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Ballast Water: Ecological and
Fisheries Implications

POLICY INCENTIVES TO PREVENT THE INTRODUCTION OF NON-INDIGENOUS SPECIES VIA SHIPPING

Hymavathi Gollamudi
Alan Randall

Dept. of Agricultural Economics, The Ohio State University,
2120 Fyffe Road, Columbus,Ohio 43210, USA

ABSTRACT

Invasion of non-indigenous species poses an ecological threat to local environments and also has a major economic impact on local communities. Measures such as Mid-Ocean Exchange (M.O.E.), if required by regulation to prevent such invasions, may imply additional monetary burden to the affecting party, namely, the shipping industry. Economic costs combined with difficulty in monitoring M.O.E. may lead to noncompliance with such regulations. This paper proposes a game-theoretic approach to ensure compliance from ships. Monitoring schemes based on game theory have been shown to be superior to random monitoring schemes. This approach treats the concerned parties (monitoring agency such as the U.S. Coast Guard and the shipping industry) as two players in a game. All ships are divided into three groups depending on their past compliance history. Probabilities of monitoring and other penalties for violation of the regulation differ according to group. This scheme is both cost effective (to the monitoring agency due to low probabilities of monitoring) and politically feasible (due to low fines and penalties). Permanent cleanup technology options are proposed by the scientific community as better alternatives to M.O.E.. If devised properly, the proposed monitoring scheme will encourage installation of such alternative technologies and phase out the M.O.E. eventually.

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1. Introduction:

Invasion of Non-Indigenous Species (NIS) can pose an ecological threat to local environments and can have a major impact on local communities. In the Great Lakes, it is estimated that the economic losses due to the invasion of Zebra Mussel alone exceeds $5 billion. Ballast water of trans-oceanic ships is mainly responsible for such accidental introductions. Mid Ocean Exchange (MOE) has been required or recommended in various jurisdictions for cleaning the ballast water. However, there are some inherent problems associated with MOE - it takes time thus delaying shipping and increasing its cost, and it jeopardizes the safety of the ships in times of bad weather. From the perspective of public authorities, MOE is not 100 percent effective, especially if both the departing port and the arriving port are salt-water based, and monitoring is costly. For these reasons, MOE is considered as a transitory technology, for use until better alternatives can be found.

A variety of permanent cleanup technology options is being considered by the scientific community as better alternatives to MOE. Most of these appear to involve capital (installation) costs for the shipping industry with low variable (operating) costs. The industry would prefer to avoid high front-end costs. Nevertheless, permanent technologies are more effective than MOE and may require little or no monitoring by the monitoring agency (hereafter referred to as the 'agency'). For a comprehensive solution to this problem, engineers must develop more cost-effective permanent technologies, the scientific community needs to develop more complete information on costs and effectiveness of alternative technologies, and policy-makers need to choose appropriate policies and implement them.

In order to address the high social and economic costs of NIS introductions, a comprehensive strategy is needed to enforce compliance with MOE in the short run and encourage ships to adopt a permanent technology in the long run. Our research cannot address the identification of optimal permanent technology. Instead it seeks to develop cost-effective monitoring and enforcement strategies, assuming a permanent technology can be identified.

The purpose of this paper is to present a monitoring and enforcement mechanism that achieves the objective of preventing accidental introduction of NIS with minimal disruption to the shipping industry and minimal costs to the agency. The proposed model is developed on the premise that MOE is made mandatory for all ships entering ports after trans-oceanic voyages. MOE is the transitory technology which the agency would like to see replaced by some kind of permanent technology. This paper discusses 1) how to monitor the transitory technology effectively and efficiently, and 2) how to encourage ships to adopt a permanent technology.

Our starting point is the economic literature on optimal monitoring and enforcement. Most related studies in the monitoring literature deal with pollution emissions, where the firms that emit the pollutants are stationary in a geographical area. Some others deal with auditing tax-evasions etc. where the evading party can be pin-pointed ex-post (Greenberg, 1984). Our study appears to be the first in dealing with monitoring a set of firms that must follow regulations in the open seas and are geographically mobile.

2. Notation and Terminology:

The following notation will be used in the rest of the paper.
G_1 = the group of ships with good MOE compliance record
G_2 = the group of ships with bad MOE compliance record
G_3= the group of ships that have installed permanent technology
p_1 = probability of a ship being monitored in G_1
p_2= probability of a ship being monitored in G_2
y_1= not following any technology
y_2= MOE technology
y_3= permanent technology
R_1= cost of MOE
R_2= cost of following alternate ballast water cleaning mechanism required by the agency, in the event a ship is found in non-compliance
R_3= cost of installing and operating permanent technology

D = cost associated with time delays due to MOE.

T = number of visits to the port by a ship

3. *Components of the Model:*

3.1 Policy Objectives

Social costs that need to be considered in policy formulation include costs to ship-operators, costs to the agency and costs to society. Our research objective is to identify monitoring and enforcement strategies that will minimize agency costs and ship-operator cost while containing NIS introduction via shipping.

Ship-operator costs consists of cost of MOE, time delays associated with MOE, penalty if found in non-compliance, and cost of installing permanent technology. Cost of Mid-Ocean Exchange refers to actual process cost only. The US Coast Guard (CGD 91-066) reports that on average a ship in the size range of 7000-10000 tons of ballast water incurs a cost of $1147 for each MOE operation. Most ships lose speed while conducting MOE. These time delays associated with MOE can reduce the number of trips that a ship undertakes each year. Since this has direct economic impact on the costs, the loss (in dollars) due to the delay in conducting MOE must be considered. A study conducted by Rigby et al, (1991) gives 12 hours as the approximate number of hours it takes for a ship size of over 140000 tons of loaded dead weight to conduct MOE assuming that the MOE is done continuously. These costs do not take into consideration the time delays that the ship may encounter at the port due to monitoring delays. Although it is difficult to assess the cost of permanent technology, a range of costs based on Carlton et al, (1992) have been used in our analysis.

It is a truism in economics that compliance (e.g., with MOE mandates) can always be attained if the costs (e.g., to ship-operators) of non-compliance can be set sufficiently high. However, there are limits to the costs that one can impose on the shipping industry, given society's need for cost-effective shipping and efficient international trade. Furthermore, society often seems unwilling to impose draconian penalties for civil offenses (for example: non-compliance of MOE). These limitations on shipping costs and the size of penalties for non-compliance motivate the approach we have chosen.

3.2 Monitoring and Enforcement concepts

A monitoring mechanism can be effective only if it is accompanied by penalties. The agency can enforce compliance only when it monitors *and* levies penalties on violators. When an agency imposes penalties, it tries to make the present value of expected penalty for non-compliance greater than the present value of compliance costs. A potential violator, who is a cost-minimizer, thus finds it in his best interest to comply with regulation.

In the case of simple monitoring schemes (also called static or state-independent monitoring schemes), a penalty would be levied whenever a ship is found in non-compliance. This static system would have a constant probability of inspection which is independent of past outcomes. The firm calculates the probability of inspection (p), penalty if caught in non-compliance (f), and the cost of compliance(c). If $pf > c$ the firm complies, otherwise it violates. In theory, the agency can reduce monitoring costs by allowing p to fall so long as f becomes very large. But, in practice very high penalties for civil violations are seldom politically acceptable. Under this system the agency does not use any information it may obtain about the behavior of ships.

On the other hand, state-dependent or dynamic systems have been shown to be more cost effective to the agency than state-independent models [Harrington (1988)]. The key idea is that the agency uses the information obtained from past monitoring to classify ships in terms of their record of compliance, and then focuses future monitoring on the"poor compliance" class. For instance, consider a dynamic scheme consisting of two states: G_1 and G_2. Let G_1 represent the "good" category and G_2 represent the "bad" category. A firm found in violation in G_1 is moved to G_2, where it will encounter greater monitoring pressure and, perhaps, higher penalties until it can re-establish a good compliance record. Then, a potential violator in G_1 considers not only the one-shot penalty if detected (static case) but also the entire stream of future costs associated with G_2. By manipulating penalties and monitoring pressures the agency can ensure that the cost to ship-operators in G_2 is always higher than in G_1. Compared to static strategies, this dynamic strategy can achieve compliance with lower penalties and less frequent but better targeted monitoring. Monitoring permits the agency to learn something about the ship-operators, and the agency can be more cost-effective when it makes use of this information to adjust monitoring pressures.

This paper proposes a state-dependant mechanism that allows for dynamic transition among states, so the agency can demote violators to G_2 and ship operators can with effort move from G_2 back to G_1 or from either of those states to G_3. This scheme will have low monitoring probabilities (and hence low costs to agency) and low penalties for violation (and hence should be politically feasible).

Our analysis makes use of dynamic game theory. As the name suggests, game theory treats different parties as "players" in a game, each trying to outplay the other player(s) by employing different strategies. In our model, the monitoring agency and the shipping industry are the two players in a game.

3.3 Dynamic Game Theory .

Dynamic games can be solved using Bellman's backward recursive equations. Under this procedure, at each time period t, present values of all future costs under each decision are calculated and that decision which minimizes the future stream of costs is taken. The results show the decision of the ship (follow/not follow MOE) under each group, at each time period. These results are used to calculate rate of compliance of MOE and rate of installation of y_3, which in turn can be used to simulate the future composition of the fleet.

We can obtain combinations of monitoring probabilities (p_1,p_2) that fetch compliance of MOE from ships. With the knowledge of number of ships that frequent port, we can also obtain an approximate monitoring budget that is needed.

3.4 Asset Replacement

We use asset replacement principles to frame incentives for the ships to install permanent technology, y_3. An important principle of asset replacement is that asset A gets replaced by asset B when the cost of operating A equals or exceeds the cost of installing and operating B.

In choosing an asset (y_3), the motivation of the asset manager (ship owner) is to minimize the present value of the entire future stream of costs associated with the asset. The asset manager has to make two decisions regarding asset replacement : 1) *when* to replace the transitory technology by permanent technology?; and 2) *which* one of the new technologies to choose from the given array?

The policy maker (agency) wants to guide the asset manager to the "right" set of assets and also provide incentives for early adoption. If the performance characteristics differ across these new technology options, then the policy maker may have an interest in the technology choice also. As indicated above, however, our results do not address choice of permanent technology.

According to economic theory, an asset gets replaced when marginal cost of holding the old asset for a further year ≥ amortized cost of a new asset ≥ marginal cost of the old asset during preceding year. i.e.

$$MC_{t+1} \geq "AC" \geq MC_t$$

In empirical applications, the best method to determine optimal replacement age is to evaluate the middle expression of the above equation for each year, n = 1,2, 3, ... and select that integer value of n for which "AC" is minimum.

In our case, a ship will adopt a new technology at time t when

$$MC_{M.O.E._{t+1}} \geq AC_{newtech.} \geq MC_{M.O.E._{t}}$$

4. *Model*

In our state-dependent monitoring scheme, we use three states - G_1, G_2, G_3. At the beginning all ships start in G_1. Ships in G_1 are presumed to be following MOE. If found to be in non-compliance they are moved to G_2. A ship in G_2 has to build its reputation as a 'good' ship by complying k consecutive times before it is moved back to G_1. Anytime a ship adopts permanent technology (either in G1 or in G_2), it is moved to G3. G3 is the "absorbing state" - any ship in G3 will remain in G3 for ever. Thus the transition of a ship among these groups is based not only on compliance rate but also on the technology followed. The dynamics of the game are summarized in figure 1.

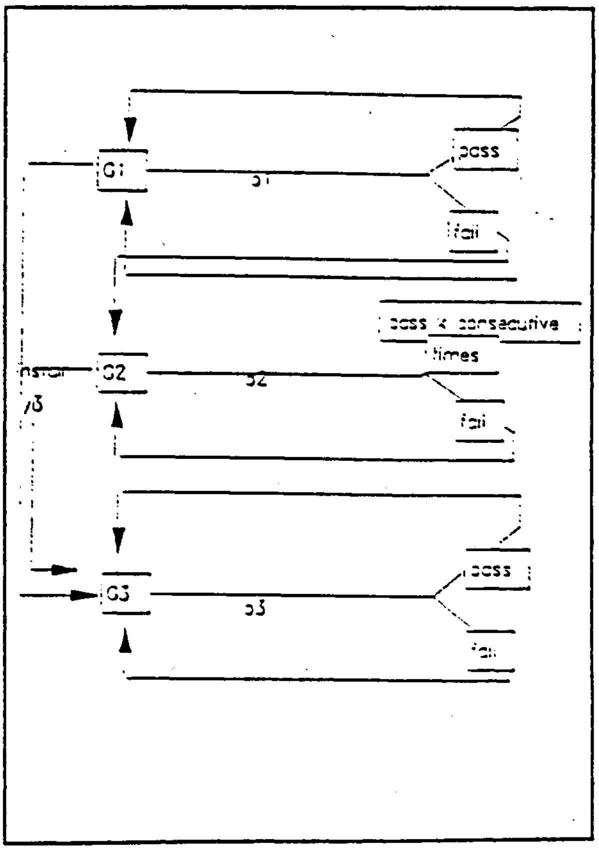

Figure 1 Structure of the Game

The probability of detection and penalties for non-compliance differ across the groups. The probability of a ship being monitored in G_1, i.e. p_1, is less than p_2, the probability of a ship being monitored in G_2. Penalties will be levied whenever a ship is found in non-compliance in G_1 and G_2. Penalties can also include cost of monitoring and time delays. To encourage ships to comply with MOE, penalties and monitoring should be adjusted so that the cost of performing MOE is made less than cost ot non-compliance. To encourage ships to install permanent technology, y_3, at some stage t, cost of conducting MOE should exceed cost of operating y_3.

Thus our strategy calls for:

$$C(y_1) > C(y_2) > C(y_3)$$

where C(y) denotes total cost of operating technology y [$y \in \{y_1, y_2, y_3\}$] to ships. $C(y_1)$ consists of (i) fine for violations, (ii) cost of alternate mechanism if caught (R_2), (iii) stream of future costs of being in G_2 if caught in G_1. $C(y_2)$ consists of (i) cost of MOE (R_1), and (ii) stream of future costs of being in G_1. $C(y_3)$ consists of cost of installing and operating y_3, (R_3).

Penalties and fines can be fine-tuned by varying parameters associated with time-delays and cost of monitoring to achieve the condition, $C(y_1) > C(y_2)$. $C(y_3)$ can be made less than $C(y_2)$ by either one of the following ways: (i) reducing R_3 via subsidies or cost-reducing innovations, or (ii) increase $C(y_2)$ relative to $C(y_3)$ by transferring cost of monitoring MOE to ships in G_1.

Given this game, the ship's problem can be characterized by the following equation:

$$\underset{i}{Min} \begin{cases} i=0 & p(R_2+D+\text{fine}+\text{cost of being } G_2)+(1-p)(\text{cost of being } G_1) \\ i=1 & R_1+D+\text{cost of being } G_1 \\ i=3 & R_3+\text{cost of being } G_3 \end{cases}$$

where i = 0 : do not follow MOE, i = 1: follow MOE, and i = 3 : move to y_3.

At each stage t, a ship in a group G calculates costs of alternate actions and takes that decision that will minimize the cost. Intuition tells us that the more often a ship comes into a particular port, the stream of costs of being in G_1 increase and will thereby bring about movement from y_2 to y_3 technology.

The game is simulated for a sample fleet of 1000 ships to illustrate the mechanism. The cost of MOE and the cost of monitoring are taken from the cost estimates reported by the USCG. The studies by Rigby et al, and Branch(1992) are used to obtain an estimate of time-delay cost (in dollar terms) due to MOE. Preliminary results show that the compliance with MOE jumps from 0 to >96% as we reach optimal combinations of (p_1, p_2). Figure 2 gives the locus of such optimal (p_1, p_2) points for a compliance of >96%. This graph is obtained by varying (p_1, p_2)

combinations with a 0.1 interval, holding all other variables constant. From the figure it can be seen that a high compliance rate can be achieved with a low p_1.

The results also show that the more often a ship visits a port (T) the faster it adopts permanent technology, y_3. Further, simulations suggest that ships in G_2 adopt permanent technology before ships in G_1. These results may be used to determine the future composition of the fleet. To get started, we considered the rate at which an existing fleet might retrofit to install permanent echnology. Figure 3 shows the composition of the fleet from time period 0 to time period 20 using p_1=0.2 and p_2=0.8.

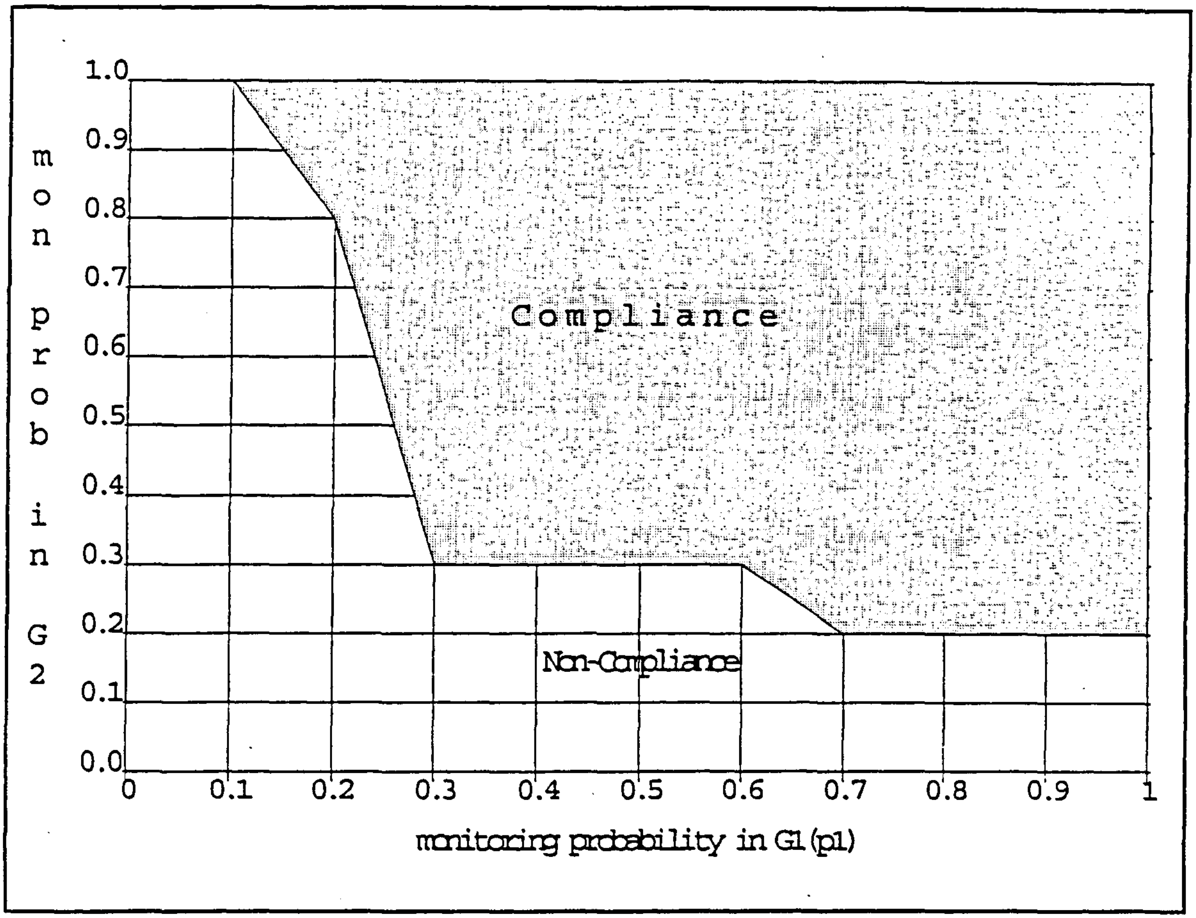

Figure 2 MOE Compliance Space

All ships are assumed to start in G_1 at time period 0. As can be seen from the figure,

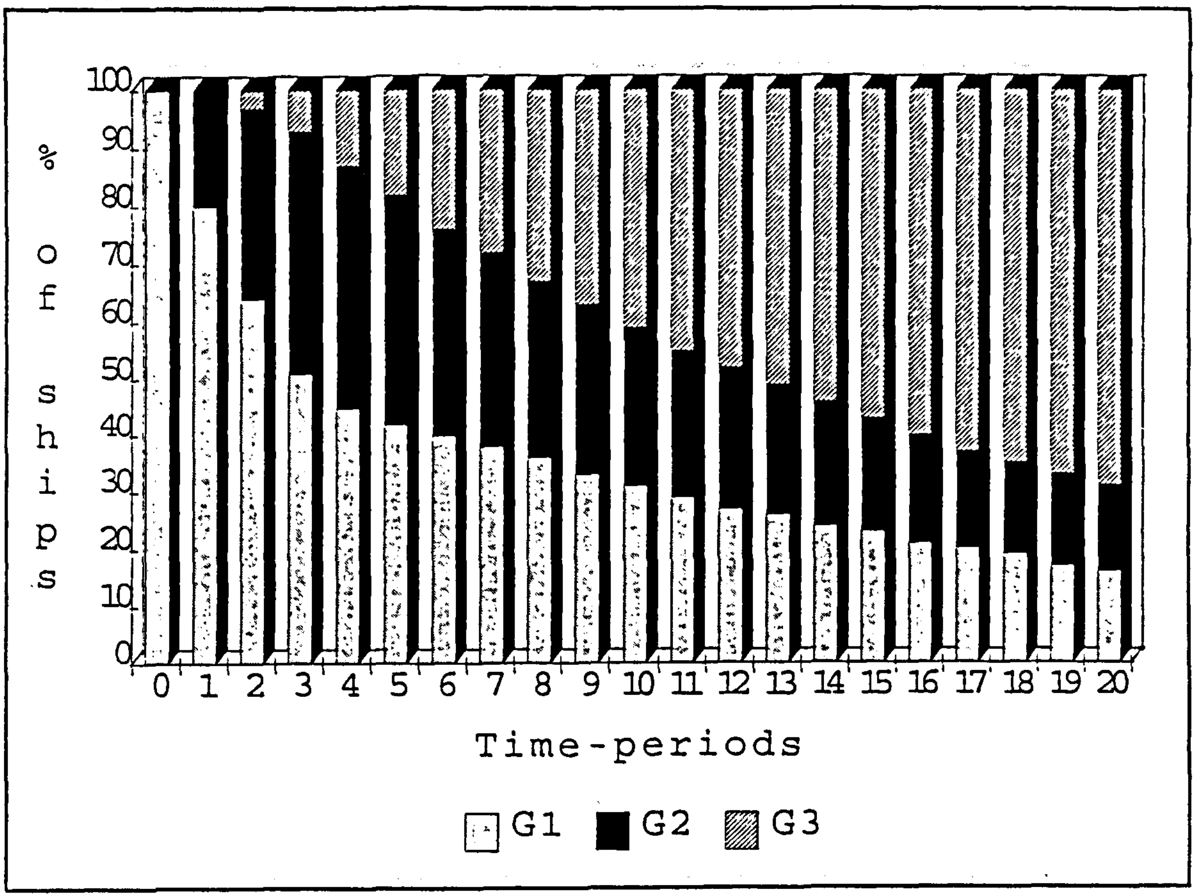

Figure 3 Composition of Fleet

more than half of the ships will move to G_3 by time period 20. By manipulating variables such as (p_1,p_2), the agency can control the percentage of ships in each of the groups over time.

We expect that by combining asset replacement principles with the monitoring mechanism it will be possible to develop a monitoring scheme that ensures that all newly built ships adopt permanent technology immediately. We have not yet modeled fleet composition with retrofitting and ship replacement, but it is reasonable to expect the proportion of ships under G_3 to increase more rapidly under that regime than with retrofitting alone.

5. Conclusion:

Invasion of NIS into local environments through the ballast water of trans-oceanic ships poses a major threat to local communities. MOE is frequently used as a transitory mechanism to control this problem. A monitoring and enforcement mechanism based on incentives deduced from game theory and asset replacement principles is presented. This mechanism ensures compliance with MOE from ships in the short run and encourages adoption of some permanent clean up technology in the long run. We have provided some illustrative results showing how penalties and monitoring pressure can be adjusted to increase compliance with MOE and to increase over time the proportion of ships adopting permanent technology. Solutions specific to each port can be obtained by using dynamic programming techniques and port specific cost data. If devised properly this scheme will encourage installation of alternate technologies and phase out MOE eventually.

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