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How do catch patterns respond to changes in international prices for different species?

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1 INTRODUCTION

Two advantages of Individual Transferable Quota (ITQ) systems are that they provide fishers with flexibility about when to catch fish and more security to invest in equipment that allows more valuable products. If fishers take advantage of these opportunities it should show in their catch behavior. As international prices for certain species and products change over time, catch patterns should also adjust.

The New Zealand system offers an excellent opportunity for empirical work; we have more than 15 years of experience in what by 1998/99 was 257 simultaneous markets involving 42 species. Newell et al. (2002) have assessed these markets empirically finding evidence of an efficient quota market and economically rational behaviour of participants. We build on their work by studying the responsiveness of fishers' harvest patterns to export price shocks.

In many places (e.g. most of the US) there are limits on total catch and fishers race to catch the fish as fast as they can at the beginning of the official season. In NZ, because property rights to harvest the fish are held individually, fishers have the freedom to decide when to catch them. Thus they can increase their revenue by catching at times when international prices are high, and reduce costs by fishing more slowly and when the conditions are more favorable. An example of this can be seen in the Alaskan halibut fishery. Since the introduction in 1994 of an ITQ system the season length has been extended from two 24-hour openings to over 200 days. Giving fishers the flexibility to alter when they harvest, allows them to catch the fish when port prices are higher. This coupled with the elimination of large supply gluts of fresh product, has resulted in increases in price per pound of more than 40% (Casey et al. 1995).

Because in the NZ system each fisher's catch is capped by their quota holdings any harvest they catch earlier in the year reduces the opportunity of catching later in the year when the price could conceivably be higher. Thus, at every point in time the fishers makes harvests decisions based on expected future conditions as well as current conditions. In this paper, we are specifically interested in how responsive fishers are to movements in export prices between years. The greater the flexibility of fishers in their response to price shocks, the more efficient production will be.

We begin with a brief description of the New Zealand ITQ system. We then develop a theoretical model of the optimal response of fishers to patterns and changes in international prices, which is related to that of other depletable resource extraction decisions. We then begin to investigate the relationship with a simple of graphical analysis of price and catch for shellfish species. We follow this with empirical analysis using a panel of data of catch levels for different fish stocks to test fishers' response across a fishing year to changes in international prices. We try and explain variation in harvest timing by including measures of contemporaneous marginal revenue using monthly export price, expectations of the future encapsulated by the lease price, and indications of bindingness, that is how likely fishers' expect the optimal catch to be bound by their quota allocation.

2 OVERVIEW OF THE QMS

An ITQ system sets a total allowable (commercial) catch (TACC) for each fish stock for each year, where regulators generally try to set TACC equal to a sustainable level. The total catch is then allocated among fishers as Individual Transferable Quota (ITQ).

The New Zealand fisheries quota management system was introduced in 1986. The quota is allocated 'in perpetuity' in which case these fishers receive the right to fish that quantity forever. Fishing quotas are tradable but generally only within the same fish stock, and not across regions or species or years. Quota can be leased or sub-leased on an annual basis; the price for which it is leased is thus equal to the future value of the catch allocation until the end of the fishing year. Straker et al. (2002) give a detailed description of the history of the system in New Zealand.

The fishing year generally begins on the 1st of October and finishes on the 30th of September.[1] During this period, it is up to fishers to decide how much or how of their quota allocation they should catch, when they should catch it.

3 MODEL OF FISHERS' BEHAVIOUR

The decision when to harvest fish is somewhat similar to that of allocation of a depletable resource over an infinite time period (or that of an inventory model). In the depletable resource

[1] Rock lobster (CRA) and Packhorse rock lobster (PHC) fishing year begins on April 1st (Clements 2002).

case, the suppliers are constrained by a resource endowment that is exogenously determined, and they must to decide is when it is optimal to extract the resource (Tietenberg, 1996). That is they face the maximization problem:

$$\max_q \pi = \sum_{t=1}^{\infty} \left(p_t(q_t) - c_t \right) q_t \ ,$$

such that

$$\overline{Q} - \sum_{t=1}^{\infty} q_t \geq 0$$

where q_t is the quantity of the resource extracted and sold at time *t*, $p_t(q_t)$ is the marginal output price as a function of that quantity and is endogenous, and c_t is the marginal cost of extracting the resource.

The Lagrangian is given by:

$$L = \sum_{t=1}^{\infty} \left(p_t(q_t) - c_t \right) q_t - \lambda \left(\overline{Q} - \sum_{t=1}^{\infty} q_t \right)$$

The Kuhn-Tucker equations are:

$$\frac{\partial L}{\partial q_t} = p_t(q_t) + \frac{\partial p_t}{\partial q_t} - c_t + \lambda = 0$$

$$\frac{\partial L}{\partial \lambda} = \overline{Q} - \sum_{t=1}^{\infty} q_t \geq 0$$

assuming constant marginal cost. With assumptions about the demand function $p_t(q_t)$ this problem can be solved in terms of the optimal harvest timing. However, in most cases the shadow value, λ, is unobservable in itself and the above conditions must be solved for in an iterative manner.

The depletable resource case is similar to our fishers' timing decision. The resource endowment is analogous to a fisher's quota allocation, a fisher decides when to harvest the fish to maximize current and expected future benefit, although the fisher's endowment is allocated on an annual basis so has a finite time horizon. A key difference however, is that price is for most fisheries is exogenous, especially in the NZ fisheries case. Also, Newell et al. (2002) illustrate that in an ITQ system the shadow value of the resource is equal to the marginal flow of profit from the enterprise, in other words the annual lease price for the fish stock. Thus with an ITQ system we can observe the shadow value.

3.1 A Simple Model

Here we design a simple model of a fisher's harvest timing decision over a fishing year. In our model, we assume that there is one profit-maximizing fisher in the fishery. We assume that our fisher can decide when and how intensively to fish, within the constraint of her quota holdings. All else is held fixed over the fishing year, although factors can change between years. These factors include the boat and its fishing capacity (limited by boat size, type, and time), the abundance and quality of fish (affected by seasonal variation, habitat, weather), and the fisher's quota holdings, in this case equal to the TACC. We also assume that she is only targeting one fish stock. So, during each fishing year our fisher will vary her catch timing in such a way as to maximize her profits.

Our fisher's catch-timing decision will depend on how returns vary across the year. However, this decision will differ depending on product type. Some fish products can be stored for a reasonably indefinite time frame (e.g. frozen and smoked fish), so we will think of them as non-perishable over the fishing year. Non-perishable fish products will be caught at the time when costs of harvest are lowest, which will depend on factors such as biology of the fish and seasonal climate costs, stored and then distributed when prices are highest. Conversely, fresh and live fish products have a significantly lower shelf life. Thus the optimal catch timing for these perishable products will depend both on costs of harvest and on how international prices vary over a fishing year.

Because the amount of fish our fisher can harvest is limited by her quota holdings for the year, her harvest choices at each period in the year are not independent. How much our fisher catches this month will affect how much she can harvest next month and, subsequently, how much she can harvest the month after and the month after that. Thus, her decision will also depend on her expectations of prices and costs for the rest of the year.

We assume, in our model, that export prices are exogenous to our fisher (as is the case in New Zealand). International prices will vary during the year based on exogenous demand. This will likely be made up of a seasonal component to price and price shocks that vary between years.

Costs will vary during the year depending on factors such as fish abundance, weather and fuel costs. Costs associated with weather will be distributed randomly, with a mean that varies seasonally. The mean of the distribution during each month can be given derived from climatological studies. However, we are not interested in the mean, but the deviations from the mean. Weather shocks do not propagate between periods (e.g. if you have lots of southerlies in July, it does not mean you will have lots of southerlies in August or less southerlies in August) but there will be a propensity for certain types of weather patterns during the year (e.g. el nino year or la nina year). Similarly, the costs associated with fish abundance will be distributed randomly, with means (based on biology) that will likely vary seasonally. Fuel prices are unlikely to have seasonality.

Other species' prices and other species and stocks' abundance will also impact on our fisher's catch-timing decision, competing for our fisher's resources. For example, imagine we are calculating the optimal catch timing for hake in quota management area one (HAK1). If in a particular month hake in quota management area seven (HAK7) becomes particularly abundant, the fisher may lower her catch in HAK1 so that she can take advantage of the lower costs of catching HAK7. Or, if the price for hoki in quota management area one (HOK1) is high, she may lower her catch of HAK1 and up her targeting of HOK1. However we do not include these effects in this simple model.

So, mathematically, in a particular month *m*, our fisher faces the optimization problem:

$$\max_{q_m} \pi = (p_m - c_m)q_m + \sum_{n=m+1}^{M}(E[p_n] - E[c_n])q_n^{\#}$$

Such that:

$$\overline{Q} - \sum_{n=1}^{M} q_m \geq 0$$

Where:

$\overline{Q}$ quota allocation for the year

q_m quantity caught in month *m*

p_m output price in month *m* (and $E[p_n]$ are expectations about future months' prices)

$c_m(q_m)$ marginal cost in month *m* (and $E[c_n]$ are expectations about future months' costs)

$q_n^{\#}$ optimal future catch choices based on expected future prices and costs

M number of months in the fishing year

Note that we have not included discounting in this model because of the short time horizon, one-year long.

For simplicity, let us now consider the case where there are only two decision periods in a fishing year. As is common with timing decisions, the final period is a simpler decision than the first as we are armed with certainty about what occurred in the first period eliminating uncertainty. Hence, in this example, we begin with the final period.

In the final period our fisher faces the simple problem:

$$\max_{q_2} (p_2 - c_2)q_2 \quad st \ \overline{Q} - q_1 - q_2 \geq 0 \tag{1}$$

The Lagrangian is given by:

$$L_2 = (p_2 - c_2)q_2 + \lambda_2(\overline{Q} - q_1 - q_2) \tag{2}$$

The Kuhn Tucker equations are given by:

$$\frac{\partial L_2}{\partial q_2^*} = p_2 - c_2 - \frac{\partial c_2}{\partial q_2^*} - \lambda_2 = 0 \tag{3}$$

$$\frac{\partial L_2}{\partial \lambda_2} = \overline{Q} - q_1^* - q_2^* \geq 0 \tag{4}$$

From equation (3), we can see that the Lagrange multiplier, λ_2, is equal to the marginal value of the catch in the final period. In tradable permit markets when quota can be leased, we can observe both the value of the resource, given by the quota price, and the shadow value, given by the lease price for the quota. Quota is leased on a year-by-year basis, so λ_2 will be equal to the quota lease price for the final period.

In an ITQ system, the lease price encapsulates fishers' past, current, and future expectations about returns in the current fishing year. If fishers expect that output prices will be higher than the year before, or input costs lower, then the lease price will be higher than the year before.

How the lease price changes with changes catch levels also gives and indications of how close the catch is to the TACC. As we are in the final period we know whether the TACC will be binding or not. The change in lease price as optimal catch changes will either be zero or infinite. If the quota allocation is non-binding our lease price will not change as optimum catch changes, and this term will be zero. However, if the TACC is binding, any change in catch will lead to an infinite change in lease price.

Let us now consider changes in catch between the same month in concurrent years. Differentiating equation (3) with respect to t gives:

$$\frac{\partial \lambda_2}{\partial q_2^*}\frac{\partial q_2^*}{\partial t} = \frac{\partial}{\partial t}\left[p_2 - c_2 - \frac{\partial c_2}{\partial q_2^*}\right] \qquad (5)$$

where *t* is a fishing year.

From equation (5) we can see that changes in catch between years is related to changes in price and cost, and to changes in lease prices as optimal catch changes. In the non-binding TACC case, the left had side of equation (5) will be zero. Our profit-maximizing fisher will harvest until marginal revenue equals marginal cost, and any change in harvest between years will be due to changes in marginal revenues and costs.

If the quota allocation is expected to be binding, then the change in lease price as optimal catch changes is non-zero so can rewrite equation (5) as:

$$\frac{\partial q_2^*}{\partial t} = \frac{1}{\frac{\partial \lambda_2}{\partial q_2^*}}\left(\frac{\partial}{\partial t}\left[p_2 - c_2 - \frac{\partial c_2}{\partial q_2^*}\right]\right) = 0\,, \qquad (6)$$

In this period, the change in lease price as optimal catch changes is infinite, and the right-hand side of equation (6) will go to zero. Thus, with TACC binding, the optimal catch will not increase between years no matter how price and cost change, and our constraint holds.

Our fisher faces a much more complicated problem in the first period of the fish year. Decisions made about catch in this period will affect catch decisions in the final period, but how exactly they will be affected is uncertain. So our fisher makes her decision based on current conditions and expectations about the future:

$$\max_{q_1} (p_1 - c_1)q_1 + \{E[p_2] - E[c_2]\}q_2^{\#} \tag{7}$$
$$st \;\; \overline{Q} - q_1 \geq 0$$

The Lagrangian is given by:

$$L_1 = (p_1 - c_1)q_1 + \{E[p_2] - E[c_2]\}q_2^{\#} + \lambda_1(\overline{Q} - q_1 - q_2) \tag{8}$$

The Kuhn Tucker equations are:

$$\frac{\partial L_1}{\partial q_1^*} = p_1 - c_1 + \{E[p_2] - E[c_2]\}\frac{\partial q_2^{\#}}{\partial q_1^*} - \frac{\partial E[c_2]}{\partial q_1^*}q_2^{\#} - \lambda_1 = 0 \tag{9}$$

$$\frac{\partial L_1}{\partial \lambda_1} = \overline{Q} - q_1^* \geq 0 \tag{10}$$

We can see from equation (9) that the Lagrange multiplier, λ_1, is once again equal to the expected marginal value of the catch until the end of the year; this is the lease price in the first period.

Differentiating equation (9) with respect to *t*, where *t* is the fishing year, gives:

$$\frac{\partial \lambda_1}{\partial q_1^*}\frac{\partial q_1^*}{\partial t} = \frac{\partial}{\partial t}\left[p_1 - c_1\right] + \frac{\partial}{\partial t}\left[\{E[p_2] - E[c_2]\}\frac{\partial q_2^{\#}}{\partial q_1^*} - \frac{\partial E[c_2]}{\partial q_1^*}q_2^{\#}\right] \tag{11}$$

In this period, expectations of probability of bindingness are likely to matter as the future is uncertain. The higher our fisher's expectation of the probability of her total catch being bound by the TACC, the higher the lease price will be. Thus, in the first period, changes in catch between years are related to changes in price and cost, expectations of changes to marginal revenue, and expectations of bindingness.

As before, if the quota allocation is "completely" non-binding our lease price will not change as optimal catch changes and the left had side of equation (11) will be zero. Our profit-maximizing fisher will harvest until marginal return for the first period and marginal expected returns for final period equals zero. Any change in harvest between years will be due to changes in revenue (including expected revenue) and changes in cost (including expected cost).

If our fisher expects that the TACC will be binding, or at least there is a reasonable probability of bindingness, then lease price in period one will change as optimal catch changes.[2] In this case, we can rewrite equation (11) as:

$$\frac{\partial q_1^*}{\partial t} = \frac{1}{\frac{\partial \lambda_1}{\partial q_1^*}} \left(\underbrace{\frac{\partial}{\partial t}[p_1 - c_1]}_{\substack{\textbf{1} \\ \text{change in} \\ \text{marginal returns}}} + \underbrace{\frac{\partial}{\partial t}\left[\{E[p_2] - E[c_2]\} \frac{\partial q_2^\#}{\partial q_1^*} - \frac{\partial E[c_2]}{\partial q_1^*} q_2^\# \right]}_{\substack{\textbf{2} \\ \text{change in expected} \\ \text{future} \\ \text{marginal returns}}} + \underbrace{\{E[p_2] - E[c_2]\} \frac{\partial^2 q_2^\#}{\partial t \partial q_1^*}}_{\substack{\textbf{3} \\ \text{changes in the} \\ \text{probability of} \\ \text{bindingness}}} \right) \quad (12)$$

In this case, as optimal harvest increases, so does the lease price. As the optimal catch gets increasingly closer to our fisher's quota allocation, lambda will become large and the right-had side of equation will go to zero. As before, with TACC binding, the optimal catch will not change between years, and our constraint will hold.

The first term in the brackets in equation (11) is the change in marginal returns. This means that as marginal returns increase (prices increase or costs decrease) catch will increase. The second term on the right-hand-side of equation (11) will be negative as long as the catch is near-binding. If expected prices increase (or expected costs decrease) in final period, then our fisher will want to increase her future optimal catch and will consequently have to decrease her current optimal catch. Conversely, if expected future prices decrease (or expected costs increase), then our fisher will want to decrease her future optimal catch and can consequently increase her current optimal catch. Thus the trade off between current and future catches, $\frac{\partial q_2^\#}{\partial q_1^*}$, will be less than zero.

The third term on the right-hand-side of equation (11) shows how the trade off between current and future catch changes with time. This is essentially about changes in the fisher's expectation of the probability of bindingness between years. To see this let us redefine our quota constraint equation as:

$$q_1^* + q_2^\# + b = \overline{Q} \quad (13)$$

[2] Newell et al. (2002) defined the effect of bindingness was defined in terms of quota demand.

where b is the residual, the amount of quota our fisher expects will be left over at the end of the fishing year.

As long as fishers have an expectation of a reasonable risk of bindingness existing, there will exist a, non-zero, trade-off between period one and period two with a residual greater than zero. To examine the relationship between the different trade-offs, we can differentiate equation (13) with respect to q_1, to get:

$$\frac{\partial q_2^{\#}}{\partial q_1^{*}} = -\left(1 + \frac{\partial b}{\partial q_1^{*}}\right) \tag{14}$$

If the fishers' expectation of the probability of bindingness were zero, then the trade-off term would be negative one. If the probability of bindingness were one, then the trade-off term would be zero. If we assume that the trade off between the residual and q_1 is linear and the probability of bindingness increases linearly with q_1, then the probability of binding will be equal to the trade-off plus one. Let ρ be the fishers' expectation of the probability of bindingness, then we can rewrite equation (14) as:

$$\frac{\partial q_2^{\#}}{\partial q_1^{*}} = -\rho \tag{15}$$

Differentiate this with respect to time gives:

$$\frac{\partial}{\partial t}\left(\frac{\partial q_2^{\#}}{\partial q_1^{*}}\right) = -\frac{\partial \rho}{\partial t} \tag{16}$$

Thus the final term in equation (12) relates to changes between years of the probability bindingness. If in our current year there is a higher probability of bindingness than the previous year, we would expect that our catch in period one would be smaller than the year before. This term is scaled by the second-period expected revenue. This indicates that the greater our fisher expects the probability of binding to be, the more of her quota allocation she will leave for the second period and this effect will be larger the larger her expected revenue for the second period.

Thus our model suggests that, when we are near-binding, an increase in first period returns between years will lead to an increase in the first-period catch, an increase final period expected returns will lead to a decrease in the first-period catch. Also, an increase in expected bindingness between years will lead to fishers' decreasing their catch in the first period.

4 DATA DESCRIPTION

In this analysis, our unit of observation is at the fish stock level for each fishing month. We use monthly data on export price for 20 species and catch for 50 fish stocks (out of a possible 141), over the 1989 to 1999 fishing years.

Table 1 gives a basic summary of the variables that we use in our regression analysis. Our dependent variable is total monthly catch as a percentage of the TACC. We then weight by TACC. Both the total allowable commercial catch and the actual catch for each fish stock over time are from the New Zealand Ministry of Fisheries. However, because we are only interested in near-binding cases, we only include years and stocks that come within 10% of the TACC.

Table 1: Descriptive statistics for the variables – binding stocks only

Description	Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	Monthly catch as % of TACC	3852	9%	9%	0	106%
Weight	TACC (tonnes)	3852	6,000	30,000	40	2,500,000
Explanatory Variables:						
1. Marginal Revenue	Perishable export price ($/tonne)	3852	3,400	5,500	0	72,000
	Log of perishable price	3852	5.4	7.2	-18.4	11.2
2. Future Expectations	Expected perishable price ($/tonne) – seasonally adjusted	3852	3,200	5,100	0	72,000
	Log of expected perishable price – seasonally adjusted	3852	4.6	8.2	-18.4	11.2
	Lease price ($/tonne)	3153	1,900	4,600	1.4	54,000
	Log of lease price	3153	6.6	1.2	0.3	11
3. Bindingness	Prior year % caught of TACC	3852	0.05	0.27	-0.83	1.7
	Prior year % caught of TACC, squared	3852	0.08	0.26	0	3.0
	Year-to-date % caught of TACC above prior year	3852	0.02	0.16	-1.2	1.5
	Year-to-date % caught of TACC above prior year, squared	3852	0.03	0.10	0	2.3

To create a measure of current revenue we generated an export price variable using free-on-board revenue data from Statistics New Zealand. We adjusted the free-on-board revenue data for inflation using the producers price index, then created a price variable by dividing the revenue for each species by the greenweight tonnage of product. The greenweight tonnage of product was created by multiplying exported tonnages of different product types, such as fillets or lobster tails, by official Ministry of Fisheries conversion factors (Clement & Associates 1997, 1998), and summing these within species. All monetary figures were adjusted for inflation to year 2000 New Zealand dollars.

We only consider the export price for perishable products in this analysis because catch timing is only important for these types of products. Non-perishable products can be harvested at any point during the year, stored as inventory, and sold when the price is highest. Perishable products have to be sold when they are caught, so the timing of catch during the year is critical. To create an all-encompassing perishable-price variable, we averaged the export price for fresh and live products weighting by the total greenweight quantity of each of the products for the year. We used a year invariant weight so that we did not introduce any product demand effects into the price variable. We then seasonally adjusted the price variable by subtracting the average seasonal price from each observation. We omitted 15 stocks because they had no perishable price data; these were the school shark species (SCH), jack mackerel (JMA), and alfonsino (BYX).

Our dependent variable is stationary. Hence, we must ensure that all our explanatory variables are also stationary.[3] We tested perishable export price for each species separately using an Augmented Dickey-Fuller test; a summary table of these results is in the appendix. Of the species that had sufficient number of binding observations, we found that rock lobster (CRA, 9 stocks) had non-stationary price data. This species has a unique market with no close substitutes so inconsistency with other species is not surprising. We omitted these stocks from this analysis. We also tested the price data for serial correlation and found that for most species there was none, suggesting that in general price shocks do not tend to propagate between months.

As measures of expectations of future revenue we use a constructed measure of expected future export prices. To create our expected future export prices, we assumed perfect foresight of fishers and let expected future export price equal actual export price. For every month, we

[3] Actually, we need either stationarity of the right hand side variables or cointegration.

created one expected price variable for the remaining months, using a weighted average of the actual export prices in those remaining months. We used as our weight the average quantity for each month, averaged over all years in our dataset.

Our lease price data came from transactions data on individual leases and sales held by New Zealand Ministry of Fisheries. The transactions dataset contains the price per ton of quotas leased, the relevant fish stock, and the transaction date; prices were available for 151,835 leases. Some of the price data was unreliable because other assets (e.g., boats) were reportedly included in the sale price, or the transaction was not arms-length or was misreported. In all, we omitted 31% of lease that did not represent true market transactions.[4] After adjusting for inflation using the producers' price index, we used the monthly average lease for each fish stock.[5] Our number of observations is further reduced when we include lease price with about a 20% reduction in observations.

As mentioned earlier, we are only interested in fish stocks that are near-binding. In this analysis, we define a fish stock as near-binding when the total catch being within 10% of the TACC. We dropped from our data each year that a stock did not reach this criterion.[6] We then dropped stocks where there was less than 5 years of data in the panel; this equated to 73 stocks.

We also include measures of probability of bindingness in our analysis. Included the previous years catch in same month the previous year, as a percentage of and the catch so far in the current year. For a more detailed description of the data analyzed in this study see Newell *et al*. (2002).

5 METHODOLOGY AND RESULTS

5.1 GRAPHICAL ANALYSIS – SHELLFISH EXAMPLE

Here we begin to investigate the nature of the relationship between catch and price over the fishing year with a simple graphical analysis of the data for shellfish. We can classify each of

[4] For more information see Newell *et al.* (2002)
[5] For more information see Newell *et al.* (2002)
[6] We found that price ceases to have a significant relationship with catch at about 30% binding.

our species as inshore, offshore, or shellfish species. We use shellfish for our example because their catch and price data is, relatively, more homogenous over the group.

Figure 1 Export price and catch by month for shell species

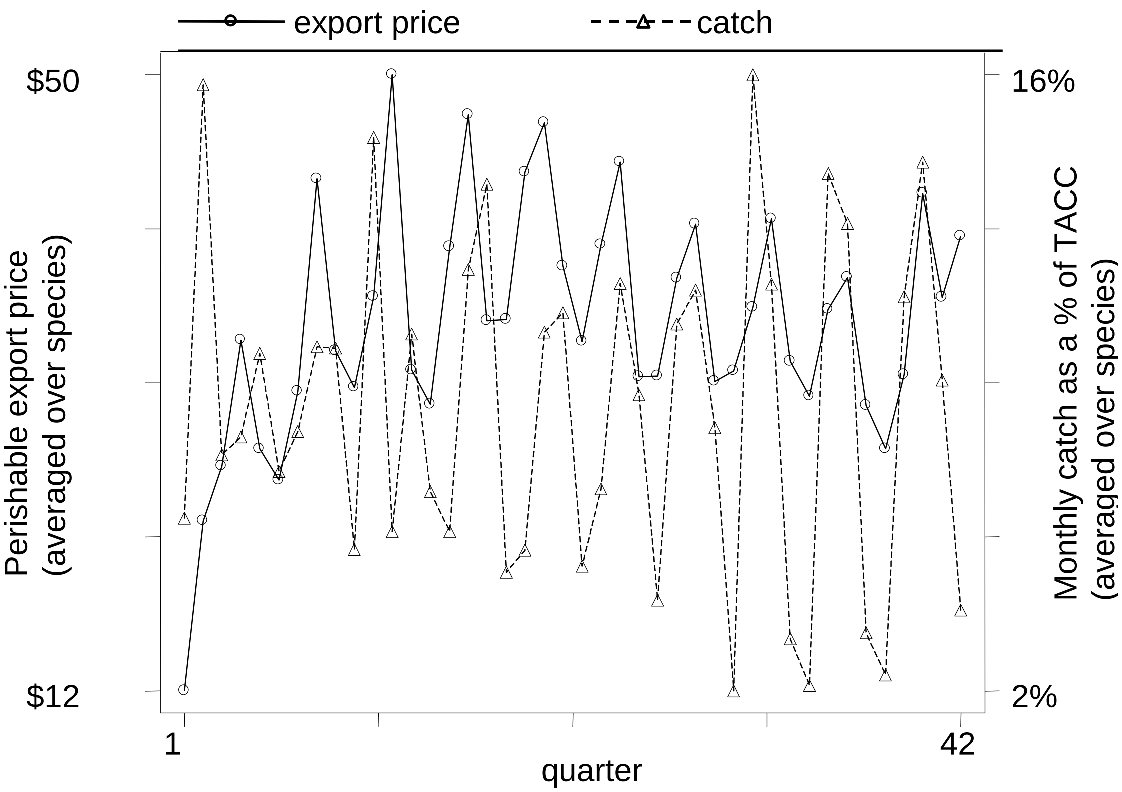
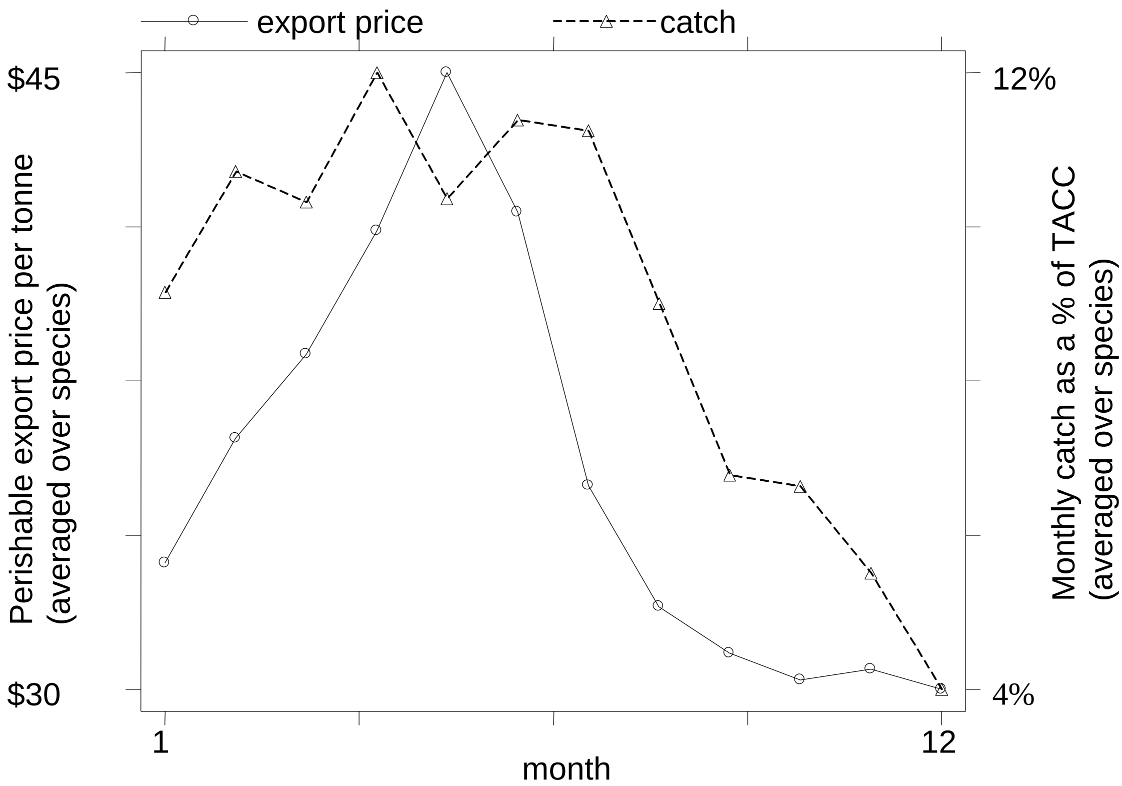


Figure 1 shows the export price and catch for shellfish by month. We can see a general correspondence between price and catch; the peaks and troughs of export price seem to roughly match the peaks and troughs of catch. We can also see quite a regular oscillation in both catch and price indicating that there may be sort of seasonal drivers for both variables.

Figure 2 shows export price and catch for shellfish over an average year. Here the relationship is obvious; both price and catch peak in the first half of the year then drop off during the second half of the year. There is not a perfect correspondence however. Price drops dramatically between the fifth and sixth month and continues this trend, whereas catch lags behind and does not drop dramatically until the seventh to eighth month.

Figure 2 Export price and catch averaged over years for shell species



As we noted in Figure 1, there seems to be a strong seasonal pattern in both price and catch. It is possible that seasonality in shellfish abundance in the Northern Hemisphere may be driving the regular seasonal oscillations that we can see in the price data. Seasonal abundance should be negatively correlated with price, but abundance in catch in the Northern and Southern Hemispheres is also likely to be negatively correlated. Thus, catch may be responding to Northern hemisphere price signals, hence the seasonality, or it may be driver by the biological seasonality. We cannot tell if it is the price is driving catch patterns or if it is just a biological coincidence?

We can remove any seasonal patterns by taking can take the difference between years for every month. Then, we can look at the correspondence between price and catch changes without the seasonal biological drivers, to see if price and catch move together.

Let us define change in price between months of consecutive years as:

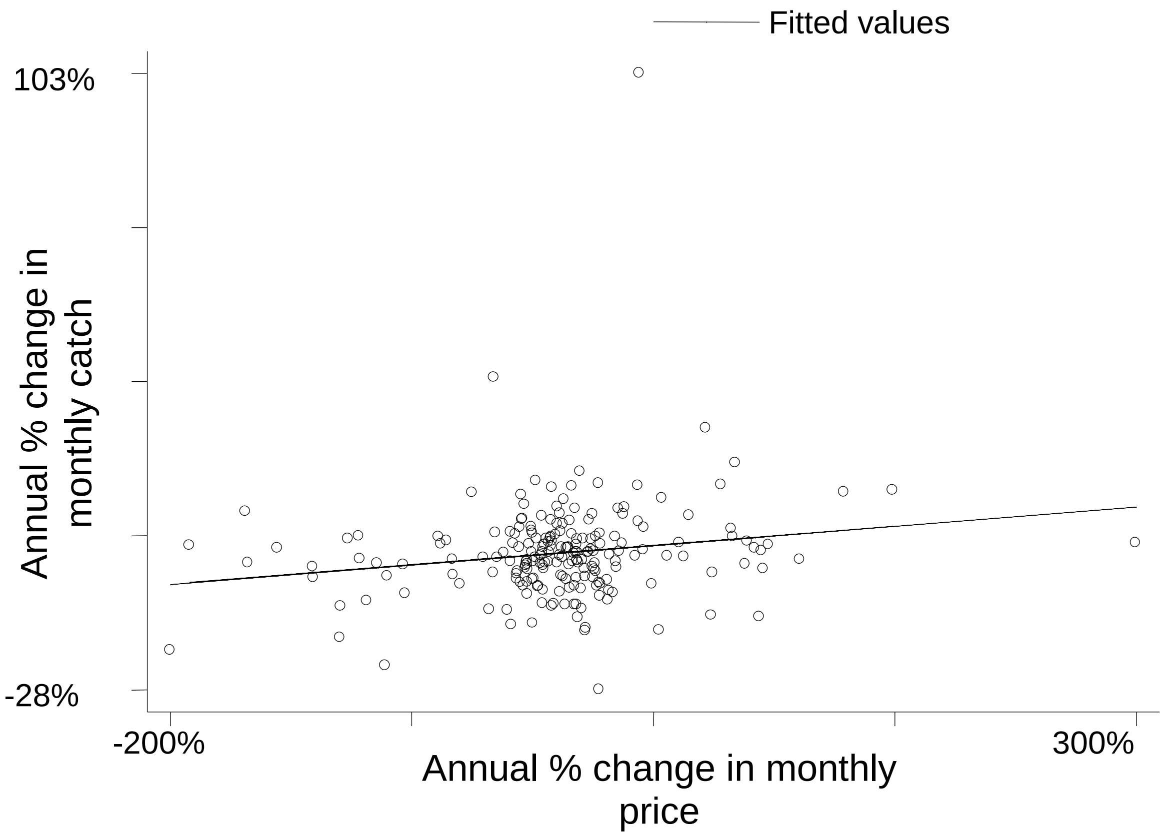
$$\Delta p = \left(\frac{p_{year=t,month=s}}{\frac{1}{12}\sum_{month=1}^{12} p_{year=t,month}} \right) - \left(\frac{p_{year=t-1,month=s}}{\frac{1}{12}\sum_{month=1}^{12} p_{year=t-1,month}} \right)$$

and change in catch between months of consecutive years as:

$$\Delta c = \frac{catch_{year=t,month=s}}{TACC_{year=t}} - \frac{catch_{year=t-1,month=s}}{TACC_{year=t-1}}$$

Figure 3 shows these price and catch changes plotted against each other for every shellfish species. In this figure we can see a slightly positive relationship (shown by the solid line), indicating that price and catch do, on average, move together.

Figure 3 Change in export price vs. change in catch



There is much deviation about the average line. In this figure, we are not accounting for differences in costs, biology, and price between species and stocks. When we include offshore and inshore species the relationship becomes even less clear. Biology, costs and price timing all confound each other. To pick up any significant relationship between price and catch we need to control for these differences.

5.2 REGRESSION ANALYSIS

To further investigate the price and catch relationship we carry out a panel ordinary least square regression, weighted by TACC.[7] In the section 3.1, we draw the hypotheses that changes in catch between years in a particular month are related positively to increases in the current month's price, decreases in expected future prices, and negatively to the probability of bindingness. Equation (17) sets up this relationship in a testable form:

$$q_{imt} = \beta_1 \log(p_{imt}) + \beta_2 \log(E[p_{imt}]) + \beta_3 \log(\lambda_{imt}) + \beta_4 \left(\frac{\sum_{n=1}^{12} q_{nt-1}}{\overline{Q}_{t-1}} \right) + \beta_5 \left(\frac{\sum_{n=1}^{12} q_{nt-1}}{\overline{Q}_{t-1}} \right) \times \log(p_{imt})$$
$$+ \beta_6 \left(\frac{\sum_{n=1}^{m-1} q_{nt}}{\overline{Q}_t} - \frac{\sum_{n=1}^{m-1} q_{nt-1}}{\overline{Q}_{t-1}} \right) + \beta_7 \left(\frac{\sum_{n=1}^{12} q_{nt-1}}{\overline{Q}_{t-1}} \right)^2 + \beta_8 \left(\frac{\sum_{n=1}^{m-1} q_{nt}}{\overline{Q}_t} - \frac{\sum_{n=1}^{m-1} q_{nt-1}}{\overline{Q}_{t-1}} \right)^2 \qquad (17)$$
$$+ \alpha_0 + \alpha_{1i} + \alpha_{2m} + \alpha_{3y} + \alpha_{4im}$$

Where q is the monthly catch as a % of the TACC, p is the monthly perishable export price, $E[p_{imt}]$ is the expected future perishable export price, λ is the monthly lease price, α_0 is a constant, α_1 are stock fixed effects, α_2 are month fixed effects for each month in the year, α_3 are year fixed effects, and α_4 are stock specific month effects, *t* is the year and *m* is the month.

We include the log of the export price to capture contemporaneous price effects and the log of our expected price variable to capture any future price effects. We base the probability of binding on the closeness to binding in the previous year; we include previous years catch as a percentage of the TACC interacted with our price variable as a measure of this. We expect that the probability of binding will alter the magnitude of catch response to a price shock. Including the interaction term means we must also include the previous years catch as in the regression. This term will also capture any serial correlation in catch between years. The third to last term is cumulative lagged catch during the current year relative to the same point last year, and will capture the changes in probability of binding between years.

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We also include the lease price, primarily to capture expectations of the future. As the lease price encompasses information on current and future prices costs as well as expectation of binding there may be some correlation between it and the other explanatory variables.

We weight by TACC to reflect accuracy in the catch data, as a stock with a small TACC is likely to lead to idiosyncratic results. All variables in our regression equation are percentage values, taking natural logarithms to achieve this where the variable is not already a percentage or a rate.

In our simple theory developed in section 3, we allowed our dependent variable to be bounded above by one. However, in reality catch as a percentage of TACC is not bounded by one; we have some observations where it exceeds one. It is therefore possible for fishers to exceed the TACC, it just becomes increasingly costly to do so. Because of this, we assume a linear relationship (and estimate using OLS) but include as explanatory variables last year's catch as percentage of TACC and its square, and a catch-up term, this year's cumulative catch relative to the cumulative catch in the prior year.

We do not explicitly control for contemporaneous costs. Instead we include in our analysis fixed effects for stocks, years, months, and stock by month. These fixed effects will pick cost variations, controlling implicitly for costs. Including fixed effects for stocks captures differences in catch associated with different species; we are implicitly controlling for stock specific costs that are constant over time (e.g. technology differences for catching different stocks). Year fixed effects capture consistent trends in catch over the 10 years, controlling for decreases or increases in stock-average costs over the years (e.g. general trends in fuel prices) and trends in bindingness (e.g. have stocks on average move closer or further aware from binding). When we include month fixed effects, that is 12 dummies for each of the months of the fishing year, we are controlling for costs that vary over the year such as costs associated with common seasonality in fish abundance and or those associated with seasonal weather effects. We also include stock specific months to allow a different average biological pattern for stocks over a year for each stock.

5.2.2 Results

Table 1 shows our regression results. In general, our results are consistent with our model hypotheses.

Table 2 Regression Results

Term	Dependent variable:	(1) Catch % TACC	(2) Catch % TACC	(3) Catch % TACC	(4) Catch % TACC
1. Marginal returns:					
Current prices	Log of perishable export price	7.3e-04*** (1.4e-04)	6.9e-04*** (1.4e-04)	8.0e-04*** (1.5e-04)	7.9e-04*** (1.6e-04)
2. Future expectations					
Future price expectations	Log of expected perishable price			-8.3e-04 (5.5e-04)	-8.3e-04 (6.1e-04)
Future returns expectations	Log of lease price				-3.6e-03** (1.5e-03)
3. Bindingness					
	Prior year % caught of TACC		1.7e-02*** (6.1e-03)		1.7e-02** (6.9e-03)
	Prior year % caught of TACC * Log of perishable export price		-2.2e-03*** (5.6e-04)		-2.8e-03*** (6.1e-04)
	Prior year % caught of TACC, squared		3.6e-02*** (1.0e-02)		4.0e-02*** (1.2e-02)
	Year-to-date % caught of TACC above prior year		2.1e-02** (8.5e-03)		3.3e-02*** (1.0e-02)
	Year-to-date % caught of TACC above prior year, squared		-4.8e-02* (2.5e-02)		-7.3e-02** (3.2e-02)
Fixed effects					
Contemporaneous costs	Month	*Jointly Significant*			
	Month*Fish stock	*Jointly Significant*			
	Fish stock	*Jointly Significant*			
Species-averaged trends in bindingness	Year	*Jointly Significant*			
	Constant	7.9e-02*** (1.4e-02)	7.4e-02*** (1.4e-02)	8.4e-02*** (1.4e-02)	1.0e-01*** (1.8e-02)
	Observations	3852	3852	3852	3153
	R-squared	0.88	0.88	0.88	0.89

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

We find a positive and significant relationship between changes in catch and changes in price (regression 1). Price and catch move together, controlling for fixed effects. Thus, the magnitude of this relationship is very robust as it is maintained as we include more controls (moving from regression 1-4). This suggests that fishers are able to respond to contemporaneous international price shocks.

The relationship between catch and future price is insignificant. We saw in section 4 that there were few species that had serially correlated price data. We still include the price expectation terms because fishers' may have had some better way of anticipating price shocks in an accurate way. However, this result suggests that what expectations of future prices they do have do not correlate with actual future prices; thus price shocks are a surprise.

Fishers' expectations may instead be adaptive, i.e. they may base their expectations this year on what happened this time last year. If this were the case then shocks would not propagate between months. This means that any price expectation effect would be picked up by the stock specific month fixed effects, leaving our future price variable insignificant. We tested for this by regressing expected price against catch without the month specific fixed effects and found that expected price was significant in this case.

We find a significant negative relationship between lease price and catch; as the lease price increases, catch decreases. This variable is telling us about expectations fishers' expectations about the remainder of the fishing year. If fishers expect future returns to rise relative to what they were the year before, the lease price will increase relative to what it was the year before. Thus, as expected future marginal returns rise, current catch decreases. Note, however, because of the possible correlation between current prices and lease prices, this effect will be less negative, because it will be capturing some of the variation due to current returns.

Our binding variables are all significant. We can see that the previous years bindingness (prior year % caught of TACC * log of export price) is negative. This suggests that the higher the fishers' expectation of the probability of bindingness the lower your catch response to a price shock; agreeing with our original hypothesis with respect to the probability of bindingness.

The impact of the "prior year % caught of TACC" variable by itself, and its square, is positive. This is simply showing that if the fishers are generally becoming closer to their overall target, they are also likely to be close to their target this year.

To draw other inferences about the impact of bindingness on catch, however, we must look at the marginal effects. Table 3 shows the marginal effects, showing the effect on catch of a one standard deviation shift in each explanatory variable relative to one standard deviation shift in catch.

Table 3 Marginal Effects

Variable	First order marginal effect (% change catch)
Log price	6%
Log lease price	-4.9%
Relative cumulative (lagged) catch	-1%
Prior year % caught of TACC	-1.3%

Overall, the effect of the prior years catch is negative; the more binding you were last year the less you will catch this year.

If so far this year you have caught more than last year, then you are more likely to be binding (and vice versa). We can see that catch and relative cumulative catch are negatively related. Thus if you are more likely to be binding this year, the lower your catch in the current month will be compared to the year before. This agrees with our original hypothesis that the higher the probability of bindingness, the more fishers' will lower their current catch, leaving some for later in the year.

The fixed effects included are jointly significant in all the regressions. Notice that we omit a stock by year interaction in the results given. This is because when we included a species by year interaction the F-statistic was lower than when only controlling for the species and year fixed effects (shown in Table 4), indicating that including the interaction does not add any additional explanatory power. We would expect explanatory power from this interaction if catch relative to the TACC had a different year trend over time for different stocks. For example, if some stocks were moving towards binding over the years and others were binding all along. In this analysis we only included fish stocks that have been consistently close to binding over the entire 10-year period, so any year trend would not be stock specific.

Table 4 F statistics

F Statistic	Fixed effects included:
33	Year, Species
26	Year by Species, Species

25	Time, Species
15	Time by Species, Species

6 CONCLUSION

The ITQ system allows fishers the flexibility to choose when to fish, by reducing the race for fish by giving each fisher an individual property right. Giving the decision of when to fish to the fishers, allows fishers to increase their revenue by fishing when international prices are high.

Overall, we find that in the New Zealand ITQ system, fishers are able to take advantage of the flexibility the system provides. Fishers do respond to contemporaneous price shocks and thus are able to increase their revenue. However, we find that fishers do not accurately anticipate future shocks; they are not good predictors of whether future prices this year will be higher than those last year. Thus their ability to increase their revenue through timing decisions that involve shocks later in the year is limited. We do find, however, that if fishers expect that there is a high probability that TACC will be unusually binding this year they are likely to reduce their catch in early months, leaving more in reserve for the remainder of the year.

The most obvious next step would be to explicitly include information on costs in a similar analysis. These include information on weather, fuel, and the opportunity cost related to the export price for other similar species. Including costs would allow us to look for differences in spatial effects, both between species, between stocks, and possibly within stocks. Shocks to costs may have different distributional effects. Although the ITQ system may eliminate the race for fish at a large scale it may not at a localized level. For example, increases in fuel prices may make populations that are further away less attractive, and may result in fishers traveling shorter distances to fish. This has the potential to cause localized "races for fish" within quota management areas as fishers race to catch the closer species first. The existence of a spatial race would be potentially by particularly detrimental on fish populations that are fairly stationary, and would suggest special management needs for such species.

7 REFERENCES

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A. APPENDIX

Table 5 Species included in the New Zealand Individual Quota System

Species	Code	Year entered quota system	Number of 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
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
Ling	LIN	1986	7	Offshore
Blue moki	MOK	1986	4	Inshore

Oreo	OEO	1986	4	Offshore
Orange roughy	ORH	1986	7	Offshore
Red cod	RCO	1986	4	Inshore
School shark	SCH	1986	7	Inshore
Gemfish	SKI	1986	4	Offshore
Snapper	SNA	1986	5	Inshore
Rig	SPO	1986	5	Inshore
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
Jack mackerel	JMA	1987	3	Offshore
Paua (abalone)	PAU	1987	10	Shellfish
Squid	SQU	1987	3	Offshore
Rock lobster	CRA	1990	9	Shellfish
Packhorse rock lobster	PHC	1990	1	Shellfish
Scallop	SCA	1992	2	Shellfish
Oyster	OYS	1996	2	Shellfish

Table 6 Timeseries properties of price by species

Species	Included in analysis	Stationary? (Augmented Dickey-Fuller test)	Significant number of lags: (Durbin-Watson h test for serial correlation)	Data Notes
BAR	Yes	Yes	0	
BCO	Yes	Yes	0	
BNS	Yes	Yes	0	
BYX	No	-	-	No perishable price
CRA	No	No	-	Unique market
ELE	Yes	Yes	0	
FLA	Yes	Yes	0	
GMU	Yes	Yes	1	
GUR	Yes	Yes	0	
HAK	Yes	Yes	1	
HOK	Yes	Yes	0	
JDO	Yes	Yes	-	Insufficient binding observations
JMA	No	-	-	No perishable price
LIN	Yes	Yes	0	
MOK	Yes	Yes	0	
OEO	Yes	Yes	0	
ORH	Yes	Yes	2	Unique market
PAU	Yes	Yes	0	
PHC	No	No	-	Insufficient binding observations
RCO	Yes	Yes	1	
SCA	Yes	Yes	1	
SCH	No	-	-	No perishable price
SKI	Yes	Yes	0	
SNA	Yes	Yes	0	
SPO	Yes	Yes	0	
SQU	Yes	Yes	0	
SWA	Yes	Yes	0	
TAR	Yes	Yes	1	

TRE	Yes	Yes	2	
WAR	Yes	Yes	0	