THE STABILITY OF RENT MAXIMIZATION IN THE WESTERN AND CENTRAL PACIFIC FISHERY*

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ABSTRACT

The potential for achieving sustainable and efficient harvesting of three species of migratory tuna in the Western and Central Pacific Ocean is examined. The stocks reside in exclusive economic zones (mainly those of Pacific island countries) and in the high seas. Most harvesting is carried out by distant water fishing nations, including the USA, Japan, Taiwan, China and Korea. Problems of achieving sustainability and efficiency in the harvesting of the stocks by disparate countries are made more difficult due to changes in the harvesting levels of one fleet affecting the rents of another fleet through changes in the age distribution of stock. These types of problem are under review by the Western and Central Pacific Fisheries Commission. Results from an age-structured steady-state bioeconomic model are used to show: the changes in fleet rents and catches of tuna if all fleets form a cooperative grand coalition to deploy fishing effort to maximize rents over the region; the likely non-stability of the grand coalition; and the inferior Nash Equilibria outcomes if fleets fish non-cooperatively to maximize their own rents.

Key words: Bioeconomic modelling, Game theory, Optimisation, Migratory tuna

INTRODUCTION

The tuna fishery in the Western and Central Pacific is the world’s largest, supplying about half of the world’s tuna supplies [1]. It is conducted by fleets from many distant water and Pacific island nations. Traditionally fishing in this area was mainly by the Japanese, using longline or pole and line gear. Over time additional nations adopted longlining in the area, especially Taiwan and Korea. Furthermore, from the 1970s on, purse seine fishing increased rapidly. Purse seining is carried out by a variety of nations: the United States, Indonesia, the Philippines, and the Pacific island nations, in addition to those involved in longlining. The Pacific island nations also do some longlining.

In 2004 the Western and Central Pacific Fisheries Commission (WCPFC) was established following the United Nations Fish Stocks Agreement (UNFSA) of 1995 to overcome the problems which arise in fisheries straddling exclusive zones and the high seas. The Commission oversees the implementation of the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. The convention advocates measures to ensure long-term sustainability of fish stocks in the Convention Area and their optimum utilisation. A current area of concern arises from the Commission’s Scientific Committee noting that biological overfishing of bigeye and yellowfin is now likely to be occurring [2].

An additional aspect of the possible economic overexploitation of the tuna stocks in the Western and Central Pacific is the effect of purse seining tuna catches on the longline catches. Purse seining is carried out primarily for skipjack tuna, but some yellowfin and bigeye tuna also get entangled in the seines. The bycatches of yellowfin and bigeye tuna have a detrimental effect on the longline catches because the
purse seiners primarily take young tuna which would otherwise have increased in unit weight and become available to the longline fleets, fetching higher prices. The question therefore arises whether reducing the purse seine catch or otherwise reducing the bycatches of bigeye and yellowfin would be advisable. Do these fish represent a higher value if left for the longline fleets, or is it economically advantageous to allow them to be taken by the purse seine fleets?

In this paper we shall look at the interaction between the purse seine fleets and the longline fleets. Would it make sense, from an overall point of view, to reduce the former for the benefit of the latter? This is a part of the larger issue of what rate and pattern of exploitation would maximize the combined economic rents of the fleets: which fleets should participate in the fisheries and on what scales? Given that such a solution would most likely entail some fleets fishing less than presently or not at all, could such a solution be implemented by some kind of rent sharing? And if not, or if a rent-maximizing solution is unlikely to be implemented for other reasons, what kind of outcome can we expect when all national fleets compete against each other? These are the types of questions being raised recently by the WCPFC (see [3]). The Commission views the consensus-based setting of a total allowable catch (TAC), with national and high seas allocations, as the most effective long-term option for conservation and management of the fish stocks. We compare nations’ recent catches with those estimated to return maximum total rents on a long-term sustainable basis. The potential for these catches to be accepted as quotas and adopted by a consensus of participating nations is examined.

We shall consider three stocks that are likely to be, to a greater or lesser degree, mixed in the fishing areas and hence jointly caught by the fishing fleets. These are bigeye, yellowfin and skipjack. All three are found mainly in the tropical areas between 10 degrees north and south of the equator. Albacore tuna, also fished in the Western and Central Pacific, is mainly found further away from the equator and therefore less likely to be included in the joint catches of the other three species.

The question of maximizing rents in the Western and Central Pacific tuna fishery has been analysed before. Bertignac et al. [4] used a detailed age-structured model with a number of different fleets to look into the effects of changing the size of different fleets. They calculated the rent gains versus losses from changing fishing effort for the different fleets and the interaction between different fleets for the different stocks involved. Kompas and Che [5] used a disaggregated, stochastic bioeconomic model to find optimal effort for the three stocks considered in this paper. The emphasis here is somewhat different; we look not just at the rent-maximizing solution, but also at whether, under ideal circumstances, a grand rent-maximizing coalition is likely to be stable, and what would be the outcome of competition among the fleets of the various nations participating in the fishery. For this reason we employ a simpler model of the tuna stocks than the one used by Bertignac et al. [4]. When possible, data from the disaggregated model are used in the much simpler and highly aggregated model, but some of the model changes lead to requirements for different parameter estimates. The way in which some parameters were tuned to obtain good model fits between modelled and actual catches is described below.

THE MODEL

The model employed is a yield-per-recruit model. Each age interval is one quarter year. Growth, natural mortality, availability, and gear selectivity parameters were taken from the WCPOBTM-model [6].

Since the 1990s most of the skipjack has been taken by purse seiners. This is true to a lesser extent for yellowfin, of which substantial catches are taken by longlines. Most of the bigeye is also taken by longliners, but there is a non-negligible catch by purse seiners which rose sharply in 1997 due to increased use of fish aggregating devices and has stayed high since, albeit with fluctuations. The use of pole and line gear is in decline.
For modelling purposes, a steady state age-structured stock system is simulated as follows. Stock in each age category is reduced over each quarterly fishing season by natural mortality, which is exogenously determined, and fishing mortality, which is determined by the harvesting efforts of $K = 14$ fleets. Stock in the first age category is replenished in each quarter at a constant rate of recruitment. This is a convenient abstraction from biological models that treat recruitment as a function of adult stock biomass. As numbers decline in older age categories, the effect on biomass is to some degree offset by the increasing weight of individual fish.

For each stock species $s$, the population $x_{i,s}$ in each quarterly age category $i$ from 1 to $I_s$ is:

$$
x_{i,s} = x_{i,s} - \frac{1}{I_s - 1} \sum_{i=2}^{I_s} e^{-f_{i,s-1}} m_{i,s}
$$

$$
x_{I_s,s} = (x_{I_s,s} + x_{1,s}) e^{-f_{I_s,s}}
$$

(1)

where $x_{i,s}$ is recruitment numbers into the first age category, $m_{i,s}$ is the quarterly instantaneous rate of natural mortality, and $f_{i,s} = \sum_{k=1}^{14} q_{s,k} v_{i,s,k} E_k$ is fishing mortality with $q_{s,k}$ and $v_{i,s,k}$ the availability and selectivity coefficients respectively for fleet $k$, and $E_k$ is quarterly fishing effort for fleet $k$.

Catch for species $s$ accumulates from each age category over the season as a function of the standing biomass, which in turn depends on natural and fishing mortality, and individual growth, as follows:

$$
c_s = \sum_{i=1}^{I_s} f_{i,s} x_{i,s} w_{i,s} \int_{0}^{1} e^{-f_{i,s-1} - m_{i,s}'} dt
$$

$$
= \sum_{i=1}^{I_s} f_{i,s} x_{i,s} w_{i,s} (1 - e^{-f_{i,s-1}}) / (f_{i,s} + m_{i,s})
$$

(2)

where $w_{i,s}$ is the average unit catch weight of fish in the $i$-th age category.

The model is not dynamic in that the decision variables $E_k$ remain the same for all quarterly time periods. However, this enables the impact of changes in $E_k$ on steady state stocks, catches and rents to be determined.

The effort vector $E_k$, to be used as a reference solution, is meant to reflect the recent status of the fleets and is estimated by solving the following problem:

$$
\min_{E_1, \ldots, E_{14}} \sum_{s=1}^{14} \sum_{k=1}^{3} (\hat{c}_{s,k} (E_1, \ldots, E_K) - \bar{c}_{s,k})^2
$$

(3)

where $\hat{c}_{s,k}$ is the share of the total catch of species $s$ taken by fleet $k$, as produced by the model (Eqs.1 and 2), and $\bar{c}_{s,k}$ is the average annual catch share 2001-2005. In this model there are $K = 14$ fishing fleets: six purse seine fleets; five longline fleets; and three contrived fleets. Each of the contrived fleets targets a single species (bigeye, yellowfin or skipjack) to account for catches over and above those modelled for the 11 other fleets. The latter three fleets are termed ‘Other fleets’ or ‘Others’ in result tables.
Taking the age-specific weight \( w_{i,s} \), natural mortality \( m_{i,s} \), availability \( q_{i,k} \) and selectivity \( s_{i,s,k} \) used in the WCPOBTM model, we define a reference solution by finding the fleet effort levels \( E_k \) that best reproduce the average catch shares taken over the reference period 2001-2005, according to (3). In this exercise it is assumed that the recruitment to all three stocks is the same. Thereafter the initial recruitment to each stock \( x_{r,s} \) was set so that the catch produced by the model equalled the average catch 2001-2005.

**ECONOMIC ANALYSIS**

For economic analysis, it is necessary to determine the cost per unit of effort for the different fleets. The present highly aggregated model is not directly comparable to the much more detailed WCPOBTM model so cost parameters from that model cannot be used directly. As a base reference case we set the cost per unit of effort so as to produce rents equal to 10 percent of revenue for all fleets in the reference solution, the cost per unit of effort being constant. The WCPOBTM model produces rents from nil to over 30 percent of revenues, varying across fleets. Later we will compare these with the rents of the fleets obtained for a non-cooperative Nash equilibrium solution for seven country groupings of the fleets, to gauge whether or not these cost assumptions are realistic.

As to prices, we rely on two alternative assumptions. First, fish prices are assumed to be fixed and insensitive to catch volumes and identical to the ones used in the reference solution discussed below. These prices are based on the average prices 2001-2004 [1]. For the longline fleets we have used the price of fresh tuna. Fresh longline tuna is the most highly priced tuna product and also the most profitable one. Using this price for all longline caught tuna will exaggerate the advantage of the longline fleets, partly because not all longline caught tuna can be sold fresh, and partly because increased catches of longline tuna are likely to lead to lower prices. Longline tuna mainly goes to the Japanese sashimi market, and it has been shown that the price declines as more fish is supplied Bertignac et al., [4].

The sensitivity of prices of various tuna products to changes in supplies from the Forum Fisheries Agency Area (which covers Pacific Island Countries and their Exclusive Economic Zones) has been studied by Reid et al. [7]. We shall investigate how our results are affected by the price changes that would result from changed supplies from the West Central Pacific, using price flexibilities reported in Reid et al. [7].

**Maximizing rents**

Table 2 compares the solution that maximizes aggregate rents with the reference solution. In the rent-maximizing exercise, the fishing mortalities applied by fleets other than purse seining and longlining are held constant at the same level as in the reference solution. They are thus not a part of the rent maximization. The aggregate rent is the maximum, undiscounted, sustainable rent, as the model is a static yield-per-recruit model that compares different long term equilibrium solutions, but including the dynamics between age groups. With fixed prices, the aggregate rent in the fishery (not shown) more than doubles, compared with the reference solution. The purse seine fleets are virtually eliminated while the fishing mortality for the longline fleets almost doubles for yellowfin and remains virtually unchanged for bigeye. Because the virtual disappearance of the purse seine fleets leaves more fish to be taken by the longline fleets the longline catches of yellowfin more than double, and catches of bigeye increase by almost 40 percent. The rent grows almost fivefold for the longline fleets. As a percent of revenue, rent is between 20 and 30 percent of revenue both for the purse seine and the longline fleets.
Table 1. Comparison of Rent-Maximizing and Reference Solutions. Catch is in thousand tonnes and rent in million US$. Numbers in parentheses refer to the case with volume-dependent prices.

<table>
<thead>
<tr>
<th>Species</th>
<th>Purse seine</th>
<th>Longline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference</td>
<td>Rent max</td>
</tr>
<tr>
<td></td>
<td>$f$</td>
<td>Change (%)</td>
</tr>
<tr>
<td>Bigeye</td>
<td>0.06081</td>
<td>0.00028</td>
</tr>
<tr>
<td></td>
<td>(0.00569)</td>
<td>(-90.6)</td>
</tr>
<tr>
<td>Yellowfin</td>
<td>0.02478</td>
<td>0.00042</td>
</tr>
<tr>
<td></td>
<td>(0.00840)</td>
<td>(-66.1)</td>
</tr>
<tr>
<td>Skipjack</td>
<td>0.03138</td>
<td>0.00072</td>
</tr>
<tr>
<td></td>
<td>(0.01442)</td>
<td>(-54.1)</td>
</tr>
</tbody>
</table>

| | Catch | Change (%) | | Catch | Change (%) |
| Bigeye | 29.0 | 0.2 | -99.4 | 87.7 | 119.8 | 36.6 |
| | (3.9) | (-86.6) | | (88.6) | (1.0) |
| Yellowfin | 199.8 | 4.0 | -98.0 | 88.9 | 203.3 | 128.7 |
| | (80.1) | (-59.9) | | (112.0) | (26.0) |
| Skipjack | 1251.7 | 33.4 | -97.3 | | 0 | 0 |
| | (626.6) | (-49.9) | |

| | Rent | Change (%) | | Rent | Change (%) |
| All | 123.0 | 7.7 | -94.1 | 114.7 | 562.5 | 390.3 |
| | (260.0) | (111.4) | | (382.6) | (233.5) |

| | Rent as % of revenue | | Rent as % of revenue |
| All | 10 | 23.0 | -94.1 | 10 | 27.0 | 390.3 |
| | (35.3) | (30.0) | | |

<table>
<thead>
<tr>
<th>Fleets active</th>
<th>All Taiwan</th>
<th>All Taiwan, Others</th>
</tr>
</thead>
</table>

Taking price sensitivity into account gives radically different results. As stated above, we have relied on the results in Reid et al. [7]. They calculated the price flexibilities for tuna products from the West Central Pacific, taking into account the elasticity of demand in different markets and the share of tuna from this area in these markets. They found a price flexibility equal to -0.1 for fresh and frozen tuna, which would apply to the longline fleet in our case, and -0.5 for light meat canned tuna, for which the purse seine fleet supplies raw material. Applying these price flexibilities produces the results shown in parentheses in Table 1. We see that the effort (fishing mortality produced) by the purse seine fleet is reduced by much less in this case. The catches of yellowfin and skipjack by the purse seine fleets are roughly halved while the catches of the longline fleet increase only moderately. These results are similar to those obtained by Bertignac et al. [4] and Kompas and Che [5] who took price sensitivity to catch volumes into account.

Solutions to the rent maximisation problems posed above would satisfy the requirements of the WCPFC in being sustainable and according with optimum utilisation (perhaps best interpreted as ‘economically efficient’), to the extent that all fishing countries have an equal right to fish anywhere in the ocean. This is not true, for example, if tuna stocks reside in the EEZs of coastal fishing countries for part of the year and migrate or straddle between EEZs, or between EEZs and the high seas. Those countries with tuna passing through their EEZs can ordinarily determine access conditions to the advantage of EEZs individually or
as a group, at the expense of global economic efficiency. In this case rent maximisation for non-spatially structured problems can only approximate globally efficient outcomes. However, the UNFSA provisions do appear to allow for alternatives to EEZs as a means of meeting the conservation and efficiency goals of management of migratory or straddling species. For example, annual quotas could be set for all fishing fleets and made transferable between fleets; the efficient total quota could be determined by the maximisation problems just considered. The applicability of whole-of-region total allowable catches is discussed in Chand et al. [8], Petersen [9] and Kennedy [3].

For other possibly more realistic coalition behaviour as an alternative to rent maximisation behaviour, we need to consider the likely players and their coalitions. The decisions on harvesting effort are made by fleets. As fleet effort is dispersed in fixed proportions across the age categories of the three tuna species and no country has exclusive property rights in any of the species, players are likely to be fleet-based.

This results in the following possibilities for coalitions of fleet players: (1) single member fleet coalitions; (2) a coalition of the fleet players by fleet type - purse seiner or longliner; (3) coalitions of purse seine fleets by country, and coalitions of long line fleets by country; and (4) coalitions of all fleets by country. The type (1) coalition setup results in the rent maximisation discussed in this section if all single member fleet coalitions act cooperatively.

Whilst opportunities exist for deals to be done between the same fleet types of different countries, it is plausible that coalitions of fleets will be country based, recognising the advantages of possible government support if needed. Consequently the type (4) coalition setup is adopted here. Thus seven country players are defined as coalitions of the fleet players of the country (or a group of countries, PICs, “Others”). Four country players have both a purse seine fleet and a longline fleet (Japan, Korea, Taiwan, and “Others”) while the remaining three country players have only a purse seine fleet (US, China and PICs). We now consider two possible types of strategic coalitions of country players.

Nash equilibrium 1: One country player against all other country players

Solutions like the rent-maximizing solution above are none too likely to be attained. They imply that the most efficient fleets should do the fishing and the others disappear, with the latter being compensated by a share in the greater profit. Such grand coalitions are sometimes not viable even in principle, as there may be incentives for some members of the coalition to break out and form their own sub-coalition, either with themselves as a single member or with more, but not all, members. See Kennedy [10] for consideration of solution concepts, with and without side-payments, and allocations to indicate the security of coalitions.

The rents accruing to the \( h \)-th player breaking out and those who remain in the coalition are given by the following Nash equilibrium, consistent with the solution to the following problem:

\[
E^* = \arg \max_{E_1, \ldots, E_N} \pi \left\{ E_i \left| E_i \right. \right\} \\
E^*_h = \arg \max_{E_1, \ldots, E_N} \pi \left\{ E_h \left| E_i \right. \right\} \\
\text{where } \pi_h \text{ is the rent generated by defecting country } h \text{ setting effort level at } E_h, \ E_g \text{ is the set of effort levels } E_g \forall g \neq h, \text{ and } \pi \{ \cdot \} \text{ is the resulting rent generated for the coalition of remaining players.}
\]

This is one thing that could threaten the grand coalition implied by the rent-maximizing solution. Suppose each country would have to be offered an outcome at least as good as the country could obtain if it decided to break out of the coalition and maximize its own rent. Table 2 shows the rent that would result
if one country acts independently and the rest act as a coalition, as well as the maximum rent (the grand coalition), which is (see Table 1) $570.2 million in the fixed price case and $642.6 with price flexibilities as discussed above. It is noteworthy that the rent obtained by a single member who breaks out of the grand coalition, summed across all possible single members, is more than twice that of the maximum rent. It would thus not be possible to offer all members of the grand coalition a share in the total rent which exceeds what each could obtain if he decides to leave the coalition and the rest remain in the coalition. This makes it doubtful whether the grand coalition would be stable. While the remaining coalition could buy one member who defects (third column in Table 2), it would not be possible to deter all members simultaneously from leaving the coalition by offering each what he would get if he went alone.

Table 2. Rent obtained by one Defecting Country Player, Rent for Coalition of Remaining Country Players, and Coalition Rent for Dissuading Defection. Million US$. Numbers in parentheses refer to volume-dependent prices.

<table>
<thead>
<tr>
<th></th>
<th>NE Single country (Defector) rent</th>
<th>NE Total rent for coalition of remaining countries</th>
<th>Maximum payment coalition could make to dissuade defection, given the maximum cooperative joint rent is 570.2(642.6)</th>
<th>NE rent for each country competing against all other countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>197.3 (252.8)</td>
<td>238.3 (280.0)</td>
<td>331.4 (362.7)</td>
<td>20.8 (44.3)</td>
</tr>
<tr>
<td>Korea</td>
<td>230.0 (265.3)</td>
<td>221.1 (283.8)</td>
<td>348.6 (358.9)</td>
<td>26.7 (43.5)</td>
</tr>
<tr>
<td>Taiwan</td>
<td>259.4 (276.8)</td>
<td>222.5 (273.8)</td>
<td>347.2 (368.9)</td>
<td>25.7 (52.5)</td>
</tr>
<tr>
<td>PICs</td>
<td>128.7 (159.4)</td>
<td>294.1 (408.9)</td>
<td>275.6 (233.8)</td>
<td>24.8 (34.3)</td>
</tr>
<tr>
<td>China</td>
<td>180.2 (164.5)</td>
<td>313.5 (425.2)</td>
<td>256.3 (217.5)</td>
<td>12.9 (22.1)</td>
</tr>
<tr>
<td>US</td>
<td>126.2 (162.2)</td>
<td>155.9 (323.7)</td>
<td>413.9 (319.0)</td>
<td>22.3 (33.4)</td>
</tr>
<tr>
<td>Others</td>
<td>223.5 (193.5)</td>
<td>272.0 (315.9)</td>
<td>297.8 (326.8)</td>
<td>21.3 (32.9)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1345.2</strong> (1474.5)</td>
<td><strong>154.5</strong> (263.0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There are conditions under which the grand coalition would be stable. This occurs, for example, if all countries realize that if one of them breaks out, all the others would do likewise. What then is important to look at is the temporary gain one country might obtain from breaking out of the coalition less the present value of the discounted loss resulting from everyone else going for the Nash equilibrium solution. The outcome of this depends on the discount rate and would require an intertemporal model to analyse fully [11].
Nash equilibrium 2: Each country player against all other country players

Given that a grand coalition is unlikely, it makes sense to look at a solution where everyone is competing against everyone else. This type of outcome can be expected to prevail in the present, virtually unregulated, situation.

For the Nash equilibrium, the following set of solutions to all one-member coalition problems holds:

\[ E^*_h = \arg \max_{E^*_h} \{ \pi_h | E^*_h \} \quad \forall h \]

where \( E^*_h = \text{the set of } E^*_g \quad \forall \ g \neq h. \) (5)

The last column of Table 2 shows the rents prevailing in this Nash equilibrium, for the case of volume-independent prices. These are only 27 and 40 percent, respectively, of the maximum rent with fixed prices and volume-dependent prices, so if the players reckon that this situation would prevail in the absence of cooperation, and if side payments are possible, the grand coalition could indeed be stable. A country that breaks out of the coalition would only make a temporary gain.

CONCLUSION

This paper has shown that considerable increase in rent can be obtained from changing the tuna fishery from its present configuration. Two changes are involved. First, purse seining should be reduced drastically. If prices are not sensitive to catch volumes the purse seine fleets would almost be eliminated and the benefits would be realized by the longline fleets, which deliver a more valuable product. If prices are sensitive to catch volume, reduced catches by the purse seine fleets would generate some benefits for them in the form of higher prices, while the benefits for the longline fleets due to more fish being available there would be limited by the volume sensitivity of prices for sashimi-grade products. The parameters we have used in fact indicate a higher price flexibility for the purse seine catches, so that a reduction in catches results in much higher prices and improved profitability.

Second, provided there is a mechanism to share the aggregate rent, the fishing should be carried out by countries with the most cost-effective fleets. This means that some fleets would disappear altogether, with the nations involved getting a share of the total rent. There are obvious practical and political obstacles to such a solution; how long would a country without any fishing fleet of its own be considered entitled to a share in the rents from fishing by others hundreds of miles away from its economic zone? Apart from that, in this particular setting this kind of solution would probably not be stable; it is unlikely that all countries can be offered rent shares that exceed what they could get on their own if one breaks out of the coalition and the others stay in it. Only if they realize that a breakdown of the coalition would end in everybody competing against everyone else and that the gains from breaking away would be temporary could the grand coalition be viable.

The biggest obstacle to achieving the cooperative solution is perhaps the fact that this would reduce the purse seine effort drastically. Some of the nations engaged in purse seining are not involved in longlining, or do so only to a limited extent, and would lose heavily from reducing their activity, unless a way could be found to give them a share in the benefits accruing to the longline fleets. For the Pacific islands countries this could come in the form of higher access fees for distant water longliners, but for those distant water nations with purse seiners only (US and China), some other mechanism would have to be found.
REFERENCES


ENDNOTE

*An extended version of this paper will appear in a forthcoming issue of the Journal of Natural Resources Policy Research.