ESSAYS ON THE MANAGEMENT OF FISHERIES IN THE PRESENCE OF STRATEGIC INTERACTIONS

by

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B.A., The University of Calgary, 1990
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Department of Economics)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

July 1998

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Date Nov 26, 1998

Abstract

The following three essays present an analysis that combines well-known models of fisheries management with contemporary theories of international trade and industrial organization. The general theme of the thesis is that countries' fisheries management policies can affect the strategic interaction between their fishing industries. The first essay examines the problem of noncooperative management of international fisheries by analyzing the strategic rent-shifting roles for such well-known national management policies as fleet licensing and effort subsidies. It is shown that the noncooperative equilibrium in each policy takes the form of a prisoner's dilemma with dissipated rents in the fishery. It is also shown that strategic effort subsidies can only lead to incomplete rent dissipation but strategic fleet licensing can lead to complete rent dissipation.

The second essay develops a theory of cooperative management of international fisheries by considering negotiation between countries over the same fleet licensing and effort subsidy policies considered in the first essay. The outcomes of negotiation over these policies are compared to the corresponding noncooperative outcomes, on the one hand, and to the efficient outcome on the other. It is shown that negotiation over effort subsidies in the absence of side payments is efficient, but negotiation over fleet sizes in the absence of side payments is inefficient.

The third essay develops a two-stage two-period model of a 'domestic' country and a 'foreign' country whose respective fishing industries harvest from separate fisheries for the same international market. The domestic country uses a harvest policy to regulate the harvest by its fishing industry, but the harvest by the foreign fishing industry is unregulated. Two types of fisheries are considered. In the case of schooling fisheries,

the domestic country may choose a conservative harvest policy in the first period if it can induce the biological collapse of the foreign fishery in the second period. In the case of search fisheries, the domestic country always chooses a conservative harvest policy in the first period in order to induce the economic degradation of the foreign fishery in the second period. The results suggest that international fisheries trade in the presence of divergent national fisheries management regimes could have unexpected consequences for world fisheries.

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Preface

An earlier version of the first essay in this thesis was published under the title "International fish wars: the strategic roles for fleet licensing and effort subsidies" in the *Journal of Environmental Economics and Management*, Volume 36, Number 1, July 1998, pages 70–88.

Acknowledgements

I would like to thank my supervisors Brian Copeland, Gordon Munro, and Scott Taylor for their guidance and encouragement. I would also like to thank my classmates and colleagues, especially Joel Bruneau, Carol McCausland, Katharine Neiss, and Zhihao Yu, for many helpful discussions and suggestions. All remaining errors are my own.

For my parents Ivanka and Kiril

1 Overview and Summary

The three essays in this thesis consider the implications of the management of fisheries in the presence of strategic interactions. Strategic interactions between agents are said to exist when the payoff to one agent is affected by the actions of other agents and when this effect is understood by the agents themselves. Strategic interactions in fisheries can occur between two or more fishing firms in one country, but they can also occur between fishing industries in two or more countries. In the literature on the economics of fisheries, the use of national management policies by countries to mitigate the effects of strategic interactions between their own fishing firms has been thoroughly researched. For example, Hartwick and Olewiler (1998) provide a textbook treatment of how countries can use harvest or effort taxes and quotas, individual transferable quotas, or sole ownership to induce the efficient exploitation of national fisheries. However, the use of national management policies in the presence of strategic interactions between fishing industries in different countries has remained unexplored. The objective of this thesis is to consider how the use of national management policies can effect the strategic interactions between fishing industries in different countries.

The United Nations Convention on the Law of the Sea, which entered into force in 1994 but has been accepted as customary international law since 1982, created well-defined property rights for coastal countries over most of the world's commercial fisheries, but it also created the problem of transboundary fisheries and may have exacerbated the problem of high seas fisheries for which international property rights are ill-defined. As well, the new Law of the Sea has also transferred international market power in fisheries products from former distant-water fishing fleets to the fishing industries in coastal countries.

Therefore this thesis considers two types of strategic interactions between fishing industries. The first two essays consider the management of fisheries that are international commmon property and as such are subject to exploitation by the fishing industries of two or more countries. In this case the strategic interaction between national fishing industries occurs on the fishing ground in the sense that the productivity of effort by the fishing industry in one country is affected by the level of effort chosen by the fishing industries in other countries. The third essay considers the management of fisheries that are international private property and as such are subject to exploitation by the fishing industry of only one country. In this case the strategic interaction between national fishing industries occurs in world markets for fisheries products in the sense that the terms of trade in fisheries products for one country with the rest of the world is affected by the level of harvest chosen by the fishing industries in other countries. In this thesis it is shown that either type of strategic interaction implies that a change in national management policy by one country has both a direct effect on its own fishing industry and an indirect or strategic effect on the fishing industries in other countries.

The analyses presented in this thesis combine theoretical models of fisheries management with well-known concepts from the theory of industrial organization. The results found here are compared and contrasted to those found in the literature on international trade and trade policy. Brander (1995) provides a useful summary of this literature. One of the main conclusions to be drawn from this thesis is that the effects of strategic interactions between fisheries management policies in different countries are similar to those of strategic interactions between international trade policies in different countries. The focus in the international trade literature is on the strategic interactions between such trade policies as export subsidies, import quotas, tariffs, and competition policies. The first two essays in this thesis focus on the strategic interactions between such well-known national management policies as fleet licensing and effort subsidies in two countries. The third essay in this thesis focuses on the strategic use of a national harvest tax or subsidy in one country.

The first essay in this thesis adds to Clark (1980), Copeland (1990), Levhari and Mirman (1980), and Welzel (1994) using the framework of Mesterton-Gibbons (1993). In particular, the work of Levhari and Mirman and Clark makes the implicit assumption that countries can choose any given level of harvest or effort without any loss of efficiency in their own fishing industries. This essay relaxes this assumption in the sense that countries can only induce a given level of harvest or effort through the use of national management policies that can in turn lead to inefficiency in their own fishing industries. The problem of noncooperative management of international fisheries is examined by analyzing the strategic rent-shifting roles for such well-known national management policies as fleet licensing and effort subsidies. It is shown that the noncooperative equilibrium in each policy takes the form of a prisoner's dilemma with dissipated rents in the fishery. It is also shown that strategic effort subsidies can only lead to incomplete rent dissipation but strategic fleet licensing can lead to complete rent dissipation. The results here are compared to those of Brander and Spencer (1985), Dixit (1984), and Horstmann and Markusen (1986) in the literature on strategic international trade policy.

The second essay in this thesis adds to Munro (1987) and Welzel (1994) using the framework developed in the first essay. This essay relaxes the assumption in the first essay that countries cannot negotiate binding agreements over national management policies. A theory of cooperative management of international fisheries is developed by considering negotiation between countries over the same fleet licensing and effort subsidy policies considered in the first essay. The outcomes of negotiation over these policies are compared to the corresponding noncooperative outcomes, on the one hand, and to the efficient outcome on the other. It is shown that negotiation over effort subsidies in the absence of side payments is efficient, but negotiation over fleet sizes in the absence of side payments is inefficient. The results here are compared to those of Dixit (1987), Mayer (1981), Riezman (1982), and Webb (1984) in the literature on international trade policy negotiations.

The third essay in this thesis adds strategic interactions between fishing industries to the nonautonomous dynamic models of Clark and Munro (1975,1980) using the framework of Mason and Polasky (1994,1997). A two-stage two-period model of a 'domestic' country and a 'foreign' country whose respective fishing industries harvest from separate fisheries for the same international market is developed. The domestic country uses a harvest policy to regulate the harvest by its fishing industry, but the harvest by the foreign fishing industry is unregulated. Two types of fisheries are considered. In the case of schooling fisheries, the domestic country may choose a conservative harvest policy in the first period if it can induce the biological collapse of the foreign fishery in the second period. In the case of search fisheries, the domestic country always chooses a conservative harvest policy in the first period in order to induce the economic degradation of the foreign fishery in the second period. In contrast to the first two essays, this essay shows that there can be a strategic interaction between countries' fisheries management policies even if fish stocks are nationally owned. The results here do not have any close comparisons, save perhaps the work of Gilbert (1978) on non-renewable resources, and instead provide a rather striking contrast to the results of Barbier and Rauscher (1994) and Brander and Taylor (1997) in the literature on international trade and trade policy in the presence of inefficient renewable resource management regimes.

2 Noncooperative Management of International Fisheries

2.1 Introduction

Extended Fisheries Jurisdiction created well-defined coastal property rights over most of the world's commercial fisheries, but it also created the problem of transboundary fisheries and it may have exacerbated the problem of high seas fisheries. Competition between national fleets in these international fisheries leads to depleted fish stocks and dissipated rents. In the most extreme case, a fish stock can be so severely depleted by noncooperative international fishing that its further exploitation becomes unprofitable. An example of this widespread "international tragedy of the commons" is the northern cod stock on the Grand Banks off Newfoundland, which was exploited by fleets from Canada, Spain, Portugal, the former Soviet Union, and Poland before its collapse led to an international fishing moratorium. More recently, Canada and the United States have been involved in an escalating "international fish war" over Pacific salmon stocks.

It has also been acknowledged by many observers that the problems of large fleet sizes and excessive subsidies to fishing industries have taken on alarming proportions in recent years. The Food and Agriculture Organization (1991) estimated that the worldwide number of registered fishing vessels with over 100 gross registered tonnes (GRT) of harvest capacity doubled from 585,000 in 1970 to over 1.17 million in 1989. Accordingly, in spite of the loss of distant-water fishing opportunities that came with Extended Fisheries Jurisdiction, Milazzo (1996) reported that the number of fishing vessels with over 500 GRT of harvest capacity operating in the high seas actually increased by more than 30 percent from 18,217 in 1975 to 23,718 in 1992. Moreover, the Food and Agriculture Organization (1995) estimated that worldwide revenues from fishing in 1989 were $70 billion while costs were $124 billion, which implies that as much as $54 billion was spent by countries to support otherwise unprofitable fishing industries. This essay explores the possible strategic motives behind the persistence of large and excessively subsidized national fleets that exploit depleted international fish stocks.

In the models developed here, the strategic rent-shifting roles for such well-known national management policies as fleet licensing and effort subsidies are examined through the use of a two-stage game between two countries and their fleets in an international fishery. In the fleet licensing model, countries unilaterally choose how many firms are allowed to participate in their fleets in the first stage and in the second stage the firms in these fleets harvest competitively from the fish stock. In the effort subsidy model, countries unilaterally choose how much to subsidize (or tax) effort in the first stage and in the second stage the firms in each fleet again harvest competitively from the fish stock. It is shown that the noncooperative equilibrium in each management policy takes the form of a prisoner's dilemma with dissipated rents in the fishery. It is also shown that strategic effort subsidies can only lead to incomplete rent dissipation but strategic fleet licensing can lead to complete rent dissipation as a special case. In both models, the strategic use of national management policies invariably depletes the international fish stock.

This essay builds mainly on the steady-state analysis of common property resource exploitation presented in Mesterton-Gibbons (1993). In showing how the problem of the commons has the form of a prisoner's dilemma, Mesterton-Gibbons considers a single-stage game in effort levels between an exogenous number of potential exploiters that are differentiated from each other by an exogenous level of harvesting efficiency. In this essay, however, the number of exploiters in an international fishery is made endogenous by the fleet licensing decision of each country. Similarly, the level of harvesting efficiency of these exploiters is made endogenous by the decision to implement an effort subsidy in each country. Thus the single-stage analysis presented in Mesterton-Gibbons is extended to a two-stage analysis in which the game in effort levels between the firms that exploit an international fishery is preceded by a game in policy levels between countries. In so doing the models developed here may help to provide an explanation for the persistence of large and excessively subsidized national fleets that exploit depleted international fish stocks.

This essay contributes to the literature on noncooperative fisheries and to the literature on endogenous policy formulation in the presence of strategic interactions. An introduction to the economics of fisheries management is provided by Munro and Scott (1985). The Cournot-Nash model developed by Levhari and Mirman (1980) was among the first to consider the consequences of non-cooperation between countries that exploit an international fish stock. Game-theoretic analyses of more recent developments in international fisheries are presented in Kaitala and Munro (1993) and Munro (1990). By motivating fleet licensing and effort subsidies as strategic policies, this essay adds to the literature on strategic international fisheries management that includes the work of Clark (1980), Copeland (1990), and Hämäläinen and Kaitala (1982). The fleet licensing model developed here resembles the Baye, Crocker, and Ju (1996) and Polasky (1992) models of strategic divisionalization among rival firms in an oligopoly and the Yuan (1996) model of strategic leasing among landowners in a common oil pool. By emphasizing the degradation of the fish stock as the consequence of non-cooperation in an international fishery, the effort subsidy model developed here provides an alternative approach to the static analysis of production subsidies presented in Welzel (1994).

Throughout the essay, the similarities of the fleet licensing and effort subsidy models to well-known models of strategic international trade policy is noted. The various propositions derived here can be viewed as familiar counterparts to propositions in the Brander and Spencer (1985) third-market model of export subsidies in an international duopoly. Related work by Dixit (1984) analyzes the strategic role for trade policies in a reciprocal-markets model of international oligopoly with any given number of firms in each country. Although these models consider the strategic roles for anti-trust policies and export subsidies (or taxes) in the context of an international market share rivalry, the models developed here consider the strategic roles for fleet licensing and effort subsidies (or taxes) in the context of an "international harvest share rivalry". This also implies that extensions of this essay to examine negotiated fleet size or effort subsidy reductions would benefit from the work of Mayer (1981), Dixit (1987), and other analyses of negotiated trade liberalization. The contrast between the effects of fleet licensing and effort subsidies in this essay is analogous to the contrast between the effects of trade policies in models of international oligopoly with a fixed number of firms and the Horstmann and Markusen (1986) model with free entry.[1]

The remainder of the essay is organized as follows. Section 2 provides evidence of the strategic interaction between national management policies in some international fisheries. Section 3 sets out the biological and production-related characteristics of the fishery considered in this essay. Section 4 develops the fleet licensing model in which countries choose how many firms are allowed to participate in their fleets. Section 5 develops the effort subsidy model in which countries choose how much to subsidize (or tax) effort by the firms in their fleets. Section 6 offers some concluding remarks.

2.2 Fleet Sizes, Effort Subsidies, and International Fisheries

The analysis presented in this essay is based on the notion that countries recognize and act upon the strategic interaction between national management policies in international fisheries. Milazzo (1996) provides some evidence of this recognition from the case of the Chinese distant-water fleet, which grew from almost nothing in 1986 to around 275 vessels in 1991. By 1996, as many as 500 Chinese vessels were reported to be operating in the already heavily exploited South Pacific and Indian Ocean tuna fisheries. Based in part on complaints from Japanese tuna fishermen about alleged subsidies to the Chinese fishing industry, Milazzo concluded that, "To achieve the results they have, one would have to assess their fisheries sector subsidies at a very substantial though hard-to-determine level... that the large bulk of these fisheries sector subsidies fall in the undesirable, effort-enhancing category." An essay in The Globe and Mail (1997) provides some more evidence from the case of the Pacific salmon war, in which an official from the United States indicated that, "The United States will meet conservation concerns, but it is not going to restrict its fleet for the sake of respecting Canadian commercial priorities." It was also reported in the same essay that, "Canadian officials have hinted that they will allow deployment of more boats than normal and larger quotas for them, and will not halt Canadian fishing to allow a certain portion of the fish to reach U.S. commercial-fleet nets further south, as has been done in the past."

The case of the pollock fishery in the high seas "Donut Hole" enclave in the Bering Sea provides an example of the consequences of non-cooperation between countries over national management policies. However, as described by Meltzer (1994), the number of vessels operating in the Donut Hole rose dramatically during the late 1980s and early 1990s with fleets from Japan, South Korea, Poland, China, the former Soviet Union, and the United States entering the fishery. Between 1985 and 1990, Meltzer reported that the Japanese fleet grew from 61 to 97 vessels (but had as many as 103 vessels in its fleet in 1988), the South Korean fleet grew from 26 to 41 vessels, and the Polish fleet grew from 15 to 39 vessels. During this period, the total pollock harvest in the Donut Hole rose from 0.363 million tons in 1985 to 1.45 million tons in 1989, and then fell to 0.92 million tons in 1990. The build-up of fleets and subsequent depletion of the pollock stock in the Donut Hole led Yonezawa (1991, p. 130) to conclude that, "Although Japan has already taken steps to freeze the size of its fishing fleet at the present level, it would be naive to expect all the other parties to see things in the same light. Many countries, some even located far from the region, have demonstrated an interest in entering this fishery or in expanding existing fisheries."

These cases can be taken to provide some support for the notion that countries recognize and act upon the strategic interaction between national management policies in international fisheries. This notion is examined in the models developed here through the use of a two-stage game in which countries unilaterally choose the level of some national management policy in the first stage and the firms in these fleets harvest competitively from an international fish stock in the second stage. Section 4 analyzes the strategic interaction between fleet licensing policies and Section 5 analyzes the strategic interaction between effort subsidy policies. These analyses are also consistent with some of the real-world consequences of non-cooperation between countries over national management policies because it is shown that the noncooperative equilibrium in each policy takes the form of a prisoner's dilemma with dissipated rents in the fishery and a depleted international fish stock.

2.3 The Schaefer Model of the International Fishery

There is a single fish stock of size x that follows the Schaefer model. Its dynamic equation is

$$\frac{dx}{dt} = G(x) - \sum_{i=1}^{2} H_i. \tag{1}$$

The first term on the right hand side is the natural rate of growth of the stock and the second term is the sum of harvests by firms in the fleets of two countries, denoted 1 and 2. It is assumed throughout that the fish stock is the common property of these two countries and that there is no threat of potential entry.[2] The natural growth function for the stock is

$$G(x) = rx\left(1 - \frac{x}{K}\right), \tag{2}$$

where r is the intrinsic rate of growth and K is the carrying capacity of the fishing ground. The harvest function for each country is assumed to be linear in the effort level chosen by its fleet and the stock size,

$$H_i = qE_ix, \tag{3}$$

where the catchability coefficient q is assumed to be the same for both countries so that neither country has a technological advantage over the other when it comes to harvesting from the fishery.

It is assumed that there is a zero rate of discount in each country so that the objective functions of firms and countries can be written in terms of steady-state values. This assumption is certainly extreme, as it implies that firms and countries are willing to make arbitrarily large current sacrifices for an arbitrarily small (but permanent) gain in the future. The dynamic resource problem is de-emphasized here in order to focus on the strategic interaction between national management policies in international fisheries. Assuming the stock is in steady-state, the dynamic equation can be set equal to zero and combined with the natural growth and harvest functions to reveal the unique steady-state size of the fish stock as a function of the effort levels chosen by the fleets in both countries,

$$x = \frac{K}{r}\left(r - q\sum_{i=1}^{2} E_i\right). \tag{4}$$

Given that the objective functions of firms and countries depend on this steady-state stock size, using (4) in (3) reveals that a change in the effort level chosen by the ith fleet ($i = 1, 2$) changes the productivity of effort in the fishery for the jth fleet ($j = 1, 2$ and $j \neq i$) in the opposite direction. Following the definition provided by Bulow, Geanakoplos, and Klemperer (1985), the relationship between fleet effort levels in the fishery implies that they are strategic substitutes.[3]

2.4 The Fleet Licensing Model

2.4.1 Noncooperative Effort Levels in the Second Stage

In this section, in order to analyze the strategic role for fleet licensing policies, it is assumed that countries do not use effort subsidies as tools of management policy. Competitive international fishing by the firms in each fleet is modeled as a two-stage game. In the second stage of the two-stage game developed here, the firms in each fleet choose effort to maximize their individual steady-state rents from the fishery, taking the effort levels chosen by rival domestic and foreign firms as given. This means that each firm plays a Nash game in effort levels against rival domestic firms and the foreign fleet. In the first stage, each country chooses how many firms are allowed to participate in its fleet, taking the size of the foreign fleet as given, with the full knowledge of how fleet sizes influence the second-stage equilibrium. This means that each country plays a Stackelberg game in effort levels against the foreign fleet and a Nash game in fleet licensing policies against the foreign country.

Turning first to the equilibrium behavior of firms and fleets in the second stage, the ith fleet ($i = 1, 2$) is comprised of $n_i \geq 1$ firms. Using a similar approach to the model developed by Dasgupta and Heal (1979, p. 56), the vth firm in the ith fleet ($v \in n_i$) chooses effort e_{iv} to maximize its individual steady-state rent from the fishery,

$$\max_{e_{iv}} \quad \Pi_{iv} = pqe_{iv}x - ce_{iv}, \tag{5}$$

where p is the exogenous price per unit of harvest and c is the exogenous cost per unit of effort faced by firms in the fleets of both countries. Each firm takes account of the effect of its own effort on the steady-state size of the fish stock, but takes as given the effort levels of rival domestic firms and the foreign fleet. Rewriting (4) in terms of the choice variable e_{iv},

$$x = \frac{K}{r}\left(r - qe_{iv} - q\sum_{w \neq v}^{n_i} e_{iw} - qE_j\right), \tag{6}$$

where $j = 1, 2$ and $j \neq i$. Substituting (6) into (5), applying symmetry to the subsequent first-order condition for e_{iv} (such that $e_{iw} = e_{iv} = e_i$ for all $w, v \in n_i$), and then multiplying by n_i yields the reaction function of the ith fleet to the effort level chosen by the jth fleet,

$$E_i\left(E_j;n_i\right)=\begin{cases}\dfrac{1}{q}\left(\dfrac{n_i}{1+n_i}\right)\left[r\left(1-b\right)-qE_j\right], & \text{if } r\left(1-b\right)>qE_j\\ 0, & \text{otherwise,}\end{cases} \tag{7}$$

where

$$b=\frac{c}{pqK}$$

is described by Mesterton-Gibbons (1993, p. 105) as an "(inverse) efficiency parameter". For any given n_i and E_j, the lower is c or the higher are p, q, or K, the lower is b and the higher is E_i. It is assumed throughout that $b<1$. This profitability condition implies that there would be a positive level of effort in the fishery if the fish stock were the private property of one country rather than the common property of both countries.

Shown in Figure 1, the reaction functions represented by (7) are the best response of each fleet to any particular level of effort chosen by the other fleet. The downward-sloping characteristic of these reaction functions illustrates how fleet effort levels are strategic substitutes as defined by Bulow, Geanakoplos, and Klemperer (1985). For any given n_1 and n_2, the slope of the reaction function of fleet 1 is always steeper than that of fleet 2 and there is a unique equilibrium in second stage effort levels, say, the point N. Because only the slope of the reaction function of fleet 1 depends on n_1, an increase in the size of fleet 1 leads to an outward rotation of the fleet 1 reaction function and an increase in E_1. Because the effort level chosen by fleet 2 is decreasing in E_1, an increase in the size of fleet 1 also leads to a decrease in E_2 (a movement downward along the fleet 2 reaction function). This result is shown in Figure 1 by the change in the equilibrium from N to S.

The reaction functions represented by (7) allow for a zero effort level as the best response of either fleet to the effort level chosen by its rival. Because fleet effort is

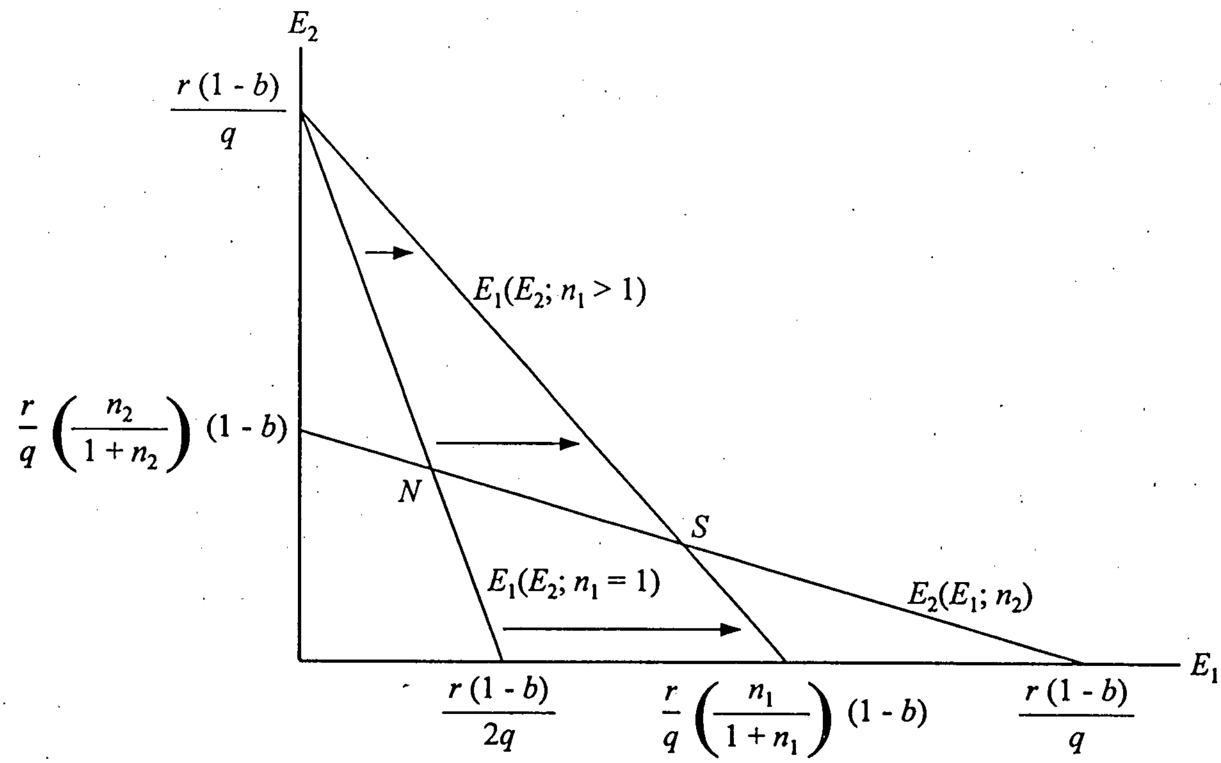

Figure 1: Reaction functions in the fleet licensing model

increasing in fleet size, this raises the possibility that a country could use the size of its fleet to deter entry in the fishery by the foreign fleet. However, the assumptions that effort costs and catchability coefficients are the same in both countries implies that only the interior portions of these reaction functions are relevant. Then the effort level chosen by the ith fleet in the second-stage equilibrium, as a function of the fleet sizes to be determined in the first stage, is

$$E_i(n_i, n_j) = \frac{rn_i}{q}\left(\frac{1-b}{1+n_i+n_j}\right). \tag{8}$$

It can be seen from (8) that the "direct effect" of a small increase in fleet size is positive, i.e., $\partial E_i/\partial n_i > 0$. According to (6), effort by new firms in the ith fleet reduces the size of the fish stock and diminishes the productivity of effort in the fishery. However, the increase in effort by the ith fleet due to these new firms more than offsets the productivity-induced decrease in effort by firms already in the ith fleet.

It can also be seen from (8) that the "strategic effect" of a small increase in fleet size is negative, i.e., $\partial E_i/\partial n_j < 0$, because effort by new firms in the jth fleet leads only to the productivity-induced decrease in effort by firms in the ith fleet. Using (8) in (4), the second-stage equilibrium size of the fish stock in terms of n_i and n_j is

$$x\left(n_i, n_j\right) = \left[\frac{1 + \left(n_i + n_j\right) b}{1 + n_i + n_j}\right] K \tag{9}$$

and it can be concluded that, taken together, the direct effect of a small increase in fleet size dominates the strategic effect in the fishery, i.e., $\partial x/\partial n_i < 0$.

Now consider the effects of a small increase in the size of the ith fleet on its equilibrium rent in the second stage. Because $\Pi_i = pqE_ix - cE_i$, where x is determined by (4),

$$\frac{\partial \Pi_i}{\partial n_i} = \frac{pqK\left(1-b\right)}{1 + n_i + n_j}\left[-\left(n_i - 1\right)\frac{\partial E_i}{\partial n_i} - n_i \frac{\partial E_j}{\partial n_i}\right]. \tag{10}$$

Notice that the first term in square brackets, the direct effect, is zero if $n_i = 1$ and negative if $n_i > 1$, because $\partial E_i/\partial n_i > 0$. In the absence of any strategic interaction between fleets in the fishery, having only a single firm in the ith fleet would lead to an efficient level of effort and maximum rent generation in the fishery. The envelope theorem then implies that the small increase in effort by the ith fleet brought about by a small increase in its size would not have any direct effect on its equilibrium rent. However, with more than one firm, competitive harvesting between firms in the ith fleet would lead to an inefficient level of effort and rent dissipation in the fishery. A small increase in its size would then further dissipate rents in the fishery through the direct effect.

The second term in square brackets in (10) is positive, whatever the size of the ith fleet, because the strategic effect of a small increase in the size of the ith fleet is negative, i.e., $\partial E_j/\partial n_i < 0$. This means that, if $n_i = 1$, a small increase in the size of the ith fleet unambiguously raises its equilibrium rent. If $n_i > 1$, the effect of a small increase in the size of the ith fleet on the rent accruing to it depends on whether the direct effect or the strategic effect dominates. Using (8) and (9) in the expression for Π_i, the equilibrium rent accruing to the ith fleet in terms of n_i and n_j is

$$\Pi_i(n_i, n_j) = rpn_iK\left(\frac{1-b}{1+n_i+n_j}\right)^2 \tag{11}$$

and it can be seen that whether the direct effect or the strategic effect dominates depends on the relative sizes of the fleets,

$$\frac{\partial \Pi_i}{\partial n_i} = rpK\left(\frac{1-n_i+n_j}{1+n_i+n_j}\right)\left(\frac{1-b}{1+n_i+n_j}\right)^2. \tag{12}$$

However, as long as the ith fleet is small relative to the jth fleet, i.e., $n_i < 1 + n_j$, the strategic effect dominates the direct effect and a small increase in the size of the ith fleet raises its equilibrium rent. If the ith fleet is large relative to the jth fleet, i.e., $n_i > 1+n_j$, the direct effect dominates the strategic effect and any further increase in the size of the ith fleet lowers its equilibrium rent.

Finally, consider the effects of a small increase in the size of the ith fleet on the equilibrium rent accruing to the jth fleet in the second stage. Because $\Pi_j = pqE_jx - cE_j$, where x is again determined by (4),

$$\frac{\partial \Pi_j}{\partial n_i} = \frac{pqK(1-b)}{1+n_i+n_j}\left[-n_j\frac{\partial E_i}{\partial n_i} - (n_j - 1)\frac{\partial E_j}{\partial n_i}\right]. \tag{13}$$

The first term in square brackets is negative, whatever the size of the jth fleet, because the direct effect of a small increase in the size of the ith fleet is positive, i.e., $\partial E_i/\partial n_i > 0$.

The second term in square brackets in (13), the strategic effect, is zero if $n_j = 1$ and is positive if $n_j > 1$, because $\partial E_j / \partial n_i < 0$. If there is a single firm in the jth fleet, the envelope theorem implies that the small decrease in effort by the jth fleet brought about by a small increase in the size of the ith fleet would not change the rent accruing to the jth fleet. With more than one firm, a small increase in the size of the ith fleet increases the rent accruing to the jth fleet to the extent that the strategic effect reduces excessive effort by the firms that harvest competitively in the jth fleet. However, using an appropriately modified version of (8) for E_j and (9) in the expression for Π_j and then differentiating with respect to n_i, it can be seen that the direct effect always dominates the strategic effect, such that the equilibrium rent accruing to the jth fleet unambiguously decreases with a small increase in the size of the ith fleet, i.e., $\partial \Pi_j / \partial n_i < 0$. The following proposition summarizes these results.

Proposition 1 *Given the size of the jth fleet, a small increase in the size of the ith fleet*

i. lowers the equilibrium size of the fish stock;

ii. lowers the equilibrium rent accruing to the jth fleet;

iii. raises the equilibrium rent accruing to the ith fleet if and only if $n_i < 1 + n_j$.

This proposition indicates that, if the domestic fleet is small relative to the foreign fleet, a small increase in domestic fleet size shifts rents in the fishery from the foreign fleet to the domestic fleet, in much the same way that an export subsidy shifts profits from a foreign firm to a domestic firm in the international market share rivalry presented in Brander and Spencer (1985). Similarly, where Brander and Spencer show that the world price of the exported good is lowered by an export subsidy, the corresponding result here is that the size of the fish stock is reduced by an increase in fleet size. In this essay, however, with the price per unit of harvest fixed, the domestic and foreign fleets are engaged in an "international harvest share rivalry" that does not have any effect on the price received for their product. However, as indicated by the change in the reaction function of the domestic fleet in Figure 1, the prior action by the domestic country in setting its fleet licensing policy changes the set of credible actions by the domestic fleet in the subsequent rivalry with the foreign fleet. Furthermore, as indicated by the change in the equilibrium from N to S in Figure 1, the result of this policy commitment by the domestic country is that the domestic fleet chooses a more aggressive effort level and the foreign fleet chooses a less aggressive effort level in the fishery.

2.4.2 Noncooperative Fleet Sizes in the First Stage

Now consider the choice of fleet size by countries in the first stage of the two-stage fleet licensing game. Each country unilaterally chooses the size of its domestic fleet taking the size of the foreign fleet as given. The choice of fleet size is made with the full knowledge of how the sizes of both fleets influence the second-stage equilibrium. The objective of the ith country ($i = 1, 2$) is to maximize the incremental domestic welfare arising from the fishery, which is assumed to be the equilibrium rent accruing to the ith fleet in the second stage minus a domestic fishery management cost,

$$\max_{n_i} \quad W_i\left(n_i, n_j\right) = \Pi_i\left(n_i, n_j\right) - n_i F. \tag{14}$$

The constant marginal fleet (or fishery) management cost F represents a social cost that is not incurred by firms in the ith fleet (say, for example, the cost of acquiring and disseminating information about the fishery to each firm in the ith fleet) and is assumed to be the same in both countries. Using (11) in (14), the first-order condition for n_i is

$$\frac{\partial W_i}{\partial n_i} = rpK\left(\frac{1-n_i+n_j}{1+n_i+n_j}\right)\left(\frac{1-b}{1+n_i+n_j}\right)^2 - F = 0 \tag{15}$$

and is the (implicit) reaction function of the ith country to the size of the jth fleet in the first stage. If F is sufficiently small but positive, there is an interior symmetric equilibrium in the first-stage choice of fleet sizes, denoted n, which is found by solving for $n = n_i = n_j$ in (15),

$$n = \frac{1}{2}\left(\left[\frac{rpK\,(1-b)^2}{F}\right]^{\frac{1}{3}} - 1\right). \tag{16}$$

It is apparent that $n > 1$ as long as the marginal fleet management cost in both countries satisfies

$$0 < F < \frac{rpK\,(1-b)^2}{27}$$

and each country chooses to have multiple firms in its fleet in the first-stage equilibrium.[4] By using (16) in (11) and (14), it can be verified that the same condition for F implies that the noncooperative equilibrium rent accruing to each fleet and incremental welfare from the fishery in each country are positive. However, it should be noted that joint incremental welfare from fishing is decreasing in fleet size for any $n_i \geq 1$ and $n_j \geq 1$,

$$\frac{\partial\left(W_i + W_j\right)}{\partial n_i} = -rpK\left(\frac{n_i+n_j-1}{1+n_i+n_j}\right)\left(\frac{1-b}{1+n_i+n_j}\right)^2 - F < 0. \tag{17}$$

This means that both countries could be made better off if at least one country reduced the number of firms in its fleet, relative to the number of firms in the symmetric noncooperative equilibrium, and was compensated for doing so by the other country. Nevertheless, because each country has a unilateral incentive to use its fleet licensing policy strategically, the noncooperative equilibrium takes the form of a prisoner's dilemma with multiple firms in each fleet. The following proposition summarizes these results.

Proposition 2 *For a sufficiently small (but positive) marginal fleet management cost in both countries the symmetric noncooperative equilibrium in fleet licensing policies is characterized by multiple firms in both fleets and incomplete rent dissipation in the international fishery.*

Propositions 1 and 2 taken together indicate that, if countries recognize that their fleet licensing policies influence the strategic interaction between fleets in an international fishery, non-cooperation between countries leads to the strategic use of fleet licensing policies within these countries and exacerbates the problem of over-exploitation in an international fishery. Furthermore, it should be noted that this "international tragedy of the commons" takes its most severe form as the marginal fleet management cost tends to zero. From (16) it can be seen that $n \to \infty$ as $F \to 0$, which implies that there is open access to the fishery in each country. Accordingly, from (8), (9), and (11) it can be seen that, while the equilibrium effort level chosen by each fleet and the equilibrium size of the fish stock approach positive levels in the limit, the equilibrium rent accruing to each fleet tends to zero. This rather striking result of strategic fleet licensing is summarized by the last proposition in this section.

Proposition 3 *However, as the marginal fleet management cost in both countries tends to zero the symmetric noncooperative equilibrium in fleet licensing policies approaches the open access equilibrium and there is complete rent dissipation in the international fishery.*

Why does the absence of fleet management costs lead both countries to continue to expand their fleets until rents in the fishery are driven to zero? Some insight into this question can be found by considering the strategic relationship between fleet sizes.

Taking the cross-partial derivative of incremental welfare from fishing in the ith country with respect to fleet sizes,

$$\frac{\partial^2 W_i}{\partial n_i \partial n_j} = \frac{2rpK\left(2n_i - n_j - 1\right)\left(1-b\right)^2}{\left(1+n_i+n_j\right)^4}. \tag{18}$$

Because (18) is positive for any symmetric noncooperative equilibrium in which $n_i = n_j = n > 1$, it can be concluded that countries regard their fleet sizes as strategic complements. However, as discussed in Bulow, Geanakoplos, and Klemperer (1985), this means that the optimal response by one country to "more aggressive play" by its rival is to also be more aggressive: the larger the size of the fleet in one country, the larger the optimal size of the fleet in the other country. Strategic complementarity between fleet sizes implies that a "fleet licensing war" can escalate even to the point of complete rent dissipation when the marginal fleet management cost in each country is zero.[5]

2.5 The Effort Subsidy Model

2.5.1 Noncooperative Effort Levels in the Second Stage

In the previous section, the strategic role for fleet licensing was examined. In this section, it is assumed instead that the size of the fleet in each country is fixed and the strategic role for effort subsidies is examined.[6] In the second stage of the two-stage game developed here, the firms in each fleet choose effort to maximize their individual steady-state rents from the fishery, taking the effort levels chosen by rival domestic and foreign firms and the level of domestic effort subsidy as given. However, as in the fleet licensing model, this means that each firm plays a Nash game in effort levels against rival domestic firms and the foreign fleet. In the first stage, each country unilaterally chooses the level of effort subsidy in its fleet, taking domestic and foreign fleet sizes and the level of foreign effort subsidy as given, with the full knowledge of how effort subsidies influence the second-stage equilibrium.[7] Once again, this means that each country plays a Stackelberg game in effort levels against the foreign fleet and a Nash game in effort subsidy policies against the foreign country.

The assumption that there is a fixed number of firms in each fleet implies that there are two roles for the effort subsidy policy in each country. The first role is to reduce the domestic inefficiency arising from competition between firms in the domestic fleet. In the absence of any strategic interaction between domestic and foreign fleets, this domestic objective would involve a negative effort subsidy or an effort tax. With more than one firm in the domestic fleet, the effect of domestic effort on the size and productivity of the fish stock is not fully internalized and the rent accruing to the domestic fleet is reduced by competitive domestic over-harvesting. An effort tax lowers the effort level chosen by the fleet and allows the country to generate rent that would otherwise have been dissipated by competition between domestic firms in the fishery.

The second role for the effort subsidy policy in each country is to influence the strategic interaction between domestic and foreign fleets. In the absence of a domestic externality, which can be achieved by having a single firm in the domestic fleet, this strategic objective would involve a positive effort subsidy. With a foreign fleet in the fishery, an effort subsidy raises domestic effort and shifts rents in the fishery from the foreign fleet to the domestic fleet in much the same way that third-market profit is shifted by an export subsidy in the Brander and Spencer (1985) model of international market share rivalry between a single domestic and foreign firm. However, as in the Dixit (1984) reciprocal-markets model of export subsidies and taxes with multiple domestic and foreign firms, whether a country chooses an effort subsidy or tax depends on the relative sizes of the domestic and foreign fleets.

Turning first to the second-stage equilibrium, the vth firm in fleet i ($v \in n_i$, $i = 1, 2$) solves the problem of maximizing its individual steady-state rent from the fishery,

$$\max_{e_{iv}} \pi_{iv} = pqe_{iv}x - (c - s_i)e_{iv}, \tag{19}$$

subject to (6) and where s_i represents the subsidy per unit of effort employed by each firm in the ith fleet. Using symmetry on the first-order condition for e_{iv} ($e_{iv} = e_i$ for all $v \in n_i$), solving for e_i, and then multiplying by n_i yields the reaction function of the ith fleet to the effort level chosen by the jth fleet,

$$E_i\left(E_j; d_i\right) = \begin{cases} \dfrac{1}{q}\left(\dfrac{n_i}{1+n_i}\right)\left[r\left(1-b+d_i\right) - qE_j\right], & \text{if } r\left(1-b+d_i\right) > qE_j \\ 0, & \text{otherwise,} \end{cases} \tag{20}$$

where the description of the (inverse) efficiency parameter b and the profitability condition $b < 1$ are carried over from the fleet licensing model and

$$d_i = \frac{s_i}{pqK}$$

can be described as an "(direct) effort subsidy parameter". For any given n_i and E_j, the higher is s_i the higher is d_i and the higher is E_i. It is worth noting that there is no restriction on the sign of the effort subsidy parameter: $d_i > 0$ implies effort by each firm in the ith fleet is being subsidized and $d_i < 0$ implies effort is being taxed.

The reaction functions for fleets 1 and 2 are shown in Figure 2 and, because their slopes are the same as those derived earlier for the fleet management model, there is a unique equilibrium in second stage effort levels, say, the point N. Although an increase in n_1 raises E_1 and lowers E_2 by rotating the reaction function of fleet 1 outward, as shown in Figure 1, an increase in d_1 raises E_1 and lowers E_2 by shifting the reaction function of fleet 1 outward. This result is shown in Figure 2 by the change in the equilibrium from N to S.

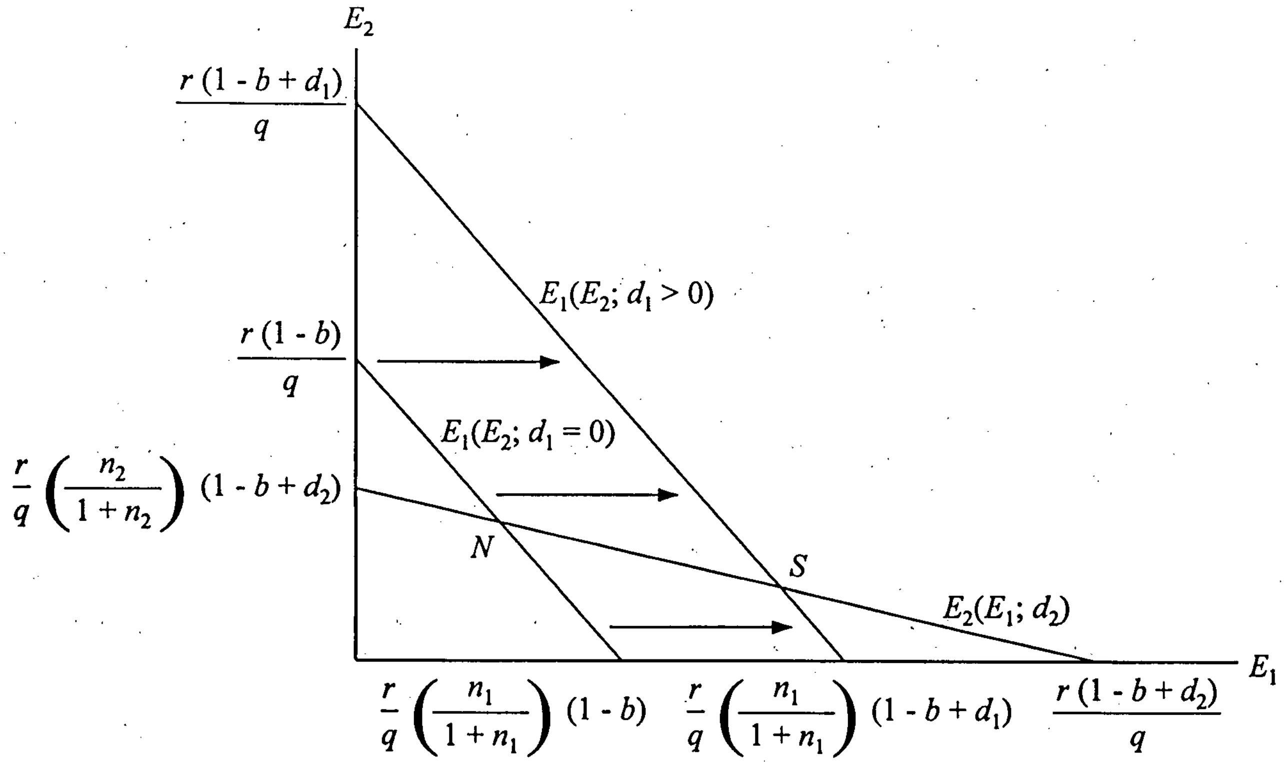

Figure 2: Reaction functions in the effort subsidy model

However, as in the fleet licensing model, the assumption that firms in both fleets share the same harvest technology and cost per unit of effort implies that only the interior portions of these reaction functions are relevant in the second-stage equilibrium. Then the effort level chosen by the ith fleet in the second-stage equilibrium, as a function of the effort subsidies to be determined in the first stage, is

$$E_i(d_i, d_j) = \frac{r}{q}\left(\frac{n_i}{1+n_i+n_j}\right)[1-b+(1+n_j)d_i - n_j d_j]. \tag{21}$$

Similarly to the effect of a small increase in fleet size in the fleet licensing model, a small increase in the effort subsidy parameter in a country has a direct effect, i.e., $\partial E_i/\partial d_i > 0$, and a strategic effect, i.e., $\partial E_i/\partial d_j < 0$. Using (21) in (4), the equilibrium size of the fish stock in terms of d_i and d_j is

$$x\left(d_i, d_j\right) = \left[\frac{1 + \left(n_i + n_j\right) b - n_i d_i - n_j d_j}{1 + n_i + n_j}\right] K \tag{22}$$

and it can be seen once again that the direct effect of a small increase in fleet size dominates the strategic effect in the fishery, i.e., $\partial x/\partial d_i < 0$.

Now consider the effects of a small increase in the effort subsidy parameter in the ith country on the equilibrium rent accruing to its own fleet in the second stage. Because $\Pi_i = pqE_i x - \left(c - s_i\right) E_i$, where x is determined by (4),

$$\frac{\partial \Pi_i}{\partial d_i} = pqK \left[\frac{1 - b + \left(1 + n_j\right) d_i - n_j d_j}{1 + n_i + n_j}\right] \left[-\left(n_i - 1\right) \frac{\partial E_i}{\partial d_i} - n_i \frac{\partial E_j}{\partial d_i} + \frac{r n_i}{q}\right]. \tag{23}$$

The term in the first set of square brackets on the right-hand side of (23) is positive by the definition of $E_i\left(d_i, d_j\right)$ in (21). There are three terms in the second set of square brackets on the right-hand side of (23), the first two of which are the direct effect and the strategic effect, respectively, of a small increase in the effort subsidy in the ith country. Once again, the direct effect is zero if $n_i = 1$ and negative if $n_i > 1$, which reflects the first role for an effort subsidy discussed earlier. If there is more than one firm in the ith fleet, a small increase in the effort subsidy (or alternatively a small decrease in the effort tax) exacerbates the problem of competitive over-harvesting by the firms in the ith fleet and lowers its equilibrium rent.

The second role for an effort subsidy is squarely captured by the strategic effect in that, whatever the size of the ith fleet, a small increase in the effort subsidy in the ith country lowers effort by the the jth fleet in the fishery. The last term in the second set of square brackets on the right-hand side of (23) represents the addition to the rent accruing to each firm in the ith fleet from receiving an effort subsidy. It should be noted that, if $n_i = 1$, a small increase in the effort subsidy in the ith country unambiguously raises the rent accruing to the ith fleet through the strategic effect and the additional benefit of the effort subsidy itself. If $n_i > 1$, however, the effect of a small increase in the effort subsidy in the ith country on the rent accruing to its fleet depends on whether or not the direct effect dominates the other two effects. Using (21) and (22) in the expression for Π_i, the equilibrium rent accruing to the ith fleet in terms of d_i and d_j is

$$\Pi_i\left(d_i, d_j\right) = rpn_iK\left[\frac{1 - b + \left(1 + n_j\right)d_i - n_jd_j}{1 + n_i + n_j}\right]^2. \tag{24}$$

and, because $E_i > 0$ in (21), it can be verified that the direct effect is dominated such that an increase in the effort subsidy in the ith country unambiguously raises the equilibrium rent accruing to its fleet, i.e., $\partial\Pi_i/\partial d_i > 0$.

Finally, consider the effects of a small increase in the effort subsidy in the ith country on the equilibrium rent accruing to the jth fleet in the second stage. Because $\Pi_j = pqE_jx - \left(c - s_j\right)E_j$, where x is again determined by (4),

$$\frac{\partial\Pi_j}{\partial d_i} = pqK\left[\frac{1 - b + \left(1 + n_i\right)d_j - n_id_i}{1 + n_i + n_j}\right]\left[-n_j\frac{\partial E_i}{\partial d_i} - \left(n_j - 1\right)\frac{\partial E_j}{\partial d_i}\right] \tag{25}$$

and it is apparent that the direct effect is always negative although the strategic effect is positive if $n_j > 1$ and zero if $n_j = 1$. However, using an appropriately modified version of (21) for E_j and (22) in the expression for Π_j and then differentiating with respect to d_i, it can be seen that the direct effect always dominates the strategic effect, such that the equilibrium rent accruing to the jth fleet unambiguously decreases with a small increase in the effort subsidy in the ith country, i.e., $\partial\Pi_j/\partial d_i < 0$. The following proposition summarizes these results.

Proposition 4 *Given the sizes of the ith and jth fleets and the effort subsidy in the jth country, a small increase in the effort subsidy in the ith country*

i. lowers the equilibrium size of the fish stock;

ii. lowers the equilibrium rent accruing to the jth fleet;

iii. raises the equilibrium rent accruing to the ith fleet.

This proposition indicates that the implementation of a small effort subsidy in the domestic country unambiguously shifts rents in the fishery from the foreign fleet to the domestic fleet and reduces the size of the fish stock. The effects of this policy commitment by the domestic country are similar to those of the small increase in domestic fleet size summarized by Proposition 1 in the fleet licensing model. The main difference is that the equilibrium rent accruing to the ith fleet in the second stage increases unambiguously with an increase in the domestic effort subsidy regardless of its own size or the size of the jth fleet. This occurs because the effort subsidy enters directly into the expression for the rent of each firm in the ith fleet. Thus an increase in the effort subsidy (or a decrease in the effort tax) in the ith country always adds to the rent accruing to the ith fleet.

2.5.2 Noncooperative Effort Subsidies in the First Stage

Now consider the choice of effort subsidy by countries in the first stage of the two-stage effort subsidy game. Each country unilaterally chooses how much to subsidize (or tax) effort by the firms in its own fleet with the full knowledge of how effort subsidies influence the second-stage equilibrium. Once again, the objective of the ith country is to maximize the incremental domestic welfare arising from the fishery, which is assumed here to be the equilibrium rent accruing to the ith fleet in the second stage minus the cost of the effort subsidy and fleet management costs,

$$\max_{d_i} \quad W_i(d_i, d_j) = \Pi_i(d_i, d_j) - pqKd_iE_i(d_i, d_j) - n_iF. \tag{26}$$

Because fleet sizes are fixed, the fleet management cost in (26) is also fixed and does not enter into the first-order condition for the optimal effort subsidy in the ith country. Using (21) and (24) in (26), the first-order condition for d_i is

$$d_i = \left(\frac{1 - n_i + n_j}{2n_i}\right)\left(\frac{1 - b - n_jd_j}{1 + n_j}\right) \tag{27}$$

and is the (explicit) reaction function the ith country to the effort subsidy parameter in the jth country. Because fleet sizes are not necessarily the same in both countries, the optimal effort subsidy in each country need not be the same. Using (27) the equilibrium effort subsidy parameter in the ith country, as a function of the fixed fleet sizes, is

$$d_i = \left(\frac{1 - n_i + n_j}{n_i}\right)\left(\frac{1 - b}{3 + n_i + n_j}\right). \tag{28}$$

Notice from (28) that whether the equilibrium effort subsidy in the ith country is positive or negative (an effort tax) depends on relative fleet sizes. If $n_i > 1 + n_j$, the ith country uses an effort tax to reduce the excessive effort arising from competition between the firms in its fleet to the strategically optimal rent-shifting level. If $n_i < 1 + n_j$, the ith country uses an effort subsidy to raise the effort level of its fleet to the strategically optimal rent-shifting level. It is also worth noting that the relationship between the sign of the effort subsidy parameter and the relative sizes of domestic and foreign fleets is similar to the relationship found in the Dixit (1984) reciprocal-markets model of export subsidies and taxes with multiple domestic and foreign firms.

Consider what the choice of d_i would be if the fish stock were exclusively owned by the ith country rather than the common property of two countries. Setting $n_j = 0$ in (28) leads to $d_i < 0$ for any $n_i > 1$, which implies that the ith country would use an effort tax instead of a subsidy if multiple firms were allowed to participate in its fleet. Notice also the striking result that, in the special case of symmetric fleet sizes, i.e., $n_i = n_j = n$, the first-stage equilibrium in strategic policies is always characterized by a positive effort subsidy (rather than a negative effort subsidy or effort tax) in each country. This suggests once again that the symmetric noncooperative equilibrium examined here has the form of a prisoner's dilemma with neither country having an incentive to deviate from its policy of excessive effort subsidization. The prisoner's dilemma outcome for the effort subsidy model can be verified by noting that the partial derivative of joint incremental welfare from fishing with respect to d_i is

$$\frac{\partial\left(W_i + W_j\right)}{\partial d_i} = \frac{rpn_iK\left[\left(1 - n_i - n_j\right)\left(1 - b\right) - 2n_id_i - 2n_jd_j\right]}{\left(1 + n_i + n_j\right)^2}, \tag{29}$$

which is negative when evaluated at the noncooperative equilibrium in effort subsidy parameters characterized by (28). Nevertheless, using (28) in (24), it can be seen that the noncooperative equilibrium rent accruing to the ith fleet remains positive. Similarly, using (21) and (24), and (28) in (26), it can also be seen that incremental welfare from fishing in the noncooperative equilibrium is positive as long as the fleet management cost in the ith country is not too large. For purposes of comparison with the fleet licensing model, these results for the special case of the effort subsidy model with symmetric fleet sizes are summarized by the last proposition in this section.

Proposition 5 *For any level of the marginal fleet management cost (including zero) in both countries the symmetric noncooperative equilibrium in effort subsidy policies is characterized by positive effort subsidies and incomplete rent dissipation in the international fishery.*

Consider the difference between this proposition and Proposition 3 in the fleet licensing model. Why can an "effort subsidy war" only lead to incomplete rent dissipation while a "fleet licensing war" can lead to complete rent dissipation? Taking the cross-partial derivative of incremental welfare from fishing in the ith country with respect to the effort subsidy parameters,

$$\frac{\partial^2 W_i}{\partial d_i \partial d_j} = -\frac{2rpn_i n_j (1+n_j) K}{(1+n_i+n_j)^2}. \tag{30}$$

Because (30) is negative, the effective subsidy parameters are regarded by both countries as strategic substitutes. Following Bulow *et. al.* (1985), this means that the optimal response by one country to "more aggressive play" by its rival is to be less aggressive: the larger the effective subsidy in one country, the smaller the optimal effective subsidy in the other country. Recall that, in the fleet licensing model, strategic complementarity between fleet sizes implies that a "fleet licensing war" can escalate even to the point of complete rent dissipation when the marginal fleet management cost in each country is zero. In contrast, however, strategic substitutability between effective subsidies implies that an "effort subsidy war" cannot escalate to the point of complete rent dissipation, even when the marginal fleet management cost in each country is zero.

2.6 Concluding Remarks

The models developed in this essay have shown that countries have a strategic rent-shifting incentive to maintain large and excessively subsidized national fleets in international fisheries. These models have also shown that strategic fleet licensing and strategic effort subsidies lead to dissipated rents, reduced welfare, and depleted international fish stocks. Based on the notion that countries recognize and act upon the strategic interaction between national management policies in international fisheries, these models have shown how the consequences of non-cooperation between countries may be even more severe than would be suggested by the single-stage approach to the problem of common property fisheries in Mesterton-Gibbons (1993). This point is made strikingly apparent in the fleet licensing model, where international non-cooperation in the form of a fleet licensing war between as few as two countries can drive economic rents to zero, which is the same outcome that would occur if there were international open access to the fish stock. In contrast to this outcome, international non-cooperation in the form of an effort subsidy war between two countries reduces economic rents, but does not drive these rents to zero.

The results found in these models depend on the presence of strategic interactions at both the level of fishing firms and the level of fishing fleets. If, on the one hand, there were no strategic interaction between firms in the fishery, then the traditional problem of the commons would not apply and there would be neither a direct efficiency-inducing incentive nor a strategic rent-shifting incentive for countries to implement national management policies for their fleets. If, on the other hand, there were no strategic interaction between fleets in the fishery, ie. if each country had exclusive access to its own fishery, then there would be a direct efficiency-inducing incentive for countries to implement national management policies, but there would not be a strategic rent-shifting incentive to alter these policies from their efficiency-inducing levels.

The results found in these models also depend on the credibility of the strategic choices made by countries. Widespread evidence of excessive subsidization and licensing of large fleets makes it clear that these commitments are credible indeed. However, as discussed in a report prepared by the New Zealand Fishing Industry Board (1996, p. 41), it is relatively much easier to consider subsidies as a strategic policy used to help a fishing industry, as opposed to other industries, because "The call for subsidies to the fishing community in North America (much of which is seen as a form of "disaster relief") seems to engender an emotional response within the population and to be acceptable to both state and federal politicians." Also, Shrank *et. al.* (1992) note that many countries are unwilling to reduce the sizes of their fishing fleets, because fisheries are often thought of as an "employer of last resort" in many small coastal communities that depend on them.

An interesting extension to the analysis presented here would be to relax the assumption that firms in both countries have equal (inverse) efficiency parameters. Just as asymmetric efficiency parameters in Mesterton-Gibbons (1993) implies that only some of the potential exploiters of the common property resource actually end up exploiting the resource, asymmetric efficiency parameters in the models developed here would imply that the country with the more efficient fleet (or lower efficiency parameter) could use its management policy to make it unprofitable for the less efficient fleet to participate in the fishery. This entry-deterring outcome of the strategic use of national management policies would be similar to the outcome in the case of non-cooperation between countries with different harvesting costs in Clark (1980). Another extension to the analysis presented here would be based on the result that the outcome of an international fish war depends on the choice of management policy. A third stage could be added to the analysis presented here in which countries must choose between national management policies, given that the levels of their chosen policies will be chosen noncooperatively in the next stage, and given that these policies and their levels will influence the strategic interaction between competitive fleets in the final stage. In the context of the national management policies examined here, the analysis could indicate whether providing an effort subsidy to the existing fleet or raising the size of the fleet is a dominant strategy for countries as they enter an international fish war.[8]

3 Cooperative Management of International Fisheries

3.1 Introduction

This essay explores the implications of negotiation between countries over national management policies in international fisheries. Well-known examples of such policies include fleet licensing and effort subsidies. In the presence of well-defined international property rights, countries can use these national management policies to influence the effort levels chosen by their fleets and thereby ensure the efficient exploitation of their fisheries. However, in the absence of well-defined international property rights, countries can use these national management policies to influence not only the effort levels chosen by their own fleets, but also the effort levels chosen by fleets from other countries. In this case, as shown in Ruseski (1998), the unilateral incentives for countries to use strategic fleet sizes and effort subsidies exacerbates the problems of rent dissipation and stock depletion in international fisheries.

A critical assumption in the Ruseski (1998) analysis of national management policies in noncooperative international fisheries is that countries cannot negotiate binding agreements over fleet sizes and effort subsidies. However, if countries recognize the consequences of their unilateral policy choices and can negotiate binding agreements over these policy choices, then it would be more appropriate to model the management of international fisheries as a cooperative game rather than a noncooperative game. Therefore this essay develops a theory of cooperative management of international fisheries by analyzing negotiation between countries over fleet sizes and effort subsidies. The outcomes of negotiation over these national management policies are compared to the corresponding noncooperative outcomes, on the one hand, and to the efficient outcome on the other. It is shown that negotiation over effort subsidies in the absence of side payments is efficient, but negotiation over fleet sizes in the absence of side payments is inefficient.

The main point of departure of this essay from the mainstream literature on the management of international fisheries is the notion that countries negotiate over national management policies rather than national effort levels.[9] An implicit assumption in this literature is that countries exercise "iron control" over the effort levels chosen by their fishing fleets. This implies that countries can direct their fleets to choose any given level of fishing effort without any loss of domestic efficiency and, more importantly, that countries can necessarily negotiate efficiently, even in the absence of side payments. This essay relaxes this assumption in the sense that, in order to induce their fleets to choose any given effort level, countries must use indirect national management policies that can lead to domestic inefficiency. This essay also relaxes this assumption in the sense that countries cannot necessarily negotiate efficiently in the absence of side payments. In this essay, depending on whether countries negotiate over fleet sizes or effort subsidies, the presence or absence of side payments determines whether or not the outcome of negotiation is efficient or inefficient.

The cooperative games over fleet sizes and effort subsidies developed in this essay are analyzed using the techniques of Mayer (1981), Dixit (1987), and Riezman (1982) in the literature on international trade policy negotiations. As well, the differences between export quota and tariff negotiations discussed by Webb (1984) resemble the differences between fleet size and effort subsidy negotiations considered here. Unlike these essays, however, in which side payments are assumed to be absent from negotiations, this essay emphasizes the potential role for side payments in achieving an efficient outcome in negotiations over the management of international fisheries.

The remainder of the essay is organized as follows. Section 2 sets out the characteristics of the fishery considered here and determines the efficient outcome. Section 3 develops the cooperative fleet size game in which countries do not use effort subsidies and only negotiate over fleet sizes. Section 4 develops the cooperative effort subsidy game in which countries have given fleet sizes and only negotiate over effort subsidy levels. Section 5 offers some concluding remarks.

3.2 Efficiency in the Schaefer Model

Following the analysis presented by Ruseski (1998), there is a single fish stock of size x that follows the Schaefer model. Its dynamic equation is

$$\frac{dx}{dt} = G(x) - \sum_{i=1}^{2} H_i(E_i, x), \tag{31}$$

where the first term on the right hand side is the natural rate of growth of the stock and the second term is the sum of harvests by firms in the fleets of two countries, denoted 1 and 2. The natural growth function for the stock is

$$G(x) = rx\left(1 - \frac{x}{K}\right), \tag{32}$$

where r and K are exogenous biological parameters, and the harvest function for each country is

$$H_i(E_i, x) = qE_ix, \tag{33}$$

where q is an exogenous technological parameter and E_i is the effort level chosen by its fleet. It is assumed that the rate of discount in each country is zero so that objective functions can be written in terms of steady-state values. Using (32) and (33) in (31) and setting the result equal to zero yields the steady-state size of the fish stock as a function of the effort levels chosen by the fleets in both countries,

$$x(E_1, E_2) = \frac{K}{r}\left[r - q(E_1 + E_2)\right]. \tag{34}$$

The efficient level of effort in the international fishery maximizes the total economic rent from fishing regardless of the distribution of effort between the two fleets. Using the linearity of the harvest function in the level of effort, the total economic rent from fishing can be written as the difference between the total steady-state revenue from the harvest and the total cost of effort by both fleets,

$$\Pi(E_1, E_2) = pq(E_1 + E_2)x(E_1, E_2) - c(E_1 + E_2), \tag{35}$$

where p is the exogenous price per unit of harvest and c is the exogenous cost per unit of effort faced by firms in the fleets of both countries. Using (34) in (35) and then maximizing over $E_1 + E_2$ yields the efficient level of effort in the international fishery,

$$E_1 + E_2 = \frac{r\,(1 - b)}{2q}. \tag{36}$$

As shown in Ruseski (1998), however, non-cooperation between countries in terms of fleet sizes and effort subsidies leads to a greater level of effort than that indicated by (36) and, as a consequence, rent dissipation and stock depletion in the international fishery. The next two sections examine how cooperation between countries may or may not lead to the efficient level of effort in the international fishery, depending on the management policy over which negotiations take place and depending on the presence or absence of side payments and other tools of management policy.

3.3 The Cooperative Fleet Licensing Model

In this section a cooperative game is considered in which countries can negotiate binding agreements over fleet sizes. It is assumed here that countries do not use effort subsidies as tools of management policy and can only negotiate over fleet sizes. It is also assumed for now that side payments are absent from the cooperative game, which implies that the payoff to each country is determined by the size and effort level of its fleet. The method of cooperation between countries used here is the Nash bargaining solution or "arbitration scheme" developed by Nash (1953). This method has also been used by Riezman (1982) and Dixit (1987) to consider the outcome of cooperation between countries over tariff policies.

Consider first the noncooperative equilibrium in which countries do not negotiate binding agreements over fleet sizes. Following Riezman (1982), it is assumed that each country can choose from only two alternative strategies: a fleet size of a single firm or the optimal fleet size given the size of the other fleet. In the absence of side payments, the single-firm strategy is the optimal "non-retaliatory strategy" for each country because it implies that there is no dissipation of rent in the international fishery due to competition between firms in the same fleet. However, because a country cannot receive a share of the rent in the international fishery if it does not have at least a single firm in its fleet, this strategy also implies that there is always some dissipation of rent in the international fishery due to competition between the firm in one fleet and the firm (or firms) in the other fleet.[10] The optimal fleet size strategy, or the multiple-firm strategy, is the optimal "retaliatory strategy" for each country considered by Ruseski (1998) and involves the dissipation of rent in the international fishery due to competition between firms in the same fleet as well as between firms in different fleets.

Following a simplified version of Ruseski (1998) in which there are no fleet management costs, the objective of each country under the multiple-firm strategy is to choose the fleet size that maximizes its payoff from the international fishery, given the size of the other fleet, which is equal to the equilibrium rent that accrues to its fleet,

$$\max_{n_i} \quad W_i(n_i, n_j) = \Pi_i(n_i, n_j), \tag{37}$$

where $i, j = 1, 2$ and $i \neq j$. If both countries choose the single-firm strategy, then the payoff to each country is represented by the point N in Figure 3. However, if country 2 chooses the single-firm strategy but country 1 chooses the multiple-firm strategy, then the payoff to each country is represented by the point R. If instead country 1 chooses the single-firm strategy but country 2 chooses the multiple-firm strategy, then the payoff to each country is represented by the point S. The results found in Ruseski (1998) and illustrated here indicate that, in the noncooperative fleet licensing game, the payoff to each country from choosing the multiple-firm strategy is always greater than that from choosing the single-firm strategy. However, Ruseski (1998) finds that the noncooperative equilibrium in fleet sizes with no fleet management costs can be characterized by open access (or unlimited firm licensing) in each country and complete rent dissipation in the international fishery. The payoff to each country in this noncooperative equilibrium is represented by the point O in Figure 3 and is also the "threat point" payoff to each country in the cooperative game.

Consider next the set of possible solutions to the cooperative game, i.e., the set of possible payoffs to each country that result from the negotiation of binding agreements over fleet sizes, which Riezman (1982) refers to as the "negotiation set". Following Riezman

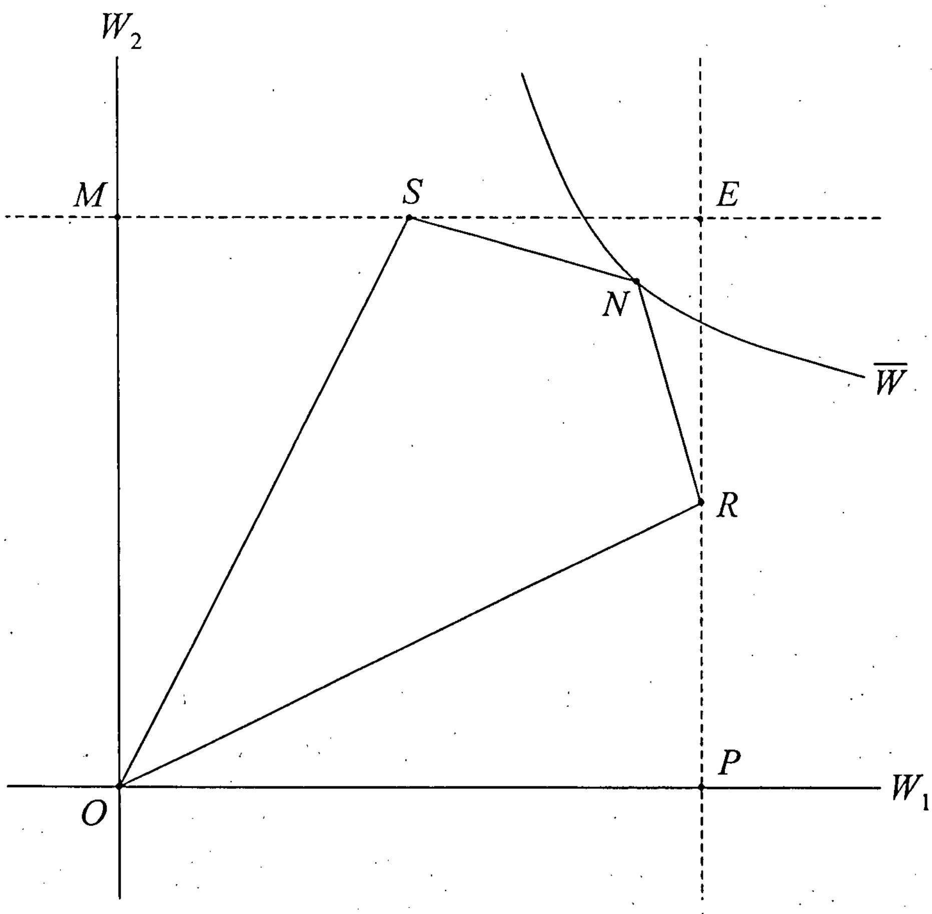

Figure 3: Payoffs in the fleet licensing model

and Dixit (1987), if mixed strategies are also allowed, then the set of possible solutions becomes the area represented by the quadrilateral $OSNR$. A solution to the cooperative game is considered infeasible if it results in a payoff to either country that is less than its threat point payoff. Given the threat point payoffs represented by the point O and assuming that the cooperative solution is Pareto optimal, the negotiation set is represented in Figure 3 by the line segment SNR.[11] Now consider how a unique cooperative solution is determined from the negotiation set. Using the Nash bargaining solution, both countries choose their fleet sizes according to the following rule,

$$\max_{n_1,n_2} \left[W_1(n_1,n_2) - \underline{W}\right]\left[W_2(n_1,n_2) - \underline{W}\right], \tag{38}$$

where $\underline{W}$ represents the threat point payoff to each country. In the absence of side payments, the best outcome that can be negotiated in this Nash bargaining framework is for each country to choose the single-firm strategy, which is represented in Figure 3 by the intersection of the curve labelled $\overline{W}$ with the negotiation set at the point N.

Both countries are better off at the negotiated point N than at the threat point O. However, using the analysis in Ruseski (1998) for the case of a single firm in each fleet, it can be shown that the level of effort associated with the point N is

$$E_1 + E_2 = \frac{r\,(1-b)}{q}, \tag{39}$$

or twice the efficient level of effort shown in (36). This means that negotiation over fleet sizes in the absence of side payments is inefficient. If side payments were now included in the cooperative fleet licensing game, then a single firm could harvest from the international fishery and each country could receive an equal share of the rent net of the fleet management cost. In the case of a single firm in the international fishery, the total level of effort in the international fishery would be the same as that shown in (36) and would result in the maximization of rent from fishing. The equilibrium payoff to each country from the cooperative game with side payments is represented in Figure 3 by the point E. Another possibility that is examined in the next section would be to introduce another tool of management policy - effort subsidies and taxes - to go along with the cooperative fleet size solution. The following proposition summarizes the main result of this section.

Proposition 6 *In the cooperative fleet licensing game, in the absence of side payments and other tools of management policy, negotiation between countries over fleet sizes is inefficient.*

3.4 The Cooperative Effort Subsidy Model

In this section a cooperative game is considered in which countries can negotiate binding agreements over effort subsidies. It is assumed here that countries do not use fleet sizes as tools of management policy, such that there is a single firm in each fleet throughout, and can only negotiate over effort subsidies. It is also assumed throughout that side payments are absent from the cooperative game, which implies that the payoff to each country is determined by its level of effort subsidy and the level of effort chosen by its fleet. Finally, it is assumed that countries can implement negative effort subsidies, or effort taxes, as well as positive effort subsidies, which will prove to be an advantage of the use of effort subsidies over the use of fleet sizes as tools of management policy.

Consider first the noncooperative equilibrium in which countries do not negotiate binding agreements over effort subsidies. As in the previous section and following Riezman (1982), it is assumed that each country can choose from only two alternative strategies: a negative effort subsidy, or an effort tax, that leads to a fleet effort level equal to half the efficient level shown in (36) or the optimal effort subsidy given the effort subsidy in the other country. In the absence of side payments, the effort tax is the optimal "non-retaliatory strategy" for each country because it implies a commitment to an equal share of the efficient effort level in the international fishery. Note that the strategy of a zero effort subsidy is not allowed here because it is neither the optimal cooperative strategy nor the optimal noncooperative strategy in the effort subsidy game. The effort subsidy strategy is the optimal "retaliatory strategy" for each country for the special case of a single firm in the fleet of each country, also considered by Ruseski (1998), and involves the incomplete dissipation of rent in the international fishery due to competition between firms in different fleets that is exacerbated by the presence of an effort subsidy.

Following Ruseski (1998), the objective of each country under the effort subsidy strategy is to choose the level of effort subsidy that maximizes its payoff from the international fishery, given the effort subsidy in the other country, which is here equal to the equilibrium rent that accrues to its fleet minus the cost of the effort subsidy,

$$\max_{s_i} \quad W_i(s_i, s_j) = \Pi_i(s_i, s_j) - s_i E_i(s_i, s_j). \tag{40}$$

If both countries choose the effort tax strategy, then the payoff to each country is now represented by the point E in Figure 4. For illustrative purposes, the payoff to each country if both countries choose neither an effort subsidy nor an effort tax is represented by the point N. However, if country 2 chooses the effort tax strategy but country 1 chooses the effort subsidy strategy, then the payoff to each country is again represented by the point R. If instead country 1 chooses the effort tax strategy but country 2 chooses the effort subsidy strategy, then the payoff to each country is again represented by the point S. The results found in Ruseski (1998) and illustrated here indicate that, in the noncooperative fleet licensing game, the payoff to each country from choosing the effort subsidy strategy is always greater than that from choosing the effort tax strategy. However, Ruseski (1998) also finds that the noncooperative equilibrium when both countries choose the effort subsidy strategy is characterized by the incomplete dissipation of rent in the international fishery for both countries. The payoff to each country in this noncooperative equilibrium is again represented by the point O in Figure 4 and is also the "threat point" payoff to each country in the cooperative game.

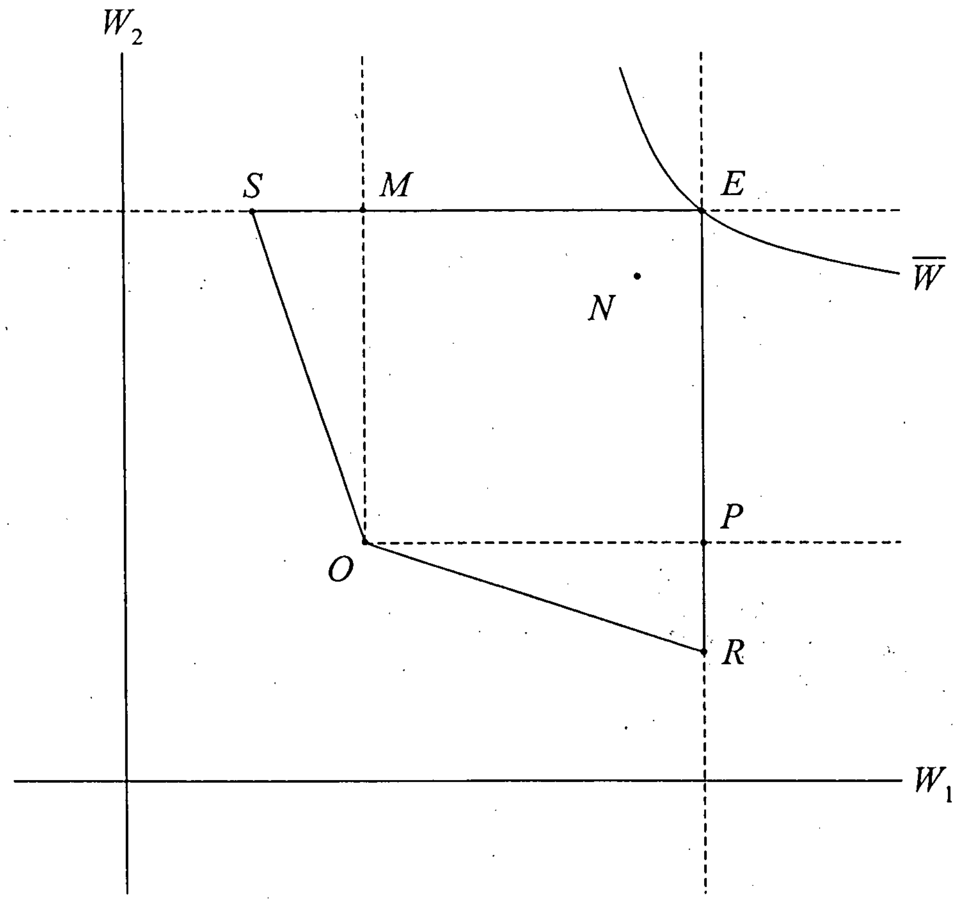

Figure 4: Payoffs in the effort subsidy model

In considering the set of possible solutions to the cooperative game, given these threat point payoffs and assuming once again that the cooperative solution is Pareto optimal, the negotiation set is represented in Figure 4 by the line segment MEP. Using the Nash bargaining solution, both countries choose their effort subsidies or taxes according to the rule,

$$\max_{s_1,s_2} [W_1(s_1, s_2) - \underline{W}] [W_2(s_1, s_2) - \underline{W}], \tag{41}$$

where $\underline{W}$ again represents the threat point payoff to each country. In the absence of side payments, the best outcome that can be negotiated in this Nash bargaining framework is for each country to choose the effort tax strategy, which is represented in Figure 4 by the intersection of the curve labelled $\overline{W}$ with the negotiation set at the point E.

Both countries are better off at the negotiated point E than at the threat point O and, moreover, the level of effort associated with the point E is the same as the efficient level shown in (36). This means that negotiation over fleet sizes in the absence of side payments is efficient. Thus there is a fundamental difference between negotiation over effort subsidies and negotiation over fleet sizes. The efficiency of negotiation over effort subsidies given a single firm in each fleet also implies that one way to improve on the outcome of negotiation over fleet sizes in the previous section is for each country to commit to the single-firm strategy and then commit to the effort tax strategy. If side payments were now included in the cooperative effort subsidy game, then one country could agree to impose a larger effort tax than that the level under the effort tax strategy while the other country could agree to impose a smaller (but always non-positive) effort tax, as long as both countries receive an equal share of the rent in the international fishery. The following proposition summarizes the main result of this section.

Proposition 7 *In the cooperative effort subsidy game, in the absence of side payments and other tools of management policy, negotiation between countries over effort subsidies is efficient.*

3.5 Concluding Remarks

This essay has developed a theory of cooperative management of international fisheries by considering negotiation over such well-known management policies as fleet sizes and effort subsidies (defined to include negative subsidies). The outcomes of negotiation over these policies were compared to the corresponding noncooperative outcomes and to the efficient outcome. It was concluded that negotiation over effort subsidies in the absence of side payments is efficient, but negotiation over fleet sizes in the absence of side payments is inefficient. This difference between the outcomes of negotiation over fleet sizes and effort subsidies provides a useful counterpart to the difference between the corresponding noncooperative outcomes examined by Ruseski (1998). In particular, it was found that non-cooperation over fleet sizes can lead to complete rent dissipation in the fishery, but non-cooperation over effort subsidies can only lead to incomplete rent dissipation. Thus, in the context of international fisheries management, both cooperation and non-cooperation between countries over fleet sizes seems to lead to outcomes that are generally inferior to those involving effort subsidies.

Several extensions to this analysis could prove to be of interest. One of these would involve relaxing the assumption of symmetry in the analysis presented here. As noted by Ruseski (1998), allowing one country to have, say, a lower cost per unit of harvest or a higher harvesting efficiency per unit of effort raises the possibility that management policies could be used as tools of strategic entry deterrence in a noncooperative game framework. This also suggests that the outcome of negotiation between asymmetric countries in a cooperative game framework would require the use of side payments from the relatively more efficient country to the relatively less efficient country, given that the efficient exploitation of the international fishery would involve harvesting only by the fleet in the relatively more efficient country. A well-known example of just such an outcome is the 1910 Fur Seal Treaty signed by Great Britain and the United States, in which Canada agreed not to hunt fur seals from its vessels in the North Pacific in exchange for a permanent share of the revenues from the sale of seal skins taken on the fur seal breeding grounds in Alaska.

Another potentially interesting extension would involve relaxing the assumption of a constant cost per unit of effort faced by the firms in each fleet. With a more general form of the effort cost function, having only a single firm in the fishery could lead to an inefficient level of fishing effort. If so, then having multiple firms in the fishery could lead to a level of fishing effort that is closer to the efficient level. In this extension, negotiation between countries over fleet sizes could be efficient if each country could agree to license the same number of firms in its fleet and the number of firms in both fleets adds up to the efficient number of firms in the fishery. Thus, with a more general form of the effort cost function, negotiation over fleet sizes could be efficient in the absence of side payments and other tools of management policy.

4 Strategic Management of National Fisheries

4.1 Introduction

The United Nations Convention on the Law of the Sea, which entered into force in 1994 but has been accepted as customary international law since 1982, has already had profound effects on global patterns of fisheries production and trade. While it has created well-defined international property rights over most of the world's fisheries, the new Law of the Sea has also transferred international market power in fisheries products from former distant-water fishing countries to coastal countries. It was expected that these effects would provide sufficient incentive for coastal countries to implement efficient fisheries management regimes within their exclusive economic zones. However, only a handful of countries have moved toward more efficient management of their fisheries, and the fishing industries in most countries have undergone rapid and unregulated expansion. Many observers have become concerned that international fisheries trade in the presence of inefficient national fisheries management regimes could jeopardize the goal of world fisheries conservation that had been intended with the new Law of the Sea. This essay explores the interaction that may exist between divergent national fisheries management regimes through international markets for fisheries products.

In this essay a two-stage two-period model of a 'domestic' country and a 'foreign' country whose respective fishing industries harvest from separate fisheries for the same international market is developed.[12] The domestic and foreign harvest in each period is determined by the zero-profit condition of open access. The domestic country uses a harvest policy to regulate the harvest by its fishing industry, but the harvest by the foreign fishing industry is unregulated. The domestic country chooses the level of its harvest policy in each period with the objective of maximizing the domestic surplus from fishing over both periods. Thus there is an efficient management regime in the domestic fishery and an inefficient management regime in the foreign fishery.[13] The timing of the two-stage game in each period is as follows: in the first stage the domestic country chooses the level of its harvest policy and in the second stage the fishing industries in both countries harvest simultaneously. The model is solved for the subgame perfect equilibrium domestic harvest policy and harvest by domestic and foreign fishing industries in each period.

Naturally, there is a direct role for the domestic harvest policy to induce an efficient domestic harvest in each period, but there can also be two indirect or strategic roles: i) to enable the domestic country to raise the domestic surplus from fishing through the terms of trade in each period; and, ii) to induce more foreign over-fishing through the terms of trade in the first period and thereby enable the domestic country to further raise the domestic surplus from fishing through the terms of trade in the second period. The first of these strategic roles produces the standard terms of trade argument for government intervention in the presence of international market power at the industry level. However, depending on the type of fishery in each country, the second of these strategic roles for the domestic harvest policy can produce rather striking results. In the case of schooling fisheries, the domestic country may choose a conservative harvest policy in the first period if it can induce the biological collapse of the foreign fishery in the second period. In the case of search fisheries, the domestic country always chooses a conservative harvest policy in the first period in order to induce the economic degradation of the foreign fishery in the second period.

The analysis presented in this essay is based on the assumption that some countries have international market power at the level of their fishing industries. Whatever the number of firms in the fishing industry of a country, if the fishery is exploited under an efficient management regime, then at some level this is equivalent to exploitation by a sole owner. If the harvest from this fishery yields a product that does not have any close substitutes, then there is also a monopoly in the international market for that product. If the same type of fishery is exploited under efficient management regimes in one or more other countries, then there is a duopoly or an oligopoly in the international market for that product. In this case countries could recognize that there is an international market rivalry between fishing industries and act accordingly. However, if there is, say, one country with an efficient management regime and one or more other countries with inefficient management regimes for the same type of fishery, it is more likely that only one of these countries can act upon the knowledge that its fishing industry has market power. The premise for this essay is the latter case.

This essay draws from the literature on trade policy in the presence of international rivalries between industries. Brander and Spencer (1985) and Dixit (1984) examine the strategic role for government intervention in a two-country model of an oligopolistic international market with a fixed number of firms in each country. The optimal domestic harvest policy in the second period of the model developed in this essay is similar to the optimal export policy in Dixit, but the optimal domestic harvest policy in the first period can be quite different under certain circumstances. Barbier and Rauscher (1994), Brander and Djajic (1983), and Brander and Taylor (1997) consider the potential roles for various trade policies that involve resource industries. One common theme in this literature is that trade policies can be used by countries to improve the global efficiency of resource exploitation. This essay develops the opposite theme in the sense that strategic behaviour by the domestic country in the form of a conservative harvest policy can not only exacerbate the over-exploitation problem in the foreign fishery, but can even result in the destruction of the foreign fishery.

This essay also draws from the literature on strategic interactions between the resource industries of different countries. While Ruseski (1998) examines the role for government intervention in the context of international fisheries, this essay examines the role for government intervention in the context of international markets for fisheries products. Similarly, while Copeland (1990) considers the strategic incentive for countries to under-invest in international fisheries, this essay considers the strategic incentive for countries to over-invest in nationally-owned fisheries in order to induce the further over-exploitation or even the destruction of fisheries in other countries. The notion of strategic interaction between countries in current and future markets for resource products has been considered by Salant (1976) and Gilbert (1978) in their studies of the structure of the world oil industry. The notion of conservation of fisheries in anticipation of more profitable market conditions in the future has been explored in the nonautonomous dynamic models of Clark and Munro (1975,1978). Finally, the strategic behaviour considered in this essay is similar in some respects to intra-industry conduct by firms that raises rivals' costs in Salop and Scheffman (1983).

The rest of the essay proceeds as follows. Section 2 describes the different biological and economic characteristics of the two types of fisheries examined in this essay. Section 3 presents the model of strategic conservation in the case of separate schooling fisheries.

Section 4 presents the model of strategic conservation in the case of separate search fisheries. Section 5 summarizes the results and offers some concluding remarks.

4.2 Biological and Economic Characteristics

Two types of fisheries are considered: schooling fisheries and search fisheries. These fisheries can be differentiated from each other by their biological and economic characteristics. In terms of their biological differences, Clark (1990) and Pitcher (1995) describe how certain species of fish often swim in dense schools as a defence mechanism against natural predation or during spawning activities. In contrast to other species, the schooling tendency of these fisheries often implies a natural mortality rate that increases as the size of the fish stock decreases. This in turn leads to a growth function that exhibits *critical depensation*: growth can become negative if the size of the fish stock should ever fall below some critical level. Since, by definition, other species of fish do not have this schooling tendency, the natural mortality rate for these fisheries most often decreases as the size of the fish stock decreases. This in turn leads to a growth function that exhibits *compensation*: growth cannot become negative as the size of the fish stock decreases. The growth function used in this essay can be modified to exhibit either critical depensation or compensation by changing the numerical value of a single parameter.

Building on the models of Mason and Polasky (1994) and Clark (1973), the sizes of the domestic and foreign fish stocks in period t are denoted by S_t and S_t^*, respectively, for $t = 1, 2$. The foreign fish stock is linked from one period to the next by the growth function $S_{t+1}^* = f(S_t^* - y_t)$, where y_t denotes the harvest by the foreign fishing industry. In this model, however, the growth function has the following properties: $f(r) > r$ for

$\underline{S} < r < \overline{S}$; $f(r) = r$ for $r = \underline{S}, \overline{S}$; $f(r) = 0$ for $r < \underline{S}$; $f' > 0$ and $f'' < 0$ for $\underline{S} \leq r \leq \overline{S}$. The initial size of the fish stock is assumed to lie between $\underline{S}$ and $\overline{S}$ and it is also assumed that the harvest in any period cannot exceed the size of the fish stock ($y_t \leq S_t^*$ or $r \geq 0$). The growth function for the domestic fish stock is assumed to be the same with the exception that x_t denotes the harvest by the domestic fishing industry.[14]

Think of $\overline{S}$ as the natural unexploited size of the domestic and foreign fish stocks and $\underline{S}$ as the *critical minimum stock size*: if the remaining stock of fish minus the harvest should fall below $\underline{S}$ in any period, then there will be a biological collapse of the fishery in the next period. In the case of schooling fisheries it is assumed that $\underline{S} > 0$ to reflect the potential for a biological collapse due to critical depensation in the growth function. In the case of search fisheries it is assumed instead that $\underline{S} = 0$ due to compensation in the growth function. An illustration of the properties of the growth function for the case of schooling fisheries is provided in fig. 1. The properties of the growth function for the case of search fisheries are illustrated instead if $\underline{S} = 0$, which would then make this figure the same as fig. 1 in Clark (1973).

In terms of their economic differences, Neher (1990) describes how it is relatively more difficult to harvest from a search fishery than from a schooling fishery because non-schooling species have a tendency to spread out over their fishing grounds. This tendency implies that the density of fish increases as the size of the fish stock increases. This in turn implies that the harvest cost function for a search fishery depends on the size of the fish stock: the larger the size of the fish stock the lower the cost per unit of harvest.[15] For schooling fisheries, however, the cost per unit of harvest need not depend on the size of the fish stock since the density of fish in individual schools does not depend as much on

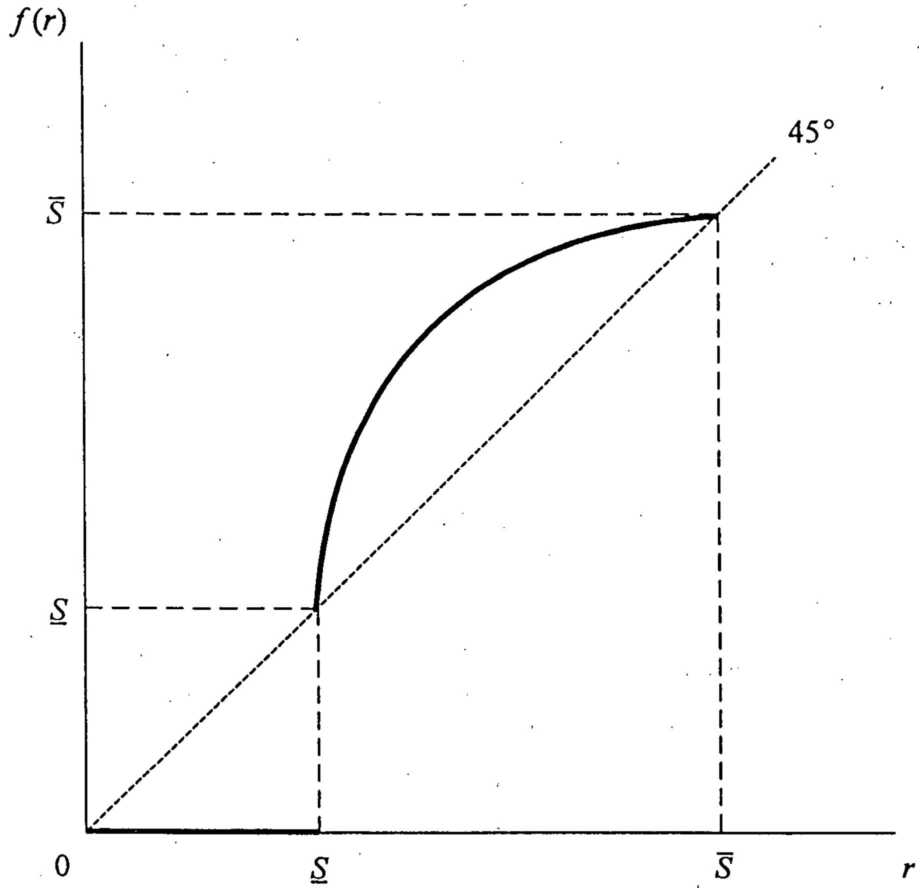

Figure 5: The growth function for schooling fisheries.

the size of the fish stock.[16]

The cost function in the domestic fishery is assumed to be $C(x_t) = c(x_t)x_t$ for a schooling fishery, such that the cost per unit of harvest is $c(x_t)$, and, following Mason and Polasky (1997), $C(x_t, S_t) = [c(x_t) + d(S_t)]\, x_t$ for a search fishery, such that the cost per unit of harvest is $c(x_t) + d(S_t)$, where $c' > 0$, $c'' \geq 0$, $d' < 0$, and $d'' \geq 0$. The cost function in the foreign fishery is assumed to be $C^*(y_t) = c^*(y_t)y_t$ for a schooling fishery, such that the cost per unit of harvest is $c^*(y_t)$, and $C^*(y_t, S_t^*) = [c^*(y_t) + d^*(S_t^*)]\, y_t$ for a search fishery, such that the cost per unit of harvest is $c^*(y_t) + d^*(S_t^*)$, where $c^{*\prime} > 0$, $c^{*\prime\prime} \geq 0$, $d^{*\prime} < 0$, and $d^{*\prime\prime} \geq 0$. It is natural to assume that, for sufficiently small (but positive) stock sizes, the additional terms $d(S_t)$ and $d^*(S_t^*)$ would become large enough for further exploitation of the search fishery to become unprofitable.

These biological and economic differences between schooling fisheries and search fisheries can lead to striking results for the subgame perfect equilibrium harvest policy chosen by the domestic country in the first period of the two-period model. In Section 4, the assumption of a non-zero minimum critical stock size implies that the domestic country may choose a conservative harvest policy in the first period if it can induce the biological collapse of the foreign fishery in the second period. In Section 5, the assumption of stock-dependent unit harvesting costs implies that the domestic country always chooses a conservative harvest policy in the first period in order to raise the foreign cost per unit of harvest in the second period. In the case of schooling fisheries, while there may or may not be sufficient incentive for the domestic country to induce the biological collapse of the foreign fishery, in the case of search fisheries there is always an incentive for the domestic country to induce the economic degradation of the foreign fishery.

4.3 Schooling Fisheries

The most important difference between the two countries examined in this essay is their fisheries management regimes: the domestic country regulates the harvest by its fishing industry through the domestic harvest policy while the foreign country does not. The analysis makes use of a two-period model with two stages in each period: in the first stage the domestic country chooses its harvest policy and in the second stage the fishing industries in both countries harvest simultaneously. The model is solved for the subgame perfect equilibrium domestic harvest policy and harvest by domestic and foreign fishing industries in each period.

It is assumed that the biological collapse of the domestic fishery in the second period cannot occur, say, because efficient management of the domestic fishery in some sense necessarily implies that there is a harvest in the second period, or because the initial size of the domestic fish stock is large enough to ensure that there can be a harvest in the second period. However, it is assumed that the biological collapse of the foreign fishery can occur by the beginning of the second period, say, because inefficient management of the foreign fishery in the first period need not imply that there is a harvest in the second period, or because the initial size of the foreign fish stock is not large enough to ensure that there can be a harvest in the second period. The assumption that the foreign fish stock is not necessarily large enough to avoid biological collapse can be justified in the sense that the foreign fishery may have been under an inefficient management regime before the two periods examined here, or in the sense that the foreign fishery may have been exploited non-cooperatively by several other countries before well-defined international property rights were established by the new Law of the Sea.

Consider first the second stage of the second period. The firms in the domestic fishing industry take the domestic harvest policy and the foreign harvest in this period as given and the firms in the foreign fishing industry take the domestic harvest in this period as given. Using $p(x_t + y_t)$ to denote the world (inverse) demand curve for the fishery product in period t, such that $p' < 0$, the total profit of the domestic fishing industry in this period is

$$\Pi_2 = [p(x_2 + y_2) - c(x_2) - t_2]\, x_2, \tag{42}$$

where t_2 denotes the domestic harvest policy in the second period: $t_2 > 0$ implies a harvest tax and $t_2 < 0$ implies a harvest subsidy. Using π_2 to denote the profit per unit of harvest, competition between domestic firms implies that the domestic harvest is determined by the condition

$$\pi_2 = p(x_2 + y_2) - c(x_2) - t_2 = 0. \tag{43}$$

If there is not a biological collapse of the foreign fishery, such that $S_2^* > 0$, then competition between foreign firms implies that the foreign harvest is determined by the condition

$$\pi_2^* = p(x_2 + y_2) - c^*(y_2) = 0. \tag{44}$$

If there is a biological collapse of the foreign fishery, such that $S_2^* = 0$, then there is no foreign harvest in the second period. These conditions determine the equilibrium domestic and foreign harvests $x_2(t_2)$ and $y_2(t_2)$ in the second period as functions of the domestic harvest policy in the second period. What are the effects of the domestic harvest policy in the second period? Totally differentiating (43) and (44),

$$\begin{aligned} \pi_{2x_2}\mathrm{d}x_2 + \pi_{2y_2}\mathrm{d}y_2 + \pi_{2t_2}\mathrm{d}t_2 &= 0, \\ \pi_{2x_2}^*\mathrm{d}x_2 + \pi_{2y_2}^*\mathrm{d}y_2 + \pi_{2t_2}^*\mathrm{d}t_2 &= 0, \end{aligned} \tag{45}$$

where $\pi_{2x_2} = p' - c' < 0$, $\pi_{2y_2}^* = p' - c^{*\prime} < 0$, $\pi_{2t_2} = -1$, $\pi_{2t_2}^* = 0$, and $\pi_{2y_2} = \pi_{2x_2}^* = p' < 0$. As long as there is a foreign harvest in the second period, using the result that

$$D \equiv \pi_{2x_2}\pi_{2y_2}^* - \pi_{2y_2}\pi_{2x_2}^* = (p' - c')(p' - c^{*\prime}) - (p')^2 > 0, \tag{46}$$

it can also be shown that

$$x_{2t_2} \equiv \frac{\mathrm{d}x_2}{\mathrm{d}t_2} = \frac{p' - c^{*\prime}}{D} < 0 \tag{47}$$

and

$$y_{2t_2} \equiv \frac{\mathrm{d}y_2}{\mathrm{d}t_2} = -\frac{p'}{D} > 0. \tag{48}$$

If there is not a foreign harvest in the second period, then it is obvious that $y_{2t_2} = y_2 = 0$ and it can also be shown that $x_{2t_2} = (p' - c')^{-1} < 0$. These results indicate that the domestic harvest decreases as the domestic harvest policy becomes more conservative (as t_2 increases) and, as long as there is a foreign harvest, the foreign harvest increases as the domestic harvest policy becomes more conservative.

Consider next the first stage of the second period. Subgame perfection implies that the domestic country anticipates the equilibrium in the second stage and chooses its harvest policy to maximize the domestic surplus from fishing in the second period,

$$G_2(t_2) = [\pi_2(x_2(t_2), y_2(t_2), t_2) + t_2]\, x_2(t_2). \tag{49}$$

Taking the total derivative of (49) yields

$$\begin{aligned} G_{2t_2} &= [\pi_2 + t_2]\, x_{2t_2} + \left[\pi_{2x_2} x_{2t_2} + \pi_{2y_2} y_{2t_2} + \pi_{2t_2} + 1\right] x_2 &(50)\\ &= t_2 x_{2t_2} + x_2(p' - c')x_{2t_2} + x_2 p' y_{2t_2}. &(51)\end{aligned}$$

Setting $G_{2t_2} = 0$ and rearranging yields the optimal domestic harvest policy for the second period,

$$t_2 = -x_2(p' - c') - \frac{x_2 p' y_{2t_2}}{x_{2t_2}} > 0. \tag{52}$$

The first term in this expression represents the direct role for the domestic harvest policy to induce the efficient domestic harvest in the second period and the second term represents the strategic role for the domestic harvest policy to raise its domestic surplus from fishing through the terms of trade in the second period. Taking into account the minus signs, the first term is positive (indicating a harvest tax) and the second term is negative (indicating a harvest subsidy), but it can be shown that the direct role for the domestic harvest policy dominates the strategic role and the optimal policy in the second period is a (positive) harvest tax.[17] A similar result is derived by Dixit (1984) in his reciprocal markets model of export policies with any number of domestic and foreign firms and is described by

Brander (1995) as the standard terms of trade argument for government intervention in the presence of international market power. Think of the optimal domestic harvest policy shown in (52) as the 'static optimum' in the second period.

Consider next the second stage of the first period. Once again, the firms in the domestic fishing industry take the domestic harvest policy and the foreign harvest in this period as given and the firms in the foreign fishing industry take the domestic harvest in this period as given. Competition between domestic firms implies that the domestic harvest in the first period is again determined by the condition that average profit per unit of harvest is zero,

$$\pi_1 = p(x_1 + y_1) - c(x_1) - t_1 = 0, \tag{53}$$

the foreign harvest in the first period is again determined by the similar condition,

$$\pi_1^* = p(x_1 + y_1) - c^*(y_1) = 0, \tag{54}$$

and the effects of the domestic harvest policy on the domestic and foreign harvests in the first period are the same as those in the second period shown in (47) and (48).

Consider next the first stage of the first period. Subgame perfection implies that the domestic country anticipates the equilibrium in the second stage of this period, but that it also anticipates the equilibrium in the second period. This means that the domestic country takes into account the effect of its harvest policy in the first period on the size of the foreign fish stock in the second period through its effect on the foreign harvest in the first period: the more conservative the domestic harvest policy in the first period, the greater the equilibrium foreign harvest in the first period and the lower the size of the foreign fish stock in the second period. Since the second period equilibrium depends on whether or not there is a biological collapse of the foreign fishery, there are three possible cases to consider. The first of these is that the equilibrium foreign harvest in the first period is never large enough to result in the biological collapse of the foreign fishery, no matter how conservative the domestic harvest policy in the first period relative to the static optimum. The second possibility is that, even if the domestic harvest policy is no more conservative than the static optimum in the first period, the equilibrium foreign harvest in the first period is large enough to result in the biological collapse of the foreign fishery. The third and most interesting possibility is that, for a sufficiently conservative domestic harvest policy in the first period relative to the static optimum, the equilibrium foreign harvest in the first period is large enough to bring about the biological collapse of the foreign fishery.

The first two possibilities are not particularly interesting, since in both cases the subgame perfect equilibrium harvest policy in the first stage of the first period is

$$t_1 = -x_1(p' - c') - \frac{x_1 p' y_{1t_1}}{x_{1t_1}}, \tag{55}$$

which is the same as the static optimum in the second period shown in (52). The only difference between the first and second possible cases is the presence or absence, respectively, of the foreign fishery in the second period. However, the third possibility indicates that, under certain circumstances, the domestic country may face a trade-off between domestic surplus in the first period and domestic surplus in the second period. On the one hand, choosing the domestic harvest policy in (55) leads to the maximum level of domestic surplus in the first period, but also accommodates a foreign harvest in the second period. On the other hand, choosing a sufficiently conservative harvest policy relative to that in (55) leads to relatively lower domestic surplus in the first period, but also results in the biological collapse of the foreign fishery and a world monopoly for the domestic fishing industry in the second period.

Let t_t^e denote the static optimum for period t shown in (52) and (55). Let t_1^m denote the domestic harvest policy in the first period that is just conservative enough to induce the biological collapse of the foreign fishery in the second period and let $t_2^m = -x_2(p' - c')$ denote the domestic harvest policy in the second period if there is a world monopoly for the domestic fishing industry in the second period. In this case, it is assumed that $t_1^m > t_1^e$ and that $S_1^* - y_1^e \geq \underline{S}$ and $S_1^* - y_1^m < \underline{S}$, where y_1^e and y_1^m denote the corresponding equilibrium foreign harvests in the first period. These inequalities mean that the biological collapse of the foreign fishery in the second period can only occur if the domestic country chooses the conservative harvest policy t_1^m instead of the static optimum t_1^e in the first period. Then the subgame perfect equilibrium for schooling fisheries involves the domestic country choosing one of two harvest policy regimes: $(t_1, t_2) = (t_1^e, t_2^e)$ or $(t_1, t_2) = (t_1^m, t_2^m)$. The domestic country chooses between these harvest policy regimes by determining which regime yields the maximum present value of domestic surplus from fishing,

$$G(t_1, t_2) = [\pi_1(x_1(t_1), y_1(t_1), t_1) + t_1]\, x_1(t_1) + \delta\, [\pi_2(x_2(t_2), y_2(t_2), t_2) + t_2]\, x_2(t_2), \quad (56)$$

where δ represents the domestic discount factor between periods. Whether or not the domestic country has enough incentive to induce the biological collapse of the foreign fishery in this case depends on the initial sizes of the domestic and foreign fish stocks and on the domestic discount factor. This section concludes by providing the following proposition that strategic conservation by the domestic country in the first period to induce the biological collapse of the foreign fishery in the second period can occur in subgame perfect equilibrium. The proof of this proposition is similar to the proof of the first proposition in Mason and Polasky (1994).

Proposition 8 *For the case of schooling fisheries, in subgame perfect equilibrium the domestic country chooses a conservative harvest policy in the first period relative to the static optimum for sufficiently small initial sizes of the foreign fish stock.*

Proof Let x_1^e be the first period equilibrium harvest by the domestic fishing industry if the domestic country chooses the domestic harvest policy t_1^e. Then the first period equilibrium harvest by the foreign fishing industry is y_1^e and, assuming there is not a biological collapse, the size of the foreign fish stock in the second period is determined by $S_2^* = f(S_1^* - y_1^e)$. In order for there not to be a collapse of the foreign fish stock, it must be the case that $S_1^* - y_1^e \geq \underline{S}$. However, there exists a critical level of S_1^* such that $S_1^* - y_1^e = \underline{S}$ and the foreign fishery is on the verge of biological collapse. At this critical size of the foreign fish stock, if the domestic country decreases its harvest policy in the first period infinitesimally below t_1^e, then the domestic country induces just enough foreign over-fishing in the first period to result in the biological collapse of the foreign fishery in the second period. Doing so leads to a discontinuous increase in the present value of domestic surplus from fishing, since there would be only an infinitesimal decrease in domestic surplus in the first period, but there would also be a world monopoly for the domestic fishing industry in the second period. For this critical size of the foreign fish stock, the domestic country would choose the conservative harvest policy over the static optimum for the first period in subgame perfect equilibrium. Q.E.D.

4.4 Search Fisheries

For search fisheries, since $\underline{S} = 0$ and unit harvesting costs decrease with the size of the fish stock, the biological collapse of the foreign fishery is de-emphasized while the economic collapse of the foreign fishing industry is emphasized. For example, depletion of the foreign fish stock in the first period could raise the cost per unit of harvest in the second period enough for it to become unprofitable for there to be a foreign harvest in that period. This leads to the possibility that the domestic country may choose a harvest policy in the first period that is conservative enough to induce more foreign over-fishing in the first period and result in the economic collapse of the foreign fishing industry in the second period. In this section, however, a less dramatic outcome can be considered in which it is shown that the domestic country always chooses a conservative harvest policy in the first period to induce more foreign over-fishing in the first period, even if it cannot result in the economic collapse of the foreign fishing industry in the second period.

Consider first the second stage of the second period. The profit of the domestic fishing industry in this period is now

$$\Pi_2 = [p(x_2 + y_2) - c(x_2) - d(S_2) - t_2]\, x_2 \tag{57}$$

and the domestic harvest is determined by the similar condition

$$\pi_2 = p(x_2 + y_2) - c(x_2) - d(S_2) - t_2 = 0. \tag{58}$$

The foreign harvest in this period is determined by the condition

$$\pi_2^* = p(x_2 + y_2) - c^*(y_2) - d^*(S_2^*) = 0. \tag{59}$$

These equations determine the equilibrium domestic and foreign harvests $x_2(S_2, S_2^*, t_2)$ and $y_2(S_2, S_2^*, t_2)$ in the second period as functions of the sizes of the domestic and foreign fish stocks and the domestic harvest policy in the second period. The effects of the domestic harvest policy and the domestic and foreign fish stocks in the second period are determined by totally differentiating (58) and (59),

$$\begin{aligned} \pi_{2x_2}\mathrm{d}x_2 + \pi_{2y_2}\mathrm{d}y_2 + \pi_{2S_2}\mathrm{d}S_2 + \pi_{2S_2^*}\mathrm{d}S_2^* + \pi_{2t_2}\mathrm{d}t_2 &= 0 \\ \pi^*_{2x_2}\mathrm{d}x_2 + \pi^*_{2y_2}\mathrm{d}y_2 + \pi^*_{2S_2}\mathrm{d}S_2 + \pi^*_{2S_2^*}\mathrm{d}S_2^* + \pi^*_{2t_2}\mathrm{d}t_2 &= 0, \end{aligned} \tag{60}$$

where π_{2x_2}, $\pi^*_{2y_2}$, π_{2y_2}, $\pi^*_{2x_2}$, π_{2t_2}, $\pi^*_{2t_2}$, and D are the same as before and $\pi_{2S_2} = -d' > 0$, $\pi^*_{2S_2^*} = -d^{*\prime} > 0$, and $\pi_{2S_2^*} = \pi^*_{2S_2} = 0$. While x_{2t_2} and y_{2t_2} are the same as in (47) and (48), it can also be shown that

$$x_{2S_2} \equiv \frac{\mathrm{d}x_2}{\mathrm{d}S_2} = \frac{(p' - c^{*\prime})d'}{D} > 0; \tag{61}$$

$$y_{2S_2} \equiv \frac{\mathrm{d}y_2}{\mathrm{d}S_2} = -\frac{p'd'}{D} < 0, \tag{62}$$

$$x_{2S_2^*} \equiv \frac{\mathrm{d}x_2}{\mathrm{d}S_2^*} = -\frac{p'd^{*\prime}}{D} < 0, \tag{63}$$

and

$$y_{2S_2^*} \equiv \frac{\mathrm{d}y_2}{\mathrm{d}S_2^*} = \frac{(p' - c')d^{*\prime}}{D} > 0. \tag{64}$$

These results indicate that the domestic (foreign) harvest in the second period increases (decreases) with the size of the domestic fish stock in the second period and decreases (increases) with the size of the foreign fish stock in the second period.

Consider next the first stage of the second period. The objective of the domestic government is to choose the level of domestic harvest in order to maximize the domestic surplus in this period,

$$G_2(S_2, S_2^*, t_2) = [\pi_2(x_2(S_2, S_2^*, t_2), y_2(S_2, S_2^*, t_2), S_2, t_2) + t_2]\, x_2(S_2, S_2^*, t_2) \tag{65}$$

and the solution is, once again, the static optimum in the second period,

$$t_2(S_2, S_2^*) = -x_2(p' - c') - \frac{x_2 p' y_{2t_2}}{x_{2t_2}} > 0, \tag{66}$$

though the optimal domestic harvest policy is now written on the left hand side as an explicit function of the domestic and foreign stock sizes in the second period.

Consider next the second stage of the first period. Once again, the firms in the domestic fishing industry take the domestic harvest policy and the foreign harvest in this period as given and the firms in the foreign fishing industry take the domestic harvest in this period as given. Competition between domestic firms implies that the domestic harvest in the first period is again determined by the condition that average profit per unit of harvest is zero,

$$\pi_1 = p(x_1 + y_1) - c(x_1) - d(S_1) - t_1 = 0, \tag{67}$$

the foreign harvest in the first period is again determined by the similar condition,

$$\pi_1^* = p(x_1 + y_1) - c^*(y_1) - d^*(S_1^*) = 0, \tag{68}$$

and the equilibrium domestic and foreign harvests in the first period are $x_1(S_1, S_1^*, t_1)$ and $y_1(S_1, S_1^*, t_1)$. The effects of the domestic harvest policy on the domestic and foreign harvests in the first period are the same as those shown in (47) and (48).

Consider finally the first stage of the first period. Subgame perfection implies that the domestic country anticipates the equilibrium in the second stage of this period, but that it also anticipates the equilibrium in the second period. This means that the domestic country takes into account the effect of its harvest policy in the first period on the sizes of the domestic and foreign fish stocks in the second period through its effect on the domestic and foreign harvests in the first period: the more conservative the domestic harvest policy in the first period, the lower(greater) the equilibrium domestic(foreign) harvest in the first period, the greater(lower) the size of the domestic(foreign) fish stock in the second period, and the lower(greater) the cost per unit of domestic(foreign) harvest in the second period. For search fisheries, since the second period equilibrium always depends on the sizes of the domestic and foreign fish stocks in the second period, there is always an incentive for the domestic country to choose a conservative harvest policy in the first period relative to the static optimum.

Given the equilibrium harvests in the second stage of the first period, $x_1(S_1, S_1^*, t_1)$ and $y_1(S_1, S_1^*, t_1)$, the domestic country chooses the first period harvest policy that yields the maximum present value of domestic surplus from fishing,

$$\begin{aligned} G(S_1, S_1^*, S_2, S_2^*, t_1) &= [\pi_1(x_1(S_1, S_1^*, t_1), y_1(S_1, S_1^*, t_1), S_1, t_1) + t_1]\, x_1(S_1, S_1^*, t_1) \\ &+ \delta\, [\pi_2(x_2(S_2, S_2^*), y_2(S_2, S_2^*), S_2, t_2(S_2, S_2^*)) + t_2(S_2, S_2^*)]\, x_2(S_2, S_2^*), \quad (69) \end{aligned}$$

subject to $S_2 = f(S_1 - x_1(S_1, S_1^*, t_1))$ and $S_2^* = f(S_1^* - y_1(S_1, S_1^*, t_1))$. Taking the derivative of (69) with respect to t_1 yields

$$\begin{aligned} G_{t_1} &= [\pi_1 + t_1]\, x_{1t_1} + \left[\pi_{1x_1} x_{1t_1} + \pi_{1y_1} y_{1t_1} + \pi_{1t_1} + 1\right] x_1 + \delta\, [\pi_2 + t_2]\, x_{2S_2} S_{2x_1} x_{1t_1} \\ &+ \delta \left[\pi_{2x_2} x_{2S_2} + \pi_{2y_2} y_{2S_2} + \pi_{2S_2} + \pi_{2t_2} t_{2S_2} + t_{2S_2}\right] S_{2x_1} x_{1t_1} x_2 \quad (70) \\ &+ \delta\, [\pi_2 + t_2]\, x_{2S_2^*} S_{2y_1}^* y_{1t_1} + \delta \left[\pi_{2x_2} x_{2S_2^*} + \pi_{2y_2} y_{2S_2^*} + \pi_{2t_2} t_{2S_2^*} + t_{2S_2^*}\right] S_{2y_1}^* y_{1t_1} x_2 \\ &= t_1 x_{1t_1} + x_1(p' - c') x_{1t_1} + x_1 p' y_{1t-1} + \delta f' x_2 d' x_{1t_1} + \delta f' x_2 d^{*\prime} \left(\frac{y_{2t_2}}{x_{2t_2}}\right) y_{1t_1}, \quad (71) \end{aligned}$$

which can be simplified and rearranged to yield the optimal domestic harvest policy in the first period,

$$t_1 = -x_1(p' - c') - \frac{x_1 p' y_{1t_1}}{x_{1t_1}} - \delta f' x_2 d' - \delta f' x_2 d^{*\prime} \left(\frac{y_{2t_2}}{x_{2t_2}}\right) \left(\frac{y_{1t_1}}{x_{1t_1}}\right) > 0. \quad (72)$$

The first term in (72) once again represents the direct role for the domestic harvest policy to induce static efficiency in the first period. The second term once again represents the strategic role for the domestic harvest policy to raise its domestic surplus from fishing through the terms of trade in the first period. These two terms taken together are just the usual static optimum in the first period. The third term represents the direct role for the domestic harvest policy to induce dynamic efficiency in the first period: the lower the domestic harvest in the first period, the larger the size of the domestic fish stock and the lower the domestic cost per unit of harvest in the second period. The last term represents the strategic role for the domestic harvest policy to exacerbate foreign over-fishing in the first period: the lower the domestic harvest in the first period, the larger the foreign harvest in the first period, the smaller the size of the foreign fish stock and the larger the foreign cost per unit of harvest in the second period. This enables the domestic country to even further raise its domestic surplus from fishing through the terms of trade in the second period.

Since the last two terms in (72) are both positive, it is clear that the subgame perfect equilibrium harvest policy is larger (more conservative) than the static optimum in the first period: the opportunity for the domestic country to raise its domestic surplus from fishing at the expense of the foreign fishing industry in the second period always provides an incentive for the domestic country to choose a conservative harvest policy in the first period, even if the economic collapse of the foreign fishery in the second period cannot occur. These results prove the following proposition that summarizes this result.

Proposition 9 *For the case of search fisheries, in subgame perfect equilibrium the domestic country always chooses a conservative harvest policy in the first period relative to the static optimum, regardless of the initial size of the foreign fish stock.*

4.5 Concluding Remarks

This essay has suggested that international fisheries trade in the presence of divergent national fisheries management regimes could have unexpected consequences for world fisheries. The results of the two-stage two-period model developed here are based on the assumption that two countries have international market power in an identical fisheries product at the level of their fishing industries. The results are also based on the assumption that the domestic country regulates its fishing industry and that the foreign fishing industry is unregulated. In the case of schooling fisheries, it has been shown that the domestic country may choose a conservative harvest policy in the first period if it can induce the biological collapse of the foreign fishery in the second period. In the case of search fisheries, it has been shown that the domestic country always chooses a conservative harvest policy in the first period, even if it cannot induce the economic collapse of the foreign fishing industry in the second period.

The analysis presented in this essay has emphasized the strategic role for government intervention in the form of a harvest policy for its fishing industry. Without this action by the government, the result that conservation of the fishery in one country can be used to induce the biological or economic collapse of the fishery in another country would not have occured. This implies that there continues to be a role for government management policies in their fishing industries, albeit a strategic role, even if these fisheries are exploited under efficient management regimes. In some sense, government intervention in the domestic country to induce the biological collapse of the foreign fishery can only occur in the presence of inefficient foreign management practices. However, in some other sense, the less drastic outcome that involves only the induced over-exploitation of the foreign fishery can occur even in the presence of efficient foreign management practices. Finally, while this essay has analyzed strategic conservation by a fishing industry and its government, the analysis developed here can be extended to consider the strategic roles for conservation in any other resource industry with a similar international market structure.

Endnotes

[1]I am grateful to an anonymous referee for providing this analogy in the trade policy literature. Implementing a domestic trade policy reduces domestic welfare in Horstmann and Markusen (1986) by inducing inefficient domestic entry without any foreign rent-shifting benefit in the integrated world market. Raising domestic fleet size in the fleet licensing model developed here can reduce domestic welfare by causing more entry-induced domestic rent dissipation than foreign rent-shifting in the international fishery.

[2]In the absence of potential entrants other than these two countries, the international fish stock can be characterized as a shared stock. The "new entrant problem" as it applies to straddling stocks and high seas stocks is discussed by Kaitala and Munro (1993).

[3]As suggested by an anonymous referee, it can be shown that fleet effort levels are strategic substitutes for a more general form of the steady-state stock size than that implied by the Schaefer model. Suppose (4) were replaced by the general form $x = F(E)$, where $E = \sum_{i=1}^{2} E_i$ and $F' < 0$. Then it turns out that fleet effort levels are strategic substitutes if and only if $F' + E_i F'' < 0$ for $i = 1, 2$, which is comparable to the regularity condition that the world demand curve is not "too convex" in world output in the traditional strategic trade policy literature (see Brander (1995)).

[4]While the size of each fleet is regarded as a continuous variable in this equilibrium, as has been indicated by Baye *et. al.* (1996), it can be shown that an equivalent equilibrium exists in which the number of firms in each fleet is restricted to an integer value.

[5]Strategic complementarity between fleet sizes does not provide a complete explanation for the outcome summarized by Proposition 3. It should be noted from (4) that the steady-state size of the fish stock is a linear function of the effort levels chosen by the fleets in both countries. This property of the steady-state stock size in the Schaefer model is an important additional factor to consider as part of a more complete explanation. For a general form of the steady-state stock size, such as that described in Endnote 4, one would expect the open access equilibrium in both countries to arise only as a special case, even in the absence of fleet management costs.

[6]This means that effort subsidies are not permitted to induce entry into or exit from the international fishery. Rather, effort subsidies are only permitted to induce more or less effort by existing firms in the international fishery.

[7]I am grateful to an anonymous referee for the suggestion that price subsidies (that raise p) or technology subsidies (that raise q) could also be modeled in much the same way that effort subsidies are modeled in this essay.

[8]I am grateful to an anonymous referee for mentioning this extension and for indicating that changes in the type of national management policy use by countries as they enter and exit an international fish war could be an interesting empirical question.

[9]See, for example, Munro (1978,1979,1987) and Kaitala and Munro (1993). In the standard model of international fisheries management, countries solve for the optimal steady-state stock size and hence the optimal steady-state national harvest and effort levels, given their own management preferences for the international fishery. Then, given that countries have made a bargain over relative harvest shares, countries must bargain over the relative weights to be given to their different management preferences. In this essay, because countries are assumed to have identical management preferences, it is only necessary for countries to bargain over the levels of their national management policies, because these policy levels determine the steady-state stock size and national harvest and effort levels.

[10]In the presence of well-defined international property rights, the efficient fleet size for the country that is the sole owner of the fishery would be a single firm.

[11]A cooperative solution is considered Pareto optimal if there does not exist an alternative combination of fleet sizes that increases the payoff to one country without decreasing the payoff to the other country. This means that points such as M and P in Figure 3 are inferior to points such as S and R, respectively, and therefore cannot be in the negotiation set even though the payoffs at these points are no less than the threat point payoff.

[12]There is neither a biological interaction nor a physical interaction between the domestic and foreign fisheries; there is only an economic interaction through the international market for their fisheries product.

[13]While the foreign management regime is deemed inefficient due to the absence of any harvest regulation, this could be the result of a rational choice by the foreign country to refrain from harvest regulation if management and enforcement costs are prohibitively high.

[14]The growth function used in this essay is just a two-period version of the recursive stock-recruitment relation in Clark (1990) that allows for biological collapse between one period and the next.

[15]A similar discussion in Clark (1990) emphasizes how differences in "concentration profiles" between species leads to different harvest cost functions. Wilen (1985) provides an alternative formulation of the harvest cost function for a search fishery in which the cost of time spent "searching" and the cost of time spent "fishing" are distinguished from each other.

[16]Paradoxically, Pitcher (1995) and Mackinson et. al. (1997) describe how the cost per unit of harvest for some schooling fisheries could actually *decrease* as the size of the fish stock decreases. This is because the behavioural response to stock decline often involves a reduction in the range over which schools travel with no significant reduction in the average school size.

[17]Substituting (47) and (48) into (52) and rearranging yields $t_2 = x_2 p' c^{*\prime} / (p' - c^{*\prime}) + x_2 c'$, which is unambiguously positive.

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