Marine Resource Economics, Volume 21, pp. 231–249
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0738-1360/00 $3.00 + .00

A New Zealand ITQ Fishery With an In-Season Stock Externality

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Abstract *This paper explores the economic performance of a fishery that operates under an individual transferable quota (ITQs) management system and that is subject to an in-season stock externality. While Boyce (1992) and others have established theoretically that ITQ management is not fully efficient under all conditions, this is the first study that empirically estimates the efficiency losses due to an in-season stock externality in an actual fishery. We study the New Zealand southern scallop fishery, which has been under ITQ management since 1992. Our analysis provides evidence of a race-to-fish in the fishery, and estimates that individual firm profits were approximately $2,300 and $2,000 (20% and 10%) less in 1996 and 1997, respectively, than they would have been under optimal management. We recommend modifications in the ITQ policy to improve the economic performance of the fishery.*

Key words Fisheries management, individual quotas, stock depletion, New Zealand, scallops.

JEL Classification Codes Q220, Q280, Q570, Q580.

Introduction

This paper examines the economic performance of a fishery that operates under an individual transferable quota (ITQ) management system and is subject to an in-season stock externality. Boyce (1992) shows that an ITQ system cannot solve in-season stock and congestion externalities in a fishery.[1] In addition, Boyce (1992, pp. 399, 403) correctly observes that whether these externalities exist, and how well ITQs can deal with them, are empirical questions. He further notes the lack of em-

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We gratefully acknowledge the support from the RI Agricultural Experiment Station and the Northeast Fisheries Science Center, NOAA Fisheries. Mike Arbuckle, former CEO of the CSEC, provided data and numerous helpful explanations and comments. Ragnar Arnason provided several comments and suggestions that significantly improved this paper. Others who provided invaluable assistance and comments include: Jim Opaluch, Mike Fogarty, John Gates, Steve Edwards, and Fred Serchuk. An earlier version of this paper was presented at the IIFET 2002 Conference in Wellington, New Zealand. We are thankful to all for their assistance. We alone are responsible for any remaining errors. Rhode Island Agricultural Experiment Station Contribution No. 4039.

[1] This finding is consistent with Clark (1980) who earlier showed that ITQs are not always fully efficient.

pirical studies of these questions. There are numerous studies that document the superior performance of ITQs as compared to other management measures (Boyce 1992, OECD 1997, Morey 1986, NRC 1999, Geen and Nayer 1988, Repetto 2001). However, to our knowledge there are no studies that empirically measure the efficiency losses caused by stock depletion, congestion, seasonality, and other factors.[2]

We develop a theoretical model of the New Zealand southern scallop fishery, which has been under ITQ management since 1992, and which exhibits an in-season stock externality. We formally compare the harvest path of ITQ management with the harvest path that is fully efficient for the fishery. A numerical version of the model is used to empirically estimate the magnitudes of the efficiency losses that are due to the in-season stock externality during the course of a fishing year in this fishery. We conclude the paper with a discussion of alternative policy measures that may improve the fishery's economic performance.

Background[3]

The Southern scallop fishery is located at the north end of New Zealand's South Island (figure 1). Annual catches have ranged from 1,246 tonnes (meat weight) in 1975 to zero in 1981 and 1982. After periods of regulated access and effort restrictions, a Quota Management System (QMS) was introduced into most of New Zealand's commercial finfish fisheries in 1986 (Arbuckle and Drummond 2000). Shellfish stocks from the northern South Island (the Challenger area) were added to the QMS in 1992 (scallops) and 1997 (dredge oysters). The QMS program is a system of harvesting rights in the form of ITQs.

Scallop beds are located within two large relatively sheltered bays, Tasman and Golden Bay, as well as the area of New Zealand known as the Marlborough Sound. A rotational fishing and enhancement regime has been operational in the Tasman and Golden Bay sections of the Challenger scallop fishery since 1989.[4] Fishing grounds are divided into nine sectors. Each year an agreed upon number of sectors is opened to commercial fishing and, after being fished down, each sector is seeded with scallop spat. The seeded spat within rotational areas are left to grow undisturbed by the commercial fleet for a period of two and a half to three years before being harvested. In some years, as much as 80% of the available stock is estimated to be of seeded origin. Up to 70 scallop vessels ranging in size from 12 to 20 meters utilize potentially 850 square kilometers of seabed during annual harvests between August and December. The total scallop harvest was 300 and 547 tonnes in 1996 and 1997, respectively.

In 1994, the ITQ owners of the southern scallop fishery established the Challenger Scallop Enhancement Company (CSEC) as a non-profit company to implement an enhancement program. The owners of Challenger scallop fishery quota exclusively hold the shares of the CSEC. Voting rights for appointment of Directors and approving the annual business plan and annual management plans (that include which sectors will be open and annual catch limits) are held in proportion to quota ownership in the fishery.

The company was successful in negotiating a contract with the government to implement an enhancement plan. Initially, levies were collected by the government

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[2] In fact, despite the strong influence of seasonality in most fisheries, there has been surprisingly little analysis of its implications for management policy.

[3] This description of the fishery is based on Arbuckle and Drummond (2000).

[4] The Ministry of Fisheries implemented and enforced rotational fishing prior to the formation of the Challenger Scallop Enhancement Company (CSEC) in 1994, when the CSEC assumed responsibility for this function.

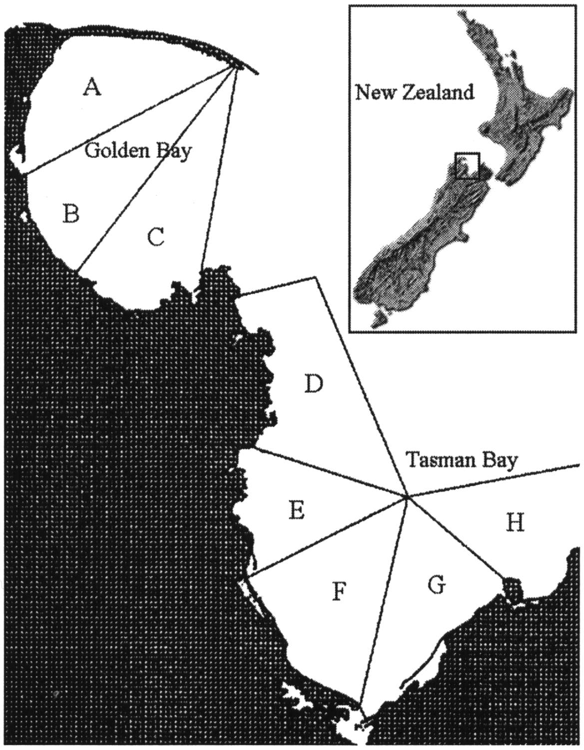

Figure 1. Golden and Tasman Bays with an Inset of New Zealand

and held in trust for the purpose of implementing the plan. In 1996, the scallop quota owners and CSEC shareholders voted to replace the government funding arrangement with a commodity levy set by a vote in their general meeting. The government discontinued their levy, and a Memorandum of Understanding was developed between the Ministry of Fisheries and the owners of the quota and the CSEC.

The CSEC's objectives were to facilitate the collection of funds to finance fisheries management activities, including research, set rules to achieve effort spreading or seasonal closures, impose sanctions for non-compliance, and represent the interests of shareholders in government processes such as setting Total Allowable Catches (TACs). The CSEC has attempted to implement its management regime by use of civil contract and regulation to overcome free riders who may not otherwise be willing to pay levies and enter into collective management agreements. The scallop fishery is relatively small, and industry participation in the management of this fishery is highly developed.

Under the QMS, the Minister of Fisheries officially sets the TAC for the fishery, which was 720 tonnes each for 1996 and 1997, even though actual observed catches were much lower.[5] To account for this disparity, the CSEC effectively lowered the

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[5] The Southern scallop fishery is exempt from normal sustainability criteria (based on maximum sustainable yield) because the purpose and principles of the Fisheries Act are better delivered in this fishery by rotational fishing and enhancement (Arbuckle and Drummond 2000).

TAC for the quota holders with what is called a leaseback program. For example, in 1996 the CSEC lowered the TAC by 51.4% to 350 tonnes. Each holder/owner of scallop quota owned a share of the 720 tonnes. Upon agreement by quota holders, the 51.4% of the TAC (370 tonnes) was 'leased back' to the CSEC. In 1997, 62.5% of the TAC was leased back to the CSEC. Sizeable portions of the quota were effectively shelved and not fished during these two years.[6] Harvesting is allowed to continue as long as it is economically feasible and does not exceed the adjusted TAC. Once an area is fished down, it is seeded and closed until it becomes economically desirable to harvest again. In addition to quota, the CSEC has governed and constrained catches by limiting access to rotational areas and imposing daily catch limits in particular sectors.

The agreement to lease back their quota to Challenger was to hold this quota and only release it if more scallops were available. This was an attempt to weaken the race-to-fish incentive by limiting the total amount of quota available. According to Arbuckle (personal communication 2002; Arbuckle and Drummond 2000) this policy was only partially effective in earlier years because the catch was less than the amount of lease left in the fishery. He thought that the policy may have removed some of the race-to-fish incentives and also may have avoided the need for government intervention to arbitrarily and inflexibly adjust the TAC.

Daily catch limits on individual vessels have been in place since the mid-1980s when the government was managing the fishery. The CSEC continued these daily limits and, in 1996, established penalties for catch taken in excess of the limits (Arbuckle and Drummond 2000). As explained below, these daily limits were not binding in 1996–97 and did not stem the race-to-fish in the fishery. The race-to-fish and excessive catches early in the season have been concerns of the CSEC at least since 1996, if not before.[7]

The company recently has sought to reduce the downsides of the race to fish by reducing daily catch quotas (pro-rated on total access to catch by vessel) to a level where vessels are able to concentrate more on quality than simply filling their quota with whatever comes over the stern (Mincher 2005). However, Mincher (2005) reports that this is not as effective as they wish for two reasons: (*i*) Vessel skippers still try to out-compete each other on the basis of how early they can get their catch and return to port; and (*ii*) daily quotas are only effective as long as catch is constrained by them; once fish density reduces so that the effective limit on catch is the time available to fish between sun-up and sun-down, the pressure to take whatever is available returns. The company has also introduced a policy of matching total vessel numbers to total anticipated catch.[8]

A Theoretical Model of the Southern Scallop Fishery

Consistent with actual practice in New Zealand, we assume that the government sets, or agrees to, a TAC for the fishing year and that the TAC may be set exogenous to (independently of) the optimization problems analyzed below. In other words, the government may set the TAC based on biological or other non-economic criteria.

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[6] New Zealand has now introduced an annual form of quota called Annual Catch Entitlement (ACE). ACE is allocated at the beginning of a fishing year based on quota holdings, and it is only ACE that can be used to balance catch. In other words, an ACE sale (purchase) is essentially the same as a quota lease.

[7] The CEO of CSEC asked the second author to investigate this issue in 1996, and this paper is the result of that (lengthy) investigation.

[8] There is a pre-established sliding scale of desirable vessel numbers, ranging from 35 at 186 tonnes of anticipated harvest, to 50 vessels at 746 tonnes.

Following Boyce (1992), our model focuses on the fishery throughout the course of a single year and uses a discount rate equal to zero.[9] The fishing year begins at $t = 0$ with a predetermined resource stock, $\overline{X}$. In contrast to Boyce (1992), we assume there is a positive net rate of natural growth of the stock during the fishing year, which is given by $G(X)$.[10] We also assume that there is no significant bycatch of scallops by other fisheries. Therefore, the stock size changes by the amount of natural growth and fish harvested each period. Harvesting costs increase and profits decrease as the stock is depleted.[11]

Optimal Harvest of the Fishery

For optimal harvest of the predetermined TAC (denoted by $Q_0 = \overline{Q}$), the problem for the CSEC is to maximize aggregate profits for its N shareholders:

$$\text{Maximize} \int_0^T \left\{ \sum_i \pi^i(q_t^i, X_t) \right\} dt \tag{1}$$

$$\text{S.T. } \dot{X} = G(X_t) - \sum_i q_t^i$$

$$\int_0^T \left(\sum_i q_t^i \right) dt \leq \overline{Q}$$

$$X_0 = \overline{X},\ X_t \geq 0,\ q_t^i \geq 0,\ Q_T \geq 0,$$

where X_t is the size of the stock in period t, T is the end of the fishing year, and q_t^i is the harvest rate in period t by firm i ($i = 1, 2, \ldots, N$). We represent the individual firm's profit function by $\pi^i(q_t^i X_t)$, where, over the relevant range, the marginal operating profit is positive and decreasing in harvest, and profits increase as the stock increases; *i.e.*, $\pi_q^i > 0$, $\pi_{qq}^i < 0$, $\pi_X^i > 0$, $\pi_{qX}^i > 0$, and subscripts other than t indicate partial derivatives. The TAC is given by $\overline{Q}$. The necessary conditions for an interior solution to this problem include:[12]

$$\pi_q^i = \mu_t + \lambda_t \tag{2}$$

$$\dot{\mu} = -\sum_i \pi_X^i - \mu_t G_X \tag{3}$$

$$\dot{\lambda} = 0 \tag{4}$$

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[9] The fishing season usually lasts less than four months.

[10] The net rate of growth is net of natural mortality. This feature of the theoretical model is incorporated in the empirical model developed below.

[11] The distributions of scallops are patchy, and the catch-per-unit-of-effort (CPUE) is high in the beginning of the year. Harvesting thins out the patches, and the CPUE of scallops decreases and vessels find it desirable to move to more dense patches. As more of the leased quota (TAC) is filled, the number of unexploited patches decreases and the search time for new patches increases over the year. As the CPUE decreases and the cost of fishing increases, the marginal value of the stock decreases for the firm as the year progresses.

[12] The Hamiltonian from which these conditions are derived is:

$$H = \textstyle\sum_{i=1}^N \pi^i(q_t^i, x_t) + \mu_t\left[G(X_t) - \sum_{i=1}^N q_t^i\right] + \lambda_t(\overline{Q} - \sum_{i=1}^N q_t^i).$$

$$\lambda_t \geq 0,\ \mu_t \geq 0,\ X_t \geq 0,\ \mu_T \cdot X_T = 0, \tag{5}$$

where μ_t is the dynamic multiplier of the resource stock, X_t, and λ_t the shadow price of the TAC. Since $\dot{\lambda}=0$, $\lambda_t=\bar{\lambda}$, a constant.

Equations (1–5) determine the path of harvest rates during the course of the fishing year. To examine how stock depletion affects harvest rates during the year, we totally differentiate the optimality condition, equation (2), and use equation (3) and the dynamic constraint on the resource stock to obtain:

$$\dot{q}_t^i = -\left\{G_X[\pi_q^i - \lambda^*] + \pi_{qX}^i\left[G(X) - \sum_i q_t^i\right] + \sum_i \pi_X^i\right\}\Big/\pi_{qq}^i\ . \tag{6}$$

As can be seen from equation (6), the optimal path of harvest may increase or decrease over the course of the fishing season. We use this equation below to explain how and why optimal harvest of the TAC is not achieved under ITQ management in this fishery.[13]

Harvest under Individual Transferable Quotas

Under ITQs, the TAC, which is equal to $\bar{Q}$ as above, is initially allocated to the firms in the fishery. The i-th firm initially receives a quota given by y_0^i, where $\sum_i y_0^i = \bar{Q}$. Each firm aims to maximize the sum of profits for the year, given that it can purchase or sell quota at a market-determined price, v_t, each period.

Following Boyce (1992), Arnason (1990), and others, we assume that each firm takes into account the resource constraint and the amount of fishing by other firms. Fishing firms predict the amount of fishing by other firms, and a Nash-Cournot equilibrium is attained when firms correctly predict each other's harvest rates. Given these conditions, the i-th firm solves the following optimization problem:

$$\text{Maximize} \int_0^T \left\{\pi_t^i(q_t^i, X_t) - v_t z_t^i\right\} dt \tag{7}$$

$$\text{S.T. } y_0^i \geq \int_0^T [q_t^i - z_t^i]\,dt \tag{8}$$

$$\dot{X} = G(X_t) - \sum_i q_t^i \tag{9}$$

$$X_0 = \bar{X},\ \ X_t \geq 0,\ \ q_t^i \geq 0,$$

where z_t^i (or $-z_t^i$) is the quantity of quota purchased (or sold) by the firm in a period, v_t is the price of quota, and y_0^i is the firm's initial allocation of quota. The necessary conditions for this problem include:[14]

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[13] It is also useful to note for the empirical analysis below that the path of aggregate production is given by $\dot{Q}_t = \sum_i \dot{q}_t^i$.

[14] The Hamiltonian in this case is: $H = \pi^i(q_t^i, x_t) - v_t z_t^i + \tau_t(q_t^i - z_t^i) + \sigma_t\left[G(X_t) - \sum_{i=1}^N q_t^i\right]$.

$$\pi^i_q = \tau^i_t + \sigma^i_t \tag{10}$$

$$v_t = \tau^i_t \tag{11}$$

$$\dot{\tau}^i = 0 \tag{12}$$

$$\dot{\sigma}^i = -\pi^i_X - \sigma^i_t G_X \tag{13}$$

$$\tau^i_t \geq 0, \;\; \sigma^i_t \geq 0, \;\; X_t \geq 0, \;\; \sigma^i_t \cdot X_t = 0, \tag{14}$$

for all i firms; where τ^i_t is the i-th firm's co-state variable on its quota holdings, and σ^i_t is the firm's assessment of its co-state variable on the resource stock.

We assume that a competitive market determines the price of a unit of quota in each period, v_t. Since $v_t = \tau^i_t$, from equation (11), and $\dot{\tau}^i = 0$, from equation (12), the equilibrium market price (v^*) is constant across the year.[15]

The expression for the path of harvest under ITQs in this case is derived by totally differentiating equation (10) and using some of the other necessary conditions above, which yields:

$$\dot{q}^i_t = -\left\{ G_X[\pi^i_q - v^*] + \pi^i_{qX}\left[G(X) - \sum_i q^i_t \right] + \pi^i_X \right\} \Big/ \pi^i_{qq} \, . \tag{15}$$

Optimal and ITQ Harvest Paths Compared

By comparing the two sets of necessary conditions — equations (2)-(5) and equations (10)-(13) — one can see that harvest rates under ITQs are different from those for optimal harvest of the TAC. This implies that ITQ management does not necessarily maximize economic yield from the TAC.

In addition, the paths of the two harvest rates over the course of the fishing year differ from one another, which can be seen by comparing equation (6) with equation (15). The term $\Sigma_i \pi^i_X$ appears in the numerator of the RHS of equation (6), while in equation (15) the comparable term is π^i_X. The individual firm under ITQs accounts only for the impact its harvest has on its own profits, whereas the optimal solution accounts for the effect each firm's harvest has on the profits of all firms. ITQ management does not induce fishermen to fully internalize the costs of their actions in the presence of a stock depletion externality.

A comparison of equation (6) for the optimal case with equation (15) for the ITQ case reveals that more scallops are harvested early in the fishing year under ITQs than in the optimal case. The ITQ harvest path is higher early in the fishing year, which reflects the race-to-fish behavior when the stock effect is not fully ac-

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[15] The derived demand for quota by each firm is given by solving equation (10), and aggregate demand is the sum of these derived demands across periods and firms. The market price of quota is where aggregate demand equals total supply, the TAC. One price for quota emerges since a unit of quota can be used at any time during the year, since units of quota are not dated by period of the year. Note that the constant market spot price of quota across the year is a theoretical result and, as such, is a hypothesis that could be tested if data on trades were available.

counted for by individual vessels. Individual firms place too low a marginal value on the stocks early in the fishing year, which is one cause of the race-to-fish in the New Zealand scallop fishery.[16]

A Numerical Model of the Fishery

Data

To empirically estimate the efficiency losses in the New Zealand southern scallop fishery, we drew on three sets of data provided by the CSEC for 1996 and 1997. The first data set consisted of data on the characteristics of the vessels participating in this fishery. The second data set included detailed trip information, while the third set of data was a report that included annual abundance estimates of the scallops in Golden and Tasman Bays (CSEC 1996, 1997; Cranfield, Micheal, and Doonan 1997).

The data on vessel characteristics includes the number of years the skipper has been fishing, vessel length, engine horsepower, and the size of the scallop dredge. Detailed trip data identified the processor that landings were sold to, vessel name and number, quantity landed, date landed, and areas fished by individual vessels. Scallop landings are measured in tonnes of meat and green weight landed, where meat is the muscle and green weight includes the shell. There were 6 individual processors and 70 vessels fished approximately 2,027 and 1,863 days in 1996 and 1997, respectively.

The empirical analysis focuses on the fishery within Golden Bay. The majority of scallop catches occurred in Golden Bay (figure 1) during 1996 and 1997 (53% and 80%, respectively). Table 1 presents the abundance estimates; total landings; and the average catch-per-unit-of-effort (CPUE) by year, location, and area. In 1996 and 1997, Golden Bay had the highest CPUE. Landings in 1996 were primarily from area A with a small amount from area B. In 1997, area A was closed and harvesting took place primarily in area C with a small amount in area B.

The fishing year was divided into week-long periods, and the weekly landings in Golden Bay were analyzed to compare ITQ harvest patterns with optimal harvest patterns. The length of the scallop season for this fishery is approximately two to three months. Our model evaluates harvesting paths over 8 and 11 weeks for 1996 and 1997, respectively. Table 2 shows total catch, total effort, and CPUE for Golden Bay and all other areas by week and year. In 1996 harvesting was very high in the first week, dropped to a quarter of the amount in the second week, and continued to drop as time passed. The same pattern can be seen in 1997.

Estimation of Production, Cost, and Growth Functions

Effort Standardization

Trip and vessel characteristics data and abundance estimates were used to standardize a vessel's fishing effort and to estimate production and cost functions parameters. We used $q^i = a^i E^i X^b$ as the form of the individual fishing firm's production function, where q^i is catch by the i-th firm; E^i is the firm's nominal effort; X is the stock level; and a^i is the firm's catchability coefficient, which is a function of a

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[16] Other causes that could explain the race-to-fish behavior include high rates of time preference and weather conditions that affect the decision to harvest, which are not examined herein due to a lack of supporting evidence.

Table 1

September Abundance Estimates (tonnes of meat), Total Catch (tonnes of meat), and the Average Catch-per-Unit-of-Effort (CPUE) by Year, Location, and Area

Year	Location	Area	Abundance	Catch	CPUE[2]
1996					
	Golden Bay	A	171.2	111.3	0.170
	Golden Bay	B	27.0	11.7	0.131
	Tasman Bay	D	47.6	10.9	0.057
	Tasman Bay	F	211.8	35.9	0.079
	Marlborough Sound[1]	29–100	140.9	61.3	0.096
1997					
	Golden Bay	B	151	39.8	0.329
	Golden Bay	C	335	198.9	0.179
	Tasman Bay	E	15	2.1	0.015
	Marlborough Sound	42–100	79	58.2	0.120

[1] Marlborough Sound lies east of Tasman Bay.
[2] CPUE is tonnes per day.

vector of vessel characteristics.[17] The vessel characteristics that most significantly affect variation of fishing power across vessels are the skipper's experience, horsepower per length of vessel, and the size of the dredge. The log of our Cobb-Douglas type production function (in the form $q^i/E^i = a^i X^b$) yields the following model for estimation:

$$\log(q^i/E^i) = b_0 \log(X) + b_1 \log(SK^i) + b_2 \log(HP^i/L^i) + b_3(Dummy^i) + e^i, \quad (16)$$

with the vessel characteristics being skipper's experience (SK^i) in years, horsepower per length of vessel (HP^i/L^i), a dummy variable for the vessel's dredge size and the error term (e^i). All variables are continuous except for the dredge size "dummy," that divides the size of dredges into two classes (table 3).[18]

In estimating equation (16), we replaced X with dummy variables for time and area since all vessels face the same price and stock conditions in each area and time period. The model also assumes the individual vessel's characteristics are stable across different levels of stock abundance. Ordinary least squares (OLS) was used to estimate equation (16). The sign of the parameters indicates that skipper experience and horsepower per length of boat increase the catch per vessel (table 4).[19]

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[17] The characteristics include the skipper's experience, horsepower, vessel length, and size of dredge.

[18] Of the 70 vessels analyzed within this fishery, 20 were missing one or more vessel characteristics. To standardize effort for the 20 vessels (with an incomplete set of vessel characteristics), we need to estimate their catch ratio. The calculated catch ratio of an individual vessel is its predicted yield divided by the median vessel's predicted yield. A value less than 1 implies the vessel has lower catching power than the median vessel. Using the data on the 50 vessels (with complete set of vessel characteristics), we regressed their individual catch ratio to their raw yield (raw catch). The parameter estimates were used to estimate a predicted catch ratio on the 20 vessels (that had an incomplete set of vessel characteristics).

[19] Condition indices indicated there was no multicollinearity. In addition, four models were examined with different independent variable combinations. Changes in parameter estimates and t-statistics were insignificant and parameter signs did not change, which also indicates no multicollinearity. This regression model assumes errors are identically and independently distributed. If the errors are not independent or the variances are not constant, the parameter estimates remain unbiased, but the estimate of the covariance matrix is inconsistent.Heteroskedasticity was rejected (df = 8, χ^2 =1.57, Prob > χ^2 = 0.99) using White's test (1980). The coefficient of determination (R^2) was 0.34.

Table 2
Weekly Total Catch (tonnes of meat), Total Effort (days), and Catch-per-Unit-of-Effort (CPUE) by Year for Golden Bay and All Areas Combined

	1996						1997					
	Golden Bay Areas A & B			All Areas			Golden Bay Areas B & C			All Areas		
Week	Catch	Effort	CPUE[1]	Catch	Effort	CPUE	Catch	Effort	CPUE	Catch	Effort	CPUE
1	79.7	321	0.248	96.9	413	0.235	129.9	433	0.300	134.1	438	0.306
2	22.0	159	0.138	39.1	311	0.126	46.6	231	0.202	62.8	306	0.205
3	6.0	65	0.093	33.3	316	0.105	47.2	315	0.150	61.6	432	0.143
4	6.8	77	0.088	33.5	415	0.081	8.2	123	0.066	16.8	214	0.079
5	1.6	21	0.079	12.3	221	0.055	2.2	42	0.052	12.9	197	0.066
6	2.5	35	0.071	6.9	146	0.047	1.0	20	0.049	5.4	93	0.058
7	2.3	33	0.070	5.4	116	0.046	2.1	36	0.058	3.1	91	0.034
8	2.1	32	0.064	3.7	89	0.042	0.7	16	0.042	1.2	57	0.021
9							0.1	4	0.038	0.2	8	0.025
10							0.5	11	0.046	0.5	14	0.037
11							0.4	12	0.036	0.4	13	0.033

[1] CPUE is tonnes per day.

Table 3
Average Skipper Experience (years), Horsepower per Vessel Length, and Number of Vessels by Dredge Class Size (standard errors in parentheses)

Dredge Size Classes (Meters)	Experience (Years)	Horsepower/Length	Number of Vessels
2.0 – 2.2	7.9 (7.3)	3.3 (0.7)	16
2.3 – 2.4	13.9 (10.1)	4.1 (1.8)	37

Table 4
Parameter Estimates of Cobb-Douglas Production Function for Effort Standardization (standard errors in parentheses)

Variable	Coefficients	
Intercept (b_0)	-2.737^{*}	(0.17)
Log Skipper Experience (b_1)	0.062^{***}	(0.03)
Log Horsepower/Length (b_2)	0.330^{*}	(0.12)
Dredge Class (b_3)	0.207^{**}	(0.09)

* Statistically significant at 1%, ** at 5%, *** at 10%.

Finally, to convert fishing effort to standardized fishing effort, a vessel's fishing effort was multiplied by the ratio of the vessel's catching power to that of an arbitrary median vessel.

Estimation of Aggregate Production and Cost Functions

We estimated the following aggregate production function for the fleet of vessels:

$$Y_t = a_t E_t^{\alpha} X_t^{\beta}, \tag{17}$$

where at time t, Y_t is aggregate catch per period, a_t is the fleet's catchability coefficient, E_t is the amount of aggregate standardized effort per period (measured in days absent from port), and X_t is the stock size (in tonnes of scallop meats).[20] The estimated form of the aggregate production function is:

$$\log Y_t = \log a_t + \alpha \log E_t + \beta \log X_t. \tag{18}$$

Several models were explored. We allowed the catchability coefficient to be constant and variable. The specification that had the best fit allowed the fleet's catchability coefficient (a_t) to vary by week, where:

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[20] Note that our model is one of the generalized harvest functions in Morey (1986), where, in his notation, $\phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = 0$, which corresponds to the Cobb-Douglas production function used here (see Morey's footnote 16).

$$a_t = e^{(intercept + \delta * week)}.$$

Since the marginal product of effort must not increase, α was restricted to be no greater than 1.0. We allowed β to be free. Table 5 presents the parameter estimates for the 1996 and 1997 productions functions. In this model β is greater than one for both years. We did not correct for multicollinearity and autocorrelation when estimating equation (18).[21]

Since cost data were not available,[22] we approximated the unknown variable cost function with the following 3rd order Taylor series expansion:

$$TVC_t = w_1 E_t + w_2 E_t^2 + w_3 E_t^3.$$

The method for estimating the parameters w_1, w_2, and w_3 is described in the appendix.

Growth Estimation

We assume a linear growth rate function, where the weekly growth rate, r, is constant for scallops in Golden Bay. That is,

$$X_{t+1} = X_t (1 + r).$$

Table 5
Parameter Estimates of the 1996 and 1997
Production Function (standard errors in parentheses)

			a_t	
Year	α	β	Intercept	δ
1996	1[1]	1.3* (0.1)	–8.2* (0.5)	–0.08* (0.013)
1997	1[1]	2.4* (1.1)	–15.77* (6.4)	–0.17** (0.03)

[1] Restricted parameter estimate.
* Statistically significant at 1%, ** at 5%, *** at 10%.

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[21] Multicollinearity exists in both models due to one independent estimate of abundance for each year. The abundance estimate in the second week is equal to the abundance estimate in the first week minus the harvest in the first week plus growth. This can be avoided in an annual model where independent annual estimates are more likely to exist. However, for estimating a seasonal model, independent abundance estimates for each week are not available. One method for reducing multicollinearity is to restrict the variables, which has been done. Restrictions reduce the variance on parameter estimates at the cost of introducing biases. The Durbin-Watson test indicated there was negative autocorrelation in 1996 and no autocorrelation in 1997. Negative autocorrelation was anticipated as the stock size in one week is related to the previous week and decreases when harvest exceeded growth. When the autocorrelation was corrected for 1996, the signs of the parameter estimates changed. Although we observed negative autocorrelation in 1996, the original model with autocorrelation was chosen over the corrected model, which means the parameter estimates are unbiased but not minimum variance.

[22] Midway through our study, researchers at Oregon State University attempted to survey vessel operators to collect costs and earnings data. However, the response rate was very poor and members of CSEC reacted negatively to the attempt to collect the data. As a result, no useful data were collected in that effort.

Linear growth is a reasonable approximation since the harvest season of 12 weeks is a short period. Meat weights at the beginning of each season were 31.6g and 27.0g in 1996 and 1997, with weekly growth rates of 1.25g and 1.08g, respectively (Cranfield, Micheal, and Doonan 1997).

Solution Methods

To assess the efficiency of the ITQ scallop fishery, we compared the numerical solution of the Nash-Cournot model, which simulates the ITQ-managed fishery, with the numerical solution of the optimal model of the fishery. As explained in the appendix, we used a GAMS numerical algorithm to solve for the harvest and effort path that maximizes profits for each firm, given that every other firm is also maximizing its profits. In addition, we used another GAMS algorithm to solve for the optimal, fully efficient set of harvest and effort rates that maximizes fleet profits over all periods of the season. Both algorithms used the same production and cost functions. The results of these computations are shown in table 6.

Results and Discussion

In comparing the numerical outcomes of the ITQ fishery and the optimal fishery, we find that the ITQ harvest is greater than the optimal harvest in the first period of both years (table 6, figure 2). As the weeks progress, the ITQ weekly harvest becomes less than the optimal weekly harvest. The optimal harvest path is flatter than the harvest path under ITQ management. The ITQ system results in the application of too much effort, resulting in higher than optimal landings of scallops early in the fishing year; the classic "race-to-fish" scenario. The optimal harvest is spread more evenly across weeks compared to the ITQ harvest path.[23]

Table 6
The 1996 and 1997 ITQ and Optimal Harvest (tonnes) and Fishing Effort (days fished) in Golden Bay by Week and Year

	1996				1997			
	Harvest		Effort		Harvest		Effort	
Week	ITQ	Optimal	ITQ	Optimal	ITQ	Optimal	ITQ	Optimal
1	75.9	30.6	399	135	113.4	73.8	434	253
2	29.1	25.9	258	146	53.8	46.6	362	241
3	12.4	20.3	150	145	25.1	30.8	242	218
4	4.2	15.5	61	135	12.6	20.8	154	188
5		11.5		119	4.1	13.7	59	151
6		8.1		98		8.0		102
7		5.0		67		1.5		21
8		0.9		12				
Total	121.6	117.6	868	857	209.0	195.2	1251	1174

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[23] The difference in total harvest between the observed ITQ and simulated ITQ fishery is 1.2% and 12% in 1996 and 1997, respectively.

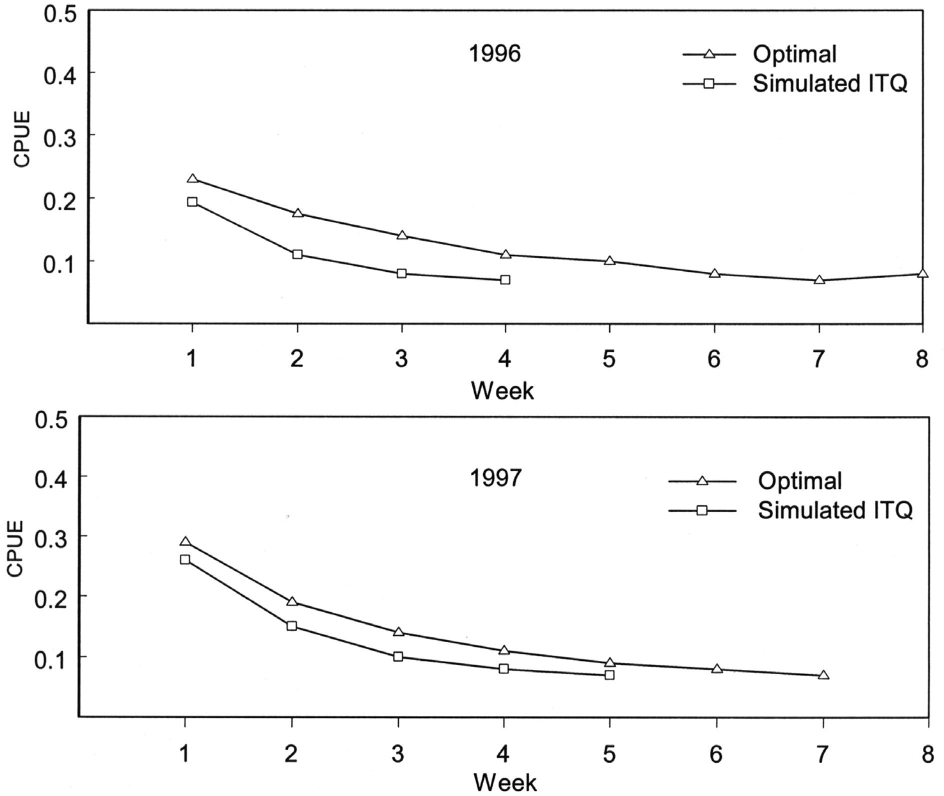

Figure 2. Catch-per-Unit-of-Effort (CPUE) of Scallop Meats (tonnes) under Optimal and Simulated ITQ Management by Week and Year

An examination of the two sets of necessary conditions—equations (2)-(5) for the optimal solution and equations (10)-(13) for the ITQ solution—helps to understand the results of this study. There are several differences between the two sets of conditions that are worth noting. First, the equilibrium price of quota, v^*, is less than or equal to the shadow price of the TAC for the optimal solution, λ^*. This induces individual firms under ITQs to harvest more than is optimal, *ceteris paribus*.[24] As explained above, optimal policy fully accounts for the stock effect; while under ITQ policy, individual firms do not fully account for the stock effect. This can be seen by comparing equation (6) for the optimal case with equation (15) for the ITQ case. The term $\Sigma_i \pi_X^i$ appears in the numerator of the RHS of equation (6), while in equation (15) the comparable term is π_X^i. The stock effect impacts the slope of the two harvest paths differently, resulting in more scallops being harvested early in the fish-

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[24] We expect $v^* \le \lambda^*$ for the following reasons. Since the optimal solution maximizes aggregate profits for the year, the multiplier, λ^*, is the marginal value of another unit of TAC, given an optimal harvest path by all firms. If the harvest path is non-optimal, total profits and the marginal value can only decline. Hence, when the harvest path is non-optimal, the marginal value of the TAC is reduced. Therefore, $v^* \le \lambda_t^i$, for a common TAC.

ing year under ITQs than is optimal. This difference is a principal cause of the race-to-fish under this ITQ management scenario.

Profits are affected by the race-to-fish behavior under the ITQ management scenario. In both years investigated, ITQ profits are estimated to be less than profits from optimal harvest (table 7). Specifically, under ITQ management we estimate that profits were 20.2% and 9.6% less in 1996 and 1997, respectively, than the maximum potential profits.[25] According to this analysis, optimal management would have provided each of the 70 firms with an additional $2,300 and $2,000 profit, on average, in 1996 and 1997, respectively, for two months of work in the fishery. Firms could have worked less over a shorter period of time and earned more under an optimal management arrangement than under the ITQ system currently employed in the fishery.

Are these losses significant? There is no clear answer to this question. First, we have not demonstrated whether the estimates of losses are statistically different from fully efficient outcomes. Second, we have not accounted for the transactions costs of negotiating and implementing arrangements to fully internalize the stock externality. Another of the limitations of this study is the lack of cost data for vessel scallop trips. As a result, the model is simplified to include a simple cubic cost function. While these simplifications may affect the magnitude of the estimated efficiency losses, the qualitative nature of the results would not be affected if cost data were available.[26] It is not known whether our cost estimate is biased up or down.

Concluding Remarks

The analysis in this paper indicates that ITQ management in the New Zealand Southern scallop fishery may not be fully efficient (as predicted by Boyce 1992 for fisheries with an in-season stock externality). It appears that the CSEC had not, as of 1996–97, fully internalized the stock externality in the fishery, with consequent estimated losses ranging from 9.6% to 20.2%, or from $2,000 to $2,300 foregone profits per firm.

In addition to the in-season stock externality, constant ex-vessel prices, which actually prevailed in the Southern scallop fishery, reinforce the race-to-fish. If price varied with landings, the harvest path under ITQ management would be flatter, since

Table 7

Total 1996 and 1997 Industry Profits, Effort, and Harvest: Optimal vs. ITQ Management

	Profit ($1,000s)			Total Effort (Days)		Total Harvest (Tonnes)	
Year	Optimal	ITQ	% Difference	Optimal	ITQ	Optimal	ITQ
1996	797.8	636.6	20.2	857	868	117.8	121.6
1997	1,491.2	1,348.7	9.6	1,174	1,251	195.2	209.0

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[25] Profits are less because, *inter alia*, CPUE is lower under ITQ management (figure 2).

[26] A sensitivity analysis on the cost parameters was conducted. Parameters were increased and decreased by 10% and 20% for both the N-C and optimal model. The percentage differences in profits between the N-C and optimal changed by less than 1% for the range of –20% to +20% in the cost parameters.

fishers would be partially compensated for their extra costs of fishing when the CPUE is low. For reasons that are not clear to us, processors have maintained constant ex-vessel prices throughout the year. While a varying processor price would change the slope of the harvest path, the outcome under ITQ management would remain sub-optimal, however.

The problem in the scallop fishery is similar to the problem commonly experienced in oil fields. When rival firms hold production rights to a common-pool resource, there is a race to produce. This results in overproduction and excessive capitalization that has characterized the US petroleum industry. The principal public policy tool to resolve this problem has been unitization of oil fields (Libecap and Smith 2001). Under unitization, a group of firms share in the risks, costs, and benefits associated with exploration, development, and production of oil. As a result, the rival firms are 'linked by a common incentive to maximize the overall economic value of the field' (Libecap and Smith 2001). Efficient production under unitization occurs when the common-pool resource consists of a single substance with a uniform value. Ideally, unitization would create a 'virtual firm' that would produce scallops at maximum efficiency. The firm would, in effect, function as the sole owner of the resource. Owners of the virtual firm would share the costs and benefits of production, and they would realize maximum profits from the common-pool resource.

We can view the establishment of the CSEC as a voluntary effort to unitize production in the fishery. The formation of the CSEC has allowed scallop quota owners to share in the risks, cost, and benefits of scallop production. It appears, however, that their efforts towards unitization have not fully succeeded in maximizing net benefits from the resource. This finding is consistent with Libecap and Smith (2001) who conclude that firms may adopt organizational arrangements that are imperfect solutions to the common-pool problem. One reason for such 'imperfect' solutions may be the high transactions costs of agreeing to and implementing a policy to fully internalize the stock externality.

Boyce (1992, p.403) argues correctly that property rights should be assigned in ways that take into account the nature of the externalities operating in that fishery. He suggests assigning shares in the profits from the fishery, which, he argues, would force fishermen to internalize the externalities. This could be achieved in the Southern scallop fishery with a complete leaseback of quota to the CSEC such that a centralized decision maker or manager controls the entire TAC. The manager would compute the optimal amounts to harvest each period (*e.g.*, weekly) and hire fishing units to produce the desired amounts. The net returns (profits) from the centralized operation would then be shared among the quota holders according to the quantity of quota each owns.

There are at least two other ways in which the CSEC may be able to stem the race-to-fish behavior and improve returns from the fishery. The key features of a second method are quota dated by period (*e.g.*, weekly) and a market for trades across periods. This method would allow decentralized production decisions. Under this method, the CSEC would distribute the TAC across periods for each quota holder, or initially assign a single date to all of the TAC. If a fluid market exists for trades of dated quota, the quota would be priced and distributed optimally across all periods of the fishing year. Dated quota prices would be higher in the earlier periods when marginal returns are higher, and prices would be lower during the latter periods, reflecting the stock depletion that has occurred.

Finally, a third method would involve assigning territorial rights to firms. Each firm could exclusively harvest an assigned territory at their individual fishing pace. Other firms would not be allowed to fish in another firm's area. The practice would be similar to farming individual plots. The spatial harvesting rights could be made tradable such that the rights are allocated efficiently and the maximum net benefits are realized from the fishery. The spatial rights can be initially auctioned, assigned by lottery, or negotiated. This method may be infeasible or undesirable, however, if the transactions costs of negotiation, monitoring, and enforcing a program of spatial harvesting rights are too great.[27]

In our judgment, there are significant benefits to future research on the management of this and similar fisheries that are subject to stock depletion. One avenue of such research could expand the current model to examine harvesting over several years, in an inter- and intra-year bioeconomic model. A forestry-type model (along the lines of Hartman (1976)) could be applied to focus on when to harvest the scallops within a year and to determine the optimal annual rotation of seeding and harvesting different areas.

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[27] The feasibility of this proposal is also contingent on the scallops not migrating, which apparently is the case here.

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Appendix

Estimation of Cost Parameters

We estimated the set of cost parameters $\boldsymbol{w} = [w_1, w_2, w_3]$ as follows: We first selected an arbitrary set of values for the cost parameters, $\boldsymbol{w}$**,** and solved the Nash-Cournot model twice, once for 1996 and once for 1997. Our General Algebraic Modeling System (GAMS) numerical algorithm solved for the harvest path, q_t^{i*}, that maximizes profits for the *i*-th firm. The specific problem is to:

$$\text{Maximize} \quad \int_0^T \left\{\pi_t^i(q_t^i, X_t) - v_t q_t^i\right\} dt$$

$$\text{S.T.} \quad \dot{X} = G(X_t) - q_t^i - \sum_{j \neq i}^{N-1} q_t^j.$$

For firm i, q_t^{i*} is endogenous, and for the other N-1 firms, q_t^j is exogenous. We chose a starting value for q_t^j and then updated it using the following equation:

$$q_t^j(r+1) = q_t^j(r) + \Delta[q_t^{i*} - q_t^j(r)], \quad r = 1, \ \ldots, \ R,$$

where r is the run or iteration number (R=50) and $\Delta = 0.10$. This resulted in a solution to the Nash-Cournot model such that all firms' harvest rates were within 1% of each other in each period; *i.e.*, such that:

$$[q_t^{i*} - q_t^j(r)] / q_t^{i*} \leq 0.001.$$

The resulting simulated Nash-Cournot harvest paths were compared to the actual observed harvest paths for 1996 and 1997. We calculated the sum of squared differences for each combination of the following parameter values.

Cost Parameter	Range of Values	Intervals
w_1	300 to 1,500	25
w_2	2 to 20	1
w_3	2 to 20	1

From our global grid search, the following set of values for ***w*** had the minimum sum of squared differences for each week and for both years:

Cost Parameter	Estimated Values
W_1	975
W_2	3
W_3	10

The year 1997 accounted for the largest proportion of the squared differences (86%). In other words, the model fit the actual observed harvest rates best for 1996 and not as well for 1997. These cost parameter values were used for calculating both the Nash-Cournot and the optimal solutions reported in the main text.