarterly catch, s is the absolute value of the southern oscillation index (SOI), 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 fishing quota market fixed effects, 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 include fixed effects for each geographic region as well as a measure of each species mortality rate. The error term ε varies by fish stock, is weighted by the number of transactions underlying each observation, and is adjusted for autocorrelation, as described further in Section 4.2.

We would expect the export price of fish to be positively associated with quota prices, a relationship that is clearly illustrated in Fig. 4, which shows a roughly linear relationship in logs between quota lease prices and fish export prices.[23] A very similar relationship holds for sale prices, but with a vertical scale 10 times in magnitude. In principal, the relevant price of fish for decisions regarding the value of a lease of duration 1 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

[22] After adjusting for inflation using the producer price index (PPI), we calculated the quarterly average lease and sale price for each fish stock. The qualitative results reported in Section 4.3 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 for a tractable relaxation of a homoskedastic assumption for 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.

[23] Although we would ideally like to use dock or port prices for fish rather than export prices, adequate port price data do not exist. Using a New Zealand government survey of port prices for specific fish stocks in 1998, we find a 95% correlation between export prices and port prices implying that export prices are an excellent proxy for the port price. For information on the derivation of export prices, see the supplementary material.

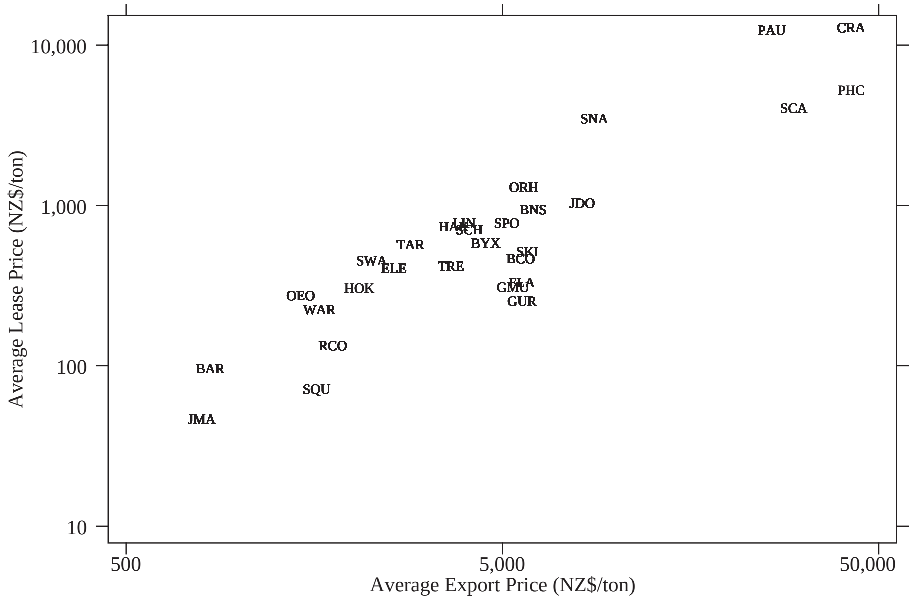

Fig. 4. Quota lease prices versus fish export prices. *Note*: Logarithmic scale. Averages by species for the 1998/1999 fishing year. Year 2000 NZ$. Data symbols are species abbreviations.

transaction was made.[24] In practice, given the short time period for leases (1 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 (see supplementary material for derivation). These costs fell by about 20% 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 and oceanographic conditions).[25] In addition, we include variables that capture differences in relative quota demand within and between fish stocks over 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 distance from port to the fishing

[24]Orazem and Miranowski [31], 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".

[25]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.

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 non-binding TAC constraint, this will not be the case where uncertainty gives rise to option value.[26] 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 over-compliance by firms facing pollution control standards [30].

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. 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.

We include additional variables, 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 fixed-effects specification. 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 [4]. The assumption is that species with higher mortality rates have population sizes that are more variable due to fewer age classes, which we argue leads to greater uncertainty in the amount of fish likely to be caught with a given level of effort. 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 and risk aversion.

The climatic variable we include is the SOI, a time-series measure of variability in water temperature and pressure.[27] Water temperature significantly influences fish ecology and location

[26] In this respect quota have option-like characteristics. Anderson [1] 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.

[27] See the supplementary material for more detail on this measure. We utilize a quarterly average in the econometric analysis.

and is an important variable used by the fishing industry when assessing the productivity of fisheries. We would expect that greater variation in the SOI 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. The regional dummies are based on the geographical distribution of the species [14]. This alternative specification may be of particular value 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 affects corporate profitability and tends to be correlated with asset prices.

To test whether the ITQ system is leading to increases in profitability (and thus quota prices) associated with improvements in fish populations and gains from consolidation and trade, we exploit a natural experiment. That is, our data set has different fish stocks that faced varying degrees of government constraint on catch levels through the setting of TACs. Theory predicts that fisheries plagued by excess capacity and overfishing, when faced with significant reductions in allowable catch at the outset of the ITQ program, would experience greater increases in profitability through stock rebuilding and cost rationalization than fish stocks without a high degree of overfishing, everything else being equal. We investigate this prediction by estimating separate time effects for those the stocks that faced significant initial cuts in the TACs and those that did not face significant reductions in catch (see supplementary material for a list of these fish stocks). We would expect the time effects to be positive and significantly larger for the stocks that faced more rationalization, after controlling for changes in fish prices, fishing input prices, and other important factors.

Caution is always in order when interpreting time effects, however, and there are other factors that could plausibly influence quota prices over time. Nonetheless, because the data provide a natural experiment from which to measure this effect, and many unmeasured factors seem likely to affect each market similarly, we are more confident that we are indeed capturing differences in profitability increases.[28]

4.2. Estimation

We estimate Eq. (1) using the comprehensive panel dataset discussed in the supplementary material. Because export price information was unavailable for HPB, OYS, and STA, we only include 30 species and (141 fish stocks) in the econometric analysis of lease and sale prices. All monetary figures were adjusted for inflation to year 2000 New Zealand dollars, using the producer price index (PPI) from Statistics New Zealand. 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 14 leases and four sales on average, ranging from 1 to 192 leases

[28]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.

Table 2
Descriptive statistics for determinants of fishing quota prices

Variable	Mean	Std. dev.	Min.	Max.
Lease price ($/ton)	1738	4321	1	43,663
Sale price ($/ton)	21,216	48,585	22	358,586
Export price ($/ton)	7592	11,246	311	60,263
Catch (tons/year)	3992	20,814	0	268,633
Total allowable commercial catch (tons/year)	5154	23,416	1	251,883
Percentage catch	0.76	0.35	0.00	5.09
Percentage cumulative catch over prior year	0.01	0.13	−1.07	3.11
Mortality rate	0.30	0.22	0.05	1.00
SOI	−2.6	10.2	−23.7	15.47
Fishing cost index (index = 1 in January 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	17	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 US dollar. Tons are metric tons.

and 1 to 75 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.[29]

We estimate separate equations for lease prices and sale prices using feasible generalized least squares (FGLS), wherein the covariance matrix of the disturbances allows for cross-sectional heteroskedasticity and first-order autocorrelation that can vary across panels (see supplementary material for the covariance matrix).[30] We also weight by the number of transactions underlying each observation (which is a quarterly average), which will correct for heteroskedasticity because averages based on more observations have lower variance. More restrictive error structures that assume no autocorrelation or stock-specific heteroscedasticity were rejected by likelihood ratio tests.

5. Results

The estimation results for both quota lease and sale prices for models both with and without individual fish stock fixed effects are presented in Table 3. Overall, the results are consistent with economic expectations about the parameters. The estimated coefficients generally 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

[29]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 SOI because we are interested not in the sign of the index but rather in its magnitude as an indication of climatic variability.

[30]The overall sample autocorrelation for lease prices was 0.21, and 0.38 for sale prices, both of which were significant according to Durbin Watson and Breusch Godfrey tests and also differed across panels.

Table 3
Determinants of fishing quota lease and sale prices

Variables	Fixed effects		No fixed effects	
	Lease	Sale	Lease	Sale
Price of fish				
Logged fish export price	0.218 (0.022)	0.244 (0.022)	1.158 (0.010)	1.045 (0.013)
Logged fish export price, squared	0.047 (0.009)	0.078 (0.009)	0.080 (0.006)	0.051 (0.006)
Cost of fishing (Log of fishing cost index)	−0.741 (0.122)	−0.306 (0.127)	−1.842 (0.195)	−0.747 (0.170)
Quota demand				
Prior year % caught of TAC	0.382 (0.031)	0.436 (0.043)	1.092 (0.030)	0.960 (0.039)
Prior year % caught of TAC, squared	−0.228 (0.023)	−0.205 (0.035)	−0.588 (0.023)	−0.566 (0.035)
Year-to-date % caught of TAC above prior year	0.076 (0.036)	0.220 (0.053)	0.350 (0.049)	0.401 (0.065)
Year-to-date % caught of TAC above prior year, squared	−0.03 (0.059)	−0.047 (0.030)	−0.141 (0.067)	−0.090 (0.036)
(Logged export price)(prior year % caught of TAC)	0.162 (0.026)	0.231 (0.037)	0.498 (0.030)	0.579 (0.030)
Ecological uncertainty				
Natural mortality rate	—	—	−1.255 (0.036)	−0.645 (0.050)
Logged absolute value of SOI	−0.017 (0.005)	0.004 (0.006)	−0.003 (0.006)	−0.013 (0.008)
Quota price trends				
Fisheries with initial reductions in TAC (annual trend interacted with reduced TAC = 1)	0.042 (0.003)	0.089 (0.003)	0.018 (0.004)	0.073 (0.005)
Other fisheries (annual trend interacted with reduced TAC = 0)	0.008 (0.002)	0.053 (0.003)	−0.004 (0.003)	0.036 (0.003)
Reduced TAC (dummy indicating fishery had initial reductions)	—	—	−0.308 (0.048)	−0.098 (0.043)
GDP growth rate	1.701 (0.190)	3.207 (0.275)	1.394 (0.287)	3.073 (0.343)
Seasonal effects	*Jointly significant*	*Jointly significant*	*Jointly significant*	*Jointly significant*
Fish stock fixed effects	*Jointly significant*	*Jointly significant*	—	—
Regional effects	—	—	*Jointly significant*	*Jointly significant*
Constant term	5.643 (0.094)	7.670 (0.094)	7.537 (0.048)	9.246 (0.047)
Number of quarterly observations	6010	4161	6010	4161

Note: The dependent variables are the average quarterly lease and sale prices. Standard errors are shown in parentheses. The 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 fixed effect (no fixed effect) lease price equation is 0.95 (0.88) and for the sale price equation is 0.92 (0.85). Estimation method is 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. Some variables are normalized to ease interpretation.

effects indicate a substantial increase in quota prices since the ITQ system was established, consistent with an increase in the profitability of the fisheries. Perhaps more convincingly, 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.[31] We also estimated the model in annual first differences, which yielded consistent qualitative results for all our main findings.

These results are compelling for a number of reasons. First, with a comparable OLS estimation of our model, we explain 95% of the variation in lease prices and 92% in sale prices. While one always has to be careful not to place too much emphasis on R^2 values, the model's explanatory power appears quite high. Second, the parameter estimates are largely consistent across the lease and sale price equations, although the estimates for variables more susceptible to short-run fluctuations tend to be larger in the lease than sale equation, as one would expect. Together these results support the assumption implicit in our sale price equation that contemporaneous conditions are a significant determinant of fishermen's expectations about future conditions. Finally, 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 Fig. 4 and the estimation results without fixed effects in Table 3, indicating that quota prices are much more sensitive to long-term cross-sectional differences in export prices than they are to fluctuations in export prices within species over time. The coefficient on the squared export price (β_2) in both equations is positive, indicating that export prices above the mean (about NZ$7,500) have a somewhat greater effect on the quota price than that given by β_1, while below average export prices have a somewhat lesser effect.

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

We also find that quota prices increase with increases in relative quota demand, and the magnitude of the effect (β_4) (which is measured at the point where the TAC is binding) is similar across the lease and sale prices.[32] 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

[31] 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. In principle the deemed value can censor the quota lease price by acting as a price ceiling. This could lead to the usual bias in means and variances that gave rise to models for handling censored data. In practice, we found that only around 1% of our lease price observations approached the level of the deemed value. Furthermore, the results were not sensitive to treating these observations as censored.

[32] 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.

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 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. 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 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 gains from trade leading to increased profitability. That is, positive time effects indicate rising quota prices, controlling for other factors.[33] The collection of stocks that faced initial reductions in allowable catch also experienced significant consolidation, with the median fish stock having a 38% reduction in the number of owners. For these stocks, we estimate that lease prices rose at an average rate of 4% and sale prices by 9% annually since the program started, holding other factors constant. For the other collection of stocks, which saw only a median 12% reduction in the number of owners, we estimate that lease prices rose a more modest 0.8% annually and sale prices by 5% annually, all else equal.[34]

[33]To measure the total increase in profitability from the implementation of the ITQ system, we would not want to control for increases in the price of fish attributable to a new emphasis on product quality, nor cost changes due to individual owner's investments in cost-saving technology. While these revenue and cost gains may not be due to stock rebuilding or gains from trade, an individual catching right is a critical factor in the ability to capture these gains. Without rights, race-to-fish conditions would persist and these gains would tend to be dissipated. In New Zealand, there is anecdotal evidence that fishermen have changed catching methods in the red snapper fishery, for example, in order to sell their catch on the highly profitable Japanese live fish market [17].

[34]We also estimated the fixed effects model with separate time effects for inshore, offshore, and shellfish fisheries. Because New Zealand's inshore and shellfish fisheries were the most depleted and overcapitalized, and the offshore fishery was managed through a quota system prior to 1986, we expect that the efficiency gains to be higher in the inshore and shellfish fisheries than offshore. This is in fact what we find for both lease and sale prices, with quota price increases for shellfish (lease 7%, sale 15%), inshore (lease 1%, sale 6%), and offshore (lease 1%, sale 4%), all else equal. That shellfish had the greatest rate of increase in quota prices is consistent with evidence that the rock lobster fisheries have shown the clearest signs of stock rebuilding [14].

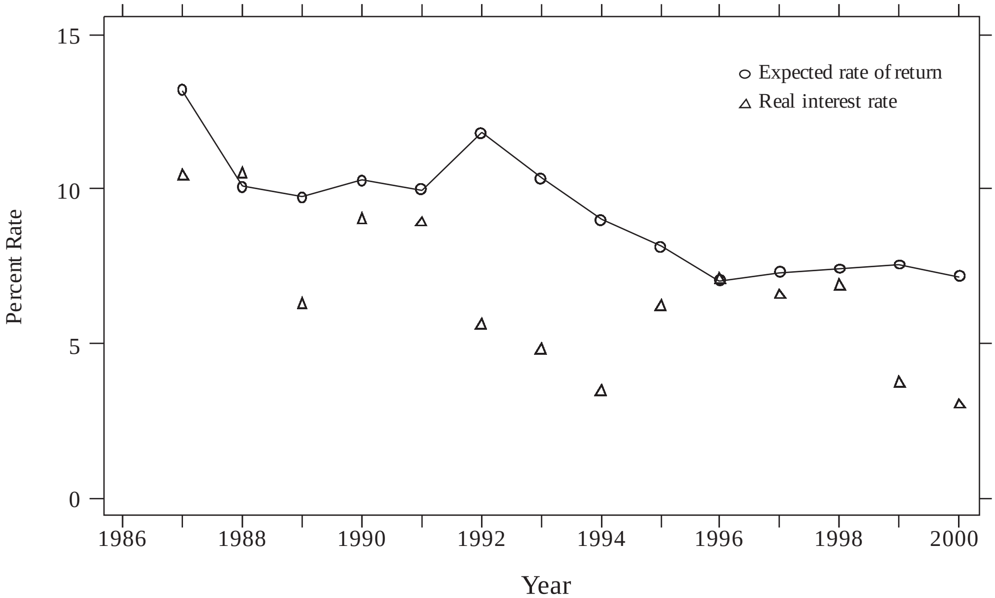

Fig. 5. Expected rate of return for quota and market interest rates. *Note*: Rates of return are medians across fish stocks in each year. The interest rate is based on New Zealand Treasury bills; the real rate is deflated using the New Zealand consumer price index.

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. 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.

5.1. Dynamic quota abitrage

The relationship between quota lease prices, sale prices, and the rate of interest is illustrated in Fig. 5. The ‘‘expected rate of return’’ plotted in the figure is the median in each year of each quota market’s quarterly average lease price divided by its quarterly average sale price.[35] 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

[35]We do not include any realized capital gains or losses in our expected rate of return calculation. If the lease price reflects the annual earnings from the quota, there should not be any expected capital gain due to retained earnings, as is the case for many shares of stock. Furthermore, any anticipated increases or decreases in earnings (lease prices) or interest rates should be quickly capitalized in the quota asset price, implying that the expected future capital gain is zero. One could of course test the proposition that capital gains in these markets are not forecastable using some version of the ‘‘predictability tests’’ employed in the finance literature regarding the efficient market hypothesis [15]—an undertaking we intend for future research. In any event, if capital gains are included, this raises the realized rate of return by about 4% annually on average.

expected future profit flows, the lease price divided by the sale price should be close to the risk-adjusted market interest rate. In other words, according to the predictions of the capital asset pricing model, we should expect to find that the expected excess returns from holding fishing quota are proportional in equilibrium to the risk of holding quota relative to the market portfolio.

We estimate the relative risk of holding fishing quota in the standard manner, by regressing the real rate of return to fishing quota on the real rate of return to the New Zealand stock market (i.e., the NZSE40 index) over the period 1987–2000. We find that the "β" coefficient reflecting the risk of holding New Zealand fishing quota relative to the New Zealand stock market is well below one, and is not statistically different from zero.[36] With a β near zero, there is little undiversifiable risk associated with holding fishing quota, so that the appropriate discount rate is close to the risk-free rate. Interestingly, Ellerman and Montero [18] estimated a β coefficient for the SO_2 allowance market, also finding a β not significantly different from zero.

Fig. 5 supports the presence of this arbitrage relationship, with the computed expected rate of return tracking both the level and the trend in New Zealand short-term interest rates over the sample period. At the same time the expected rate of return fell by about half from 13% to 7%, the interest rate as measured by New Zealand Treasury Bills fell from 10% to about 4% real. As illustrated in the figure, the expected quota return is about 2–3% higher than the risk-free rate on average. We note that if quota market participants were factoring in expected growth in lease prices, the actual expected rates of return would be higher than we have estimated ignoring such increases.

Nonetheless, the results regarding quota sale prices and quota lease-sale relationships are subject to the 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.

6. Conclusion

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. With very few empirical studies of created markets, it is often hard to counter worries that these markets may be thin or plagued with information problems 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 market activity, which is rising steadily over the years, to support a competitive quota market. Not all is rosy, however—some markets have relatively few transactions, although these tend to be economically

[36]We checked the sensitivity of this result by conducting the analysis using both monthly returns and quarterly returns, by estimating the β both for each quota market separately and for an aggregate index of quota returns, and over sub-periods of data. Based on monthly returns (168 observations), the β coefficient for the aggregate quota market was -0.08 with a standard error of 0.12, while the median β from individual quota market estimations was -0.05 with a standard error of 0.36. Results using quarterly returns (56 observations) as well as shorter sample periods were qualitatively similar.

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, social, and administrative 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, particularly for quota sales, and is comparable to that found in other well-functioning markets. Due to uncontrolled differences in lease characteristics, it is difficult to be definitive about whether the higher dispersion we observe in lease prices is worrisome. Overall, 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. The observed dispersion could potentially be reduced through establishment of a central trading exchange, thereby improving the quality of information for market participants.

Our estimates indicate 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 expected rate of return 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 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 fishing stocks that were initially overcapitalized and overfished and 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 the overall flexibility of the system and the ability to transfer shares has high economic value. Furthermore, the flexibility provided to quota holders by having the option to lease appears to have significant value as revealed by the dramatic increase in leasing over time. In addition, the opportunity to arbitrage across the sale and lease market provides an additional dimension across which relevant market information can be exchanged and rationalized.

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

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Appendix A. Supplementary analysis tools

A collection of macros that can be applied to sequence batches of up to 5000 sequences can be obtained from our web site (schroeder/publications/).

Appendix B. Supplementary data

The online version of this article contains additional supplementary data. Please visit doi:10.1016/j.jeem.2004.06.005.

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