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**THE ECONOMICS OF AQUATIC NUISANCE SPECIES PREVENTION  
IN THE GREAT LAKES**

By

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## **ABSTRACT**

### **THE ECONOMICS OF AQUATIC NUISANCE SPECIES PREVENTION IN THE GREAT LAKES**

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Just over a decade ago, the zebra mussel came to the Great Lakes. This rapidly expanding species brought new attention to an issue of great importance to the Great Lakes, Aquatic Nuisance Species (ANS). The term Aquatic Nuisance Species refers to aquatic organisms not indigenous to a particular ecosystem, in this case the Great Lakes, which impose costs on the ecosystem and society. The devastating ecological consequences and the considerable direct economic costs of certain introductions, and the potential for future invaders, give the ANS issue importance and argue for efforts to prevent future threats. This paper provides an introduction to the economics of the ANS issue for the purpose of policy evaluation. The analysis in this paper utilizes a framework for policy evaluation that focuses on two facets of good policy design: the basis, the measure to which the policy is applied, and the instrument, which is the policy tool used. An effective policy will use an appropriate basis and instrument. This paper contains a review of a variety of different policy bases and instrument and explore their strengths and weakness with regard to economic theory and the unique nature of ANS invasions as well as which bases might be appropriate for which instruments.

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## **Chapter One**

### **Introduction and Literature Review**

#### **I. Introduction to the Aquatic Nuisance Species Dilemma**

Just over a decade ago, the zebra mussel came to the Great Lakes. This rapidly expanding species brought new attention to an issue of great importance to the Great Lakes, Aquatic Nuisance Species (ANS). The term Aquatic Nuisance Species refers to aquatic organisms not indigenous to a particular ecosystem, in this case the Great Lakes, which impose costs on the ecosystem and society. While not all non-indigenous species are necessarily nuisances, the effects of all non-indigenous species may not have been comprehensively studied, and so this paper will consider all non-indigenous species to be ANS for ease of exposition.

The zebra mussel may be one of the best known ANS, although it is certainly not the only one. The Great Lakes host over 140 non-indigenous species, representing a wide range of taxonomic groups. ANS have a variety of effects on the Great Lakes ecosystem due to their predatory and competitive behavior which can result in habitat modification, the introduction of various pathogens and parasites as well as genetic effects (Leach *et al.*, 1999). Certain species, such as the sea lamprey, play a largely predatory role. It feeds on an assortment of fish species such as trout and salmon, occupying a unique position in the food chain. Other ANS have altered the Great Lakes ecosystem through their competition with native species. The purple loosestrife competes with native plant species and has widely modified habitat in the region.



While Aquatic Nuisance Species have indelibly changed the Great Lakes ecosystem, many individual non-indigenous species have had little noticeable impact. Overall, the damage to the ecosystem from ANS can result in a number of changes. These changes can include the extermination of species, changes in the food chain, changing habitats, and loss of recreational opportunities.

Along with the ecological effects of ANS lie the economic costs. The economic costs of Aquatic Nuisance Species can be divided into the direct economic costs and the indirect economic costs. The direct economic costs result from such ANS activities as the zebra mussels' fouling of fishing gear or the sea lampreys' effect on the trout fishing industry (Reeves, 1999). The indirect economic costs derive from the value lost due to a changing ecosystem. For instance, the watermilfoil's effect on its habitat imposes a cost to society by altering the ecosystem.

Valuing the ecological changes due to Aquatic Nuisance Species poses many challenges. However, estimates of the economic costs of the ANS give an idea of the enormous consequences of ANS invasions. The zebra mussel alone has resulted in hundreds of millions of dollars spent on clearing water intake pipes, while the sea lamprey has potentially caused billions of dollars (Reeves, 1999) in lost revenue to the recreation and commercial fishing industries. Again, while not all ANS produce such serious problems, the ecological and economic effects of some of these species are real and quite significant.

The devastating ecological consequences and the considerable direct economic costs of certain introductions, and the potential for future invaders, give the ANS issue importance and argue for efforts to prevent future threats. This chapter provides an introduction to the ANS issue. It profiles the ANS which have come to the Great Lakes,

reviewing their effects, the vectors used for introduction, current policies, and possible prevention strategies. In so doing, this chapter provides the necessary background for later analysis of the prevention policies.

## **II. ANS in the Great Lakes and Vectors of Introduction**

ANS vary with respect to taxonomic grouping, economic costs, ecological effects and notoriety. Aquatic plants are the best represented taxonomic group and include both the Purple Loosestrife and the Eurasian Watermilfoil: two plants with significant ecological impacts in the Great Lakes region. The remaining taxonomic groups include fish, algae, mollusks, crustaceans, oligochaets, disease pathogens, hydrozoans, insects, and flatworms. Worth noting is the fact that a higher proportion of fish species, relative to other taxonomic groups, have significant economic and ecological costs. Figure 1.1 lists the different ANS taxonomic groups and the number of species within each.

The entire list of Aquatic Nuisance Species includes a large number of relatively obscure organisms along with a few well-known species. Additionally, while a large number of ANS have come to the Great Lakes, only a small portion, roughly 10%, have had significant effects on the ecosystem (Mills *et al.*, 1993). Table 1.1 lists a number of ANS which have substantially affected the Great Lakes ecosystem, the year of their first sighting in the Great Lakes, as well as the probable modes of introduction.

The vectors of ANS introduction are identified in Table 1.1 by the following acronyms: R(AQ) for release from an aquarium, R(F) for release of bait fish, R(A) for an accidental release (a rather broad vector), R(D) for deliberate release like fish stocking, S(F) for ship fouling, S(SB) for solid ballast, S(BW) for ballast water, and C for canals. Two other

vectors also exist, unintentional release through cultivation as well as railroads and highways.

These ten vectors can be arranged into five categories (Mills *et al.*, 1993). First, deliberate release; this class of vectors includes both the stocking programs of governments as well as the intentional introduction of non-indigenous species by individuals. These vectors have not been responsible for any new introductions into the Great Lakes in more than 40 years. The second category, unintentional releases includes the release of bait fish and other organisms spread in that manner, release from aquariums, release from cultivation, and accidental releases(a catch-all category). Unintentional releases have contributed to the introduction of a large number of new ANS in the last fifty years. Third, shipping activities; this category includes solid ballast, hull-fouling, and ballast water. Ballast water in particular has become a very important vector for ANS introduction. Highways and railroads make up the fourth category, and they have largely ceased to be a significant vector. Canals are the final vector. The Erie and Illinois Canals have allowed some ANS into the Great Lakes, still posing a threat, though less so than certain other vectors.

Introductions of non-indigenous species into the Great Lakes were first recognized in the 1800's. ANS have utilized all the vectors listed above to enter the Great Lakes, while the relative frequency of use has shifted over time among the vectors. Most of the ANS currently in the Great Lakes came here as a result of human action, as can be seen in the list of vectors. Table 1.1 lists the various vectors utilized by a selection of ANS. Figure 1.2 displays the different categories of introduction vectors, and when species utilized them.

Ships have played a role in introducing 29 non-indigenous species into the Great Lakes from 1960-1991. That number constitutes over 60% of the ANS introductions during

that time period. Since the early 1800s the shipping industry has aided about 28% of the ANS in the Great Lakes. While the percentage has increased, the means have changed. Historically, ships have introduced ANS through solid ballast and hull-fouling (organisms attaching themselves to the hulls of ships and being scraped off in different areas). Throughout much of the last two centuries hull-fouling and solid ballast were important vectors for ANS introduction due to ship construction and technology. Because of anti-fouling methods and ballast tanks, these two vectors have declined in importance as a vector of introduction. The hulls of wooden ships provided a place for organisms to attach themselves and for other organisms to bore into. The general switch from wooden ships to steel hulled ships generally thwarted hull-boring species, while the application of anti-fouling paints on hulls and increased ship speeds further reduced the likelihood of hull-fouling. However, hull-fouling still poses a threat for transporting organisms (Rainer, 1995), despite the advances in the shipping industry.

Solid ballast has largely ceased to exist, and therefore poses no threat to introduce potential ANS. However, solid ballast was responsible for certain introductions such as purple loosestrife. When ships were not constructed with ballast tanks, they often required weight to balance the ship properly. Solid ballast was that weight, and it could take many different forms. Occasionally plants or other organisms were included in the ballast and then deballasted in other regions. In this manner solid ballast transported potential invaders.

At present, shipping activities, particularly ballast water, and unintentional releases are the main vectors responsible for ANS introductions. Ballast water has become a quick route for species to migrate. Ships that take on ballast in fresh water ports around the world and unload the ballast in Great Lakes ports allow freshwater organisms to avoid saltwater

which provides a buffer zone for the Great Lakes ecosystem. Unintentional releases result through many different ways including boaters, gardeners, fishermen, and aquarium owners. Identification of the vectors of introduction will aid in the formulation of policies to prevent ANS introduction.

### **III. Effects of ANS in the Great Lakes Region**

As noted earlier, the consequences of ANS in the Great Lakes vary greatly among species and may or may not have significant economic impacts. Generally, these economic effects can be separated into two categories, the direct economic costs caused by ANS along with the economic values of the changes in the Great Lakes ecosystem. Certain species, such as the sea lamprey produce both economic costs and changes in the environment with significant economic value. First, the sea lamprey causes losses in the fishing industry by killing valuable sport and food fish. Secondly, through its predatory behavior on the fish population, the sea lamprey has changed the Great Lakes ecosystem, thereby posing an economic cost for those who enjoyed the Great Lakes in their unaltered state. Other organisms, like the purple loosestrife, create economic impacts largely through its ability to change the ecosystem. Table 1.2 presents some of the most economically and ecologically damaging Aquatic Nuisance Species along with their effects.

Counting the costs imposed by the ANS on the economy presents far less difficulty than valuing changes in the ecosystem. Randall and Gollamudi (1998) write that “As befits the attempt to value what is basically a state of the world, non-use values, non-market values, and values arising from uncertain future uses of various kinds loom large in the analysis.” Many of the abovementioned species as well as other ANS compete with native species and

have the potential to greatly change their environment. Some changes, like the reduction of trout populations by the sea lamprey, pose readily measurable direct economic costs for industry which may run into the billions of dollars (Reeves, 1999), along with the changes produced in the Great Lakes ecosystem.

#### **IV. Prevention of ANS**

As outlined above, ANS can have significant effects on the Great Lakes ecosystem and economy, thus prevention is an important topic to consider. Within the last two hundred years a number of policies potentially may have helped prevent the introduction of ANS. For instance, stricter policies on fish stocking would have kept certain fish species out. This relatively inexpensive measure may have prevented the introduction of several different ANS. (Prohibiting the stocking of non-indigenous fish would have had mixed results though, since the sport fishing industry benefits from their presence.) However, deliberate fish stocking has ceased to be a major vector for non-indigenous species entering the Great Lake.

Within the last forty years two vectors have been responsible for new ANS introductions, it is these two vectors which merit targeting: shipping (mainly through ballast water) and unintentional releases. Both of these vectors contain its own set of difficulties and requires a unique approach. The shipping industry presents a somewhat stochastic threat to the Great Lakes ecosystem from ships that vary according to age, origin, condition, and amount of ballast water among other factors. Each ship coming from a foreign port carries either ballast or sludge (in the case of a NOBOBs, ships with no ballast on board),

which may contain potential ANS. Different alternatives exist to neutralize these organisms. Currently, the U.S. government mandates that ships partially exchange ballast water in the open ocean to flush fresh water organisms and exchange them with organisms native to the open ocean which will have a much greater difficulty adapting to the Great Lakes ecosystem. This requirement does not apply to NOBOBs however, which account for the majority of the ships entering the Great Lakes. Figure 1.3 diagrams the scope of ballast water management. The treatment measures currently receiving the most attention are onboard treatment measures.

The other recently-utilized vector, unintentional releases, is broader and thus its many facets will require different tools. Many of the prevention options for ballast water will not work for unintentional releases, particularly the technical options, which are tailored for the ballast water problem. Other more general tools, such as education, subsidies, and regulations may work well in different forms for both vectors.

With all these different prevention options, why has the government only instituted regulations that basically direct captains to exchange ballast water when possible? Economic efficiency and cost-effectiveness concern both the shipping industry and the government. The government could adopt more severe behavioral regulations mandating every ship entering the St. Lawrence Seaway to attain a high salinity standard, such as 95%, regardless of weather or safety issues. This however would immediately decrease the profitability of the shipping industry by forcing fleets to keep some ships out of the Great Lakes altogether or face high retrofitting costs. The fact that many policies do pose a threat to the profitability of the shipping industry means that it will have the incentive to oppose the ANS prevention policies it views as too stringent. While table 1.3 does list a number of options,

they do not share equal levels of feasibility. Also, the potential for new and improved technical solutions exists, which has provided an argument against the implementation of current options. Table 1.4 gives more detailed descriptions of a selection of the prevention technologies that have received attention.

#### *The Role of Shipping in ANS Introductions*

For purposes of analysis, the Great Lakes shipping industry contains roughly three segments (Reeves, 1999). U.S. lakers comprise the first group. These U.S. ships stay within the Great Lakes and pose no risk for introducing ANS to the Great Lakes, however, they could be a potential vector for aiding the spread of species among the lakes. Canadian lakers and salty lakers make up the second group. The lakers operate entirely within the Great Lakes while the salty lakers generally stay within the lakes and coastal waters. The salty lakers pose a risk, although much less than the final group, the third party salties. This final segment of the shipping industry presents the greatest threat to the Great Lakes. Third party salties, as their name suggests, carry the flags of countries other than the U.S. and Canada and engage in transatlantic commerce. They can introduce Aquatic Nuisance Species by taking on ballast water in a foreign port and then dumping it in the Great Lakes. This process works most effectively when the third party salties take on ballast in a freshwater port, preferably with a similar climate to the Great Lakes. It is in this way that the zebra mussel immigrated to the Great Lakes from Western Europe. The U.S. currently has in place a policy whereby all ships must partially exchange ballast outside the EEZ (exclusive economic zone, about 200 miles) to obtain a 85% level of ballast exchange, unless the ship's captain considers it unduly risky (Reeves, 1999). This measure was instituted to kill as many potential ANS as possible by switching freshwater organisms in the ballast water with



saltwater species. This policy definitely helps, but it certainly does not eliminate the risk of ships introducing new organisms to the Great Lakes through their ballast water.

## **V. ANS Prevention Policies**

Conservation legislation has existed in the United States for many years in some form, but only recently have laws been enacted which address Aquatic Nuisance Species in the Great Lakes. The most recent major piece of national legislation was the National Invasive Species Act of 1996 (NISA, 1996), which ultimately had the effect of enacting mandatory reporting requirements for ballast water exchange. Along with this important contribution to the ANS solution have come efforts from around the world as Table 1.5 shows.

Policies that effect the Great Lakes have come from three fronts. Most importantly, both the U.S. and Canadian governments have passed legislation in an attempt to prevent the introduction of potential ANS. International organizations, such as the International Maritime Organization have issued guidelines for dealing with this challenge. Indeed, non-indigenous species pose a threat to many countries beside the U.S. and Canada. Thirdly, many states and provinces have issued management plans to deal with the further spread of Aquatic Nuisance Species. Table 1.6 contains some of the actions taken by different governments and groups in confronting the ANS threat. While steps have been taken to prevent ANS introductions, more work remains. The following chapters analyze the economics of this issue and policies to deal with it.

## **Chapter Two**

### **Modeling ANS Invasions**

Invasive species are a form of biological pollution, and so it is natural to turn to the economic literature on pollution control to search for potential solutions. Very often people think about air pollution problems when they think about the economics of pollution control. This literature is well-developed (e.g., Hanley et al., 1997) and offers some relatively simple solutions that are being increasingly used in practice (U.S. EPA, 2001). But biological pollution exhibits some complexities that make the application of conventional solutions problematic. For instance, biological emissions are stochastic and essentially unobservable, which makes implementation of the sorts of emissions-based policies that are usually proposed infeasible. Rather, biological pollution is more like nonpoint source pollution such as agricultural runoff, although there are still differences that make biological pollution unique. In this chapter, a model of ANS invasions is developed and used to study the economic tradeoffs associated with the control of this type of pollution. The next chapter uses the results to address policy design issues.

#### **I. A Model of ANS Introductions and Invasions**

Complexities abound in the ANS introduction process, but a model will help to elucidate the process and aid analysis. Figure 2.1 graphically illustrates the different components of the ANS invasion process and their interaction. ANS introductions are a particular environmental outcome which can cause economic damages. The contributing factors to the environmental outcomes are the choices firms make regarding production and

pollution control in order to maximize its own economic benefits as well as random forces of nature. These two factors interact to produce environmental outcomes which may cause economic damages. The following paragraphs explore in more detail the components presented in figure 2.1.

The choices that firms make are the first component of the ANS introduction process. In the ANS case, the firms referred to can be almost anyone, although this analysis concentrates on the companies which operate commercial shipping vessels in the Great Lakes. Firms make a number of production choices with biosecurity consequences that affect the likelihood or probability of introducing a new ANS, which I refer to as the risk of ANS introduction. These choices may involve decisions of whether to purchase certain inputs or technologies, such as filters, which can drastically reduce the probability of an ANS introduction, or management practices regarding the handling of ballast water, i.e., open-ocean ballast exchanges, ballasting locations, and ballast loading practices. The production choices firms make can be either discrete or variable. Discrete choices, with a fixed number of options, include decisions relating to whether or not to adopt a particular technology such as water filters or whether or not to exchange ballast water. Variable choices, as the name suggests, include choices without a fixed number of options such as biocide applications.

Conventional pollution analyses often focus on emissions, which in the ANS case, can be defined as introduced species. However, in the ANS case, firms cannot prevent emissions or introductions with certainty. In addition to firms' choices, ANS introductions depend on such random factors as environmental variables affecting whether an organism gets into the ballast tank, survives the journey and is dumped into the new environment. The stochastic nature of introductions can be illustrated by the fact that two ships ballasting

in the same port will not receive the same species in the same proportion, nor will two identical sets of organisms dumped from two ships in the same port experience equal survival rates. For instance, a ship with far more organisms in its ballast tank could introduce fewer organisms into an area than a ship with far fewer organisms because such factors as the length of the voyage and ballast water temperature and salinity affect whether an introduction will actually occur. Another factor reducing the ability of ships to control ANS introductions is the issue of detecting ANS emissions. Analogous to nonpoint pollution problems, these introductions are largely unobservable given current monitoring technologies. The inability to detect introductions means that firms will not know how much effort to expend on biosecurity improvements to cost-efficiently achieve a desired level of introductions. Nonetheless, the choices a firm makes certainly affects the environmental outcome, although there is by no means a perfect correlation between the two. Firms' choices therefore only affect the risk of introduction, and any reduction in the probability of ANS introduction will have to originate from this component of the process.

An introduction may or may not lead to an invasion, which is the establishment of a measurable and sustainable population within a region. Just as random factors affect the occurrences of ANS introduction, so too does randomness (e.g., water temperature and salinity in the new ecosystem, unfilled niches or existence of predators) affect whether an introduction leads to an invasion. An invasion is therefore a complex process that is filled with uncertainties. Still, at least part of the risk of an introduction is controllable through firms' choices: if firms can undertake biosecurity measures to reduce the risk of an introduction then the risk of invasion is also reduced. To make appropriate biosecurity choices, it is helpful to know which species might pose the greatest risk of an invasion. This

can be a difficult task. Peterson and Vieglais (2001) and Ricciardi and Rasmussen (1998) demonstrate that the identity of likely potential invaders can be predicted by considering the similarity between the species' native ranges and the potential area of invasion as well as the niche an invader could fill. Random factors affect the occurrences of ANS introduction, and whether an introduction leads to an invasion, which is the establishment of a measurable and sustainable population within a region.

Ultimately, our concern lies with the economic outcomes of firms' choices. Firms' choices directly create both beneficial and damaging economic outcomes. The economic benefits of a firms' production have both private and public portions; the private being the profits that firms earn, while the public portion is the consumer surplus, or the benefit that consumers gain from having a certain amount of risk-creating shipping. In the ANS case, the economic damages of production derive from ANS invasions. While the effects of future invaders are unknown, their predecessors have shown that certain ANS do inflict serious economic damages, however the economic damages that any particular future ANS will create are quite uncertain. Economic damages can include the costs of adapting to the new ecosystem, lost recreational opportunities and lower aesthetic values (e.g., zebra mussels on docks, fewer sport fish due to sea lamprey and dead alewives on beaches). Certain ANS, particularly sport fish such as salmon, can actually create a degree of economic benefit through their introduction, but most other species, such as zebra mussels and sea lampreys, have caused economic damages. While estimates of economic damages should be read with caution, the economic damages of the zebra mussel have been estimated at \$3 billion a year (Pimentel, 1999).

What can be done to prevent future environmental outcomes of increasing numbers of ANS and potentially large economic damages? Before answering this question, it is useful to consider how much prevention is desirable. To do this, I focus on economic tradeoffs that emerge as control efforts are increased.

## **II. Economic Efficiency**

Tradeoffs are the central theme of ANS policy analysis. The overarching tradeoff or the risk of ANS introductions is between the benefits and damages to society. This relates to the idea of economic efficiency. Economic efficiency refers to the maximization of social welfare, which is the difference between social benefits and social costs.

### *Social Welfare*

Reducing the risk of ANS invasions and the resulting expected economic damages is possible, however, this will generally come at a cost. It is worth asking whether society would benefit from less risk at the price of less production, assuming a correlation exists between invasions and production. Figure 2.2 visually depicts the economic tradeoffs for the single firm case, with risk of ANS introduction on the horizontal axis and dollars on the vertical axis. The risk of introduction is modeled on the horizontal axis because introductions (not invasions) are most closely tied with an individual firm's choices and we wish to illustrate the economic/environmental tradeoffs facing individual firms (in a multiple firm setting, the risk of invasion depends on the choices of all firms). The downward sloping line represents the marginal social benefit (MSB) of risk (unless otherwise noted, firm-level risk refers to the risk of an introduction). Here, firms choose the level of risk indirectly

based on their production and biosecurity choices, which in turn create benefits to firms, consumers, and factors of production such as labor. The upward sloping line represents the expected marginal damage (MD), or the expected marginal cost imposed on society, of the risk of ANS introduction.<sup>1</sup>

The existence of a social benefit from risk derives from the fact that it is linked to production, and the production of a certain quantity of a product gives society a greater benefit than the damage of the pollution it creates, up to a point. Total social benefits of producing a particular level of risk are defined as the area under the MB curve at that risk level. Similarly, total damages are defined as the area under the MD curve at the particular risk level. As long as the MSB curve is above the MD curve so that the benefit of additional risk exceeds the damage, then society gains from additional risk. This occurs at lower levels of risk. However, when the MD curve is above the MSB curve, then each additional unit of risk imposes more damages for society than the benefits it creates. For society to maximize its welfare, the risk level should equal the point where the MSB and MD curves intersect,  $r^*$ . Moving away from this point in either direction would cause society's welfare to decrease. If society does not accept any risk then neither will it reap any of the benefits of a shipping industry.

It is important to emphasize that while society may recognize  $r^*$  as its optimal level of risk,  $r^*$  is only a probability measure that describes the level of randomness. The actual environmental outcome may be much different than predicted by the amount of risk due to stochastic natural forces. While this fact deserves consideration, society can neither control

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<sup>1</sup>Expected marginal damages equal the expected value of marginal damages of invasion times the marginal risk of an invasion due to increased risk of an introduction.

nor predict the effect of the random natural forces, and so it does not know the exact state of the world that will arise after the level of risk has been selected. Thus, the ex ante societal optimum remains at  $r^*$  since society can only make decisions based on its expectation of outcomes under different potential states of the world.

### **Multiple Firms**

The case in which multiple firms influence the probability of an invasion is illustrated in figure 2.3. This figure focuses on the two firm case, although the results extend readily to incorporate additional firms.

Firms receive different benefits from producing a given level of risk. Optimally, each firm should equate its marginal profits from generating risk with the marginal damages arising as a result of the risk. Figure 2.3<sup>2</sup> graphically illustrates this for the case of two firms with different marginal profit ( $M\pi$ ) curves. The shapes of  $M\pi$  curves differ, and may possibly intersect, indicating that the marginal profit per unit of risk varies among firms. Also, for a given level of risk, the firm with the greater  $M\pi$  curve produces larger profits (the area under the  $M\pi$  at a particular risk level). Thus the marginal social benefit of risk also differs among firms. The differences between the MD curves indicate that for any given level of risk, firms with larger MD curves are expected to create more damage (e.g., an introduction by one firm is more likely to cause an invasion, due to the types of species it may be carrying). The variation among  $M\pi$  and MD curves indicates that the socially

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<sup>2</sup>Figure 2.3 portrays a special case in which the marginal damage curve for one firm is independent of the risk created by the other firm and the risk of invasion is independent across firms. This is only for illustration purposes. In reality, the MD curve of one firm depends on the actions of the other firm(s).



optimal level of risk varies among firms. Figure 2.3 demonstrates this;  $M\pi_1$ , the marginal cost of firm 1, intersects the marginal damage ( $MD_1$ ) curve at  $r_1^*$ , whereas  $M\pi_2$  intersects  $MD_2$  at  $r_2^*$ .

Recognizing that firms have different MD and  $M\pi$  curves leads to a critical question: What is the efficient allocation of risk (i.e., Who should optimally do more to reduce risk)? Table 2.1 categorizes firms by their marginal profits as well as their marginal damages in order to visually illustrate which firms should reduce their risk. As noted, a tradeoff exists between social benefits, which include profits, and the expected damages of the risk of ANS invasions. However, not all firms face exactly the same tradeoffs at the margin. For instance, all else equal, it is beneficial to allow firms with the highest marginal profit levels to reduce their risk less than firms with lower marginal profits. This is because, for each unit of additional risk, the firms with larger marginal profits will generate larger economic benefits than firms with smaller marginal profits. Similarly, society benefits when firms with greater marginal damages lower risk more than firms with smaller marginal damages. This is because, for each unit of additional risk reduction, the firms with larger marginal damages will reduce expected damages by more than firms having smaller marginal damages. Table 2.1 demonstrates that, when all else is held constant, the expected marginal damage and the marginal profit of a firm affect its optimal level of risk reduction. Figure 2.3 graphically illustrates the different optimal levels of risk for two firms with differing marginal profit and marginal damage levels.

### *Market Failure*

Properly functioning markets force firms to account for all the costs of productions. However, occasionally externalities exist. Externalities are damages caused by the production process, such as pollution, borne by society rather than the firms responsible for the pollution. ANS introductions are an example of an externality, since society bears the cost of the economic damages from ANS instead of the firms responsible for the pollution. Hence, a degree of economic inefficiency exists here, and trading lower risk for lower profits could improve the efficiency of the economy.

Figure 2.4 is a variation of figure 2.2, the difference being that the marginal profit ( $M\pi$ ) curve replaces the MSB curve. The  $M\pi$  and MD curves in figure 2.4 segment the graph into four triangles numbered I-IV. A profit-maximizing firm will produce up to the point where the marginal profit from creating additional risk equals zero,  $r_0$ . At this point, the firm's profits equal the sum of triangles I, II, and III. However, at  $r_0$ , the expected damage from the risk of ANS introduction equals the sum of triangles II, III and IV, meaning that the net social benefit of the risk equals the difference between triangles I and IV. This is not socially efficient. Producing at the point  $r^*$  would maximize net social welfare, represented by triangle I, while limiting profits to triangles I and II. While reducing the probability of ANS introduction does increase social net benefits, the reduction it causes in firms' profits likely means that firms will not voluntarily undertake actions to curb the amount of risk they create, thus implying the need for government intervention. In the case of ANS, the MD of the risk of new introductions does not equal the MSB. Figure 2.4 illustrates the similar relationship to that depicted in figure 2.2, but from the perspective of the firm. In this case, the downward sloping curve represents the marginal profit of the firm

and the upward sloping line represents the marginal damages to society. The vertical and horizontal axes remain the same. The socially optimal level of risk is  $r^*$ , the point where marginal profits equal marginal damages. However, profit maximizing firms will accept risk up to the point where additional risk yields no additional profits,  $r_0$ , if the market does not force firms to absorb the marginal damages of the risk they accept. The social costs of market failure equal the area between the MD and  $M\pi$  to the right of  $r^*$ , which means that the social costs of market failure equal the total damages of risk beyond the optimal level,  $r^*$ , minus the profits from the risk beyond  $r^*$ . To society's disadvantage, the market does not hold firms responsible for the risks they pose, and thus firms create a level of risk,  $r_0$ , higher than the social optimum,  $r^*$ . This situation is indicative of a market failure induced by an externality of the production process: a well-recognized cause of market failure (Arrow, 1969). Market failure means that operation of market forces has not yielded the socially optimal outcome, thus imposing unnecessary costs on society. Figure 2.2 represents these social costs as the area between the MSC and MSB curves between  $r^*$  and  $r_0$ . To obtain an outcome with a higher degree of social welfare will require government intervention to induce firms to bear a level of risk closer to  $r^*$ .

ANS invasions are low probability, non-incremental events that can have very large damages. Policy makers who fear the potential down-side risk may not wish to pursue an economically efficient solution. Rather, they may wish to pursue a 'safety-first' outcome in which invasion risk is reduced to some pre-specified level in a least-cost manner. Often the specified level of risk would be small or even possibly zero. Such an outcome would not be optimal ex ante as it may imply that large costs are incurred at the margin in return for small reductions in expected damages. But if a least cost solution is to be obtained then economic

tradeoffs are still important and the previous discussion essentially applies. The only difference is that tradeoffs occur between the benefits of firm-level risk and the risk of an invasion, as opposed to the benefits of firm-level risk and expected damages. The only case in which tradeoffs are not relevant is when the risk of invasion is zero. Essentially such a constraint would imply a situation in which *no* trade is allowed in the Great Lakes. It is doubtful that such an outcome would ever be deemed desirable. Because economically efficient and safety-first outcomes are each determined based on similar sorts of tradeoffs, the focus is mainly on ex ante efficiency in what follows.

### **III. Level of Governance**

The identification of market failure and the recognition of the need for government intervention lead to the difficult task of crafting public policy. This task becomes more difficult when there is uncertainty surrounding who has the responsibility for drafting the public policy. In the case of the ANS, three different levels of government have a stake in the condition of the Great Lakes: the national (the US and Canada), provincial (Ontario), and state (eight US states). Throughout this paper the word ‘government’ refers to the governments listed above. Various governments on the different levels have already taken steps to address the introduction of ANS. Government mandates have mostly come from the two national governments involved, while the state governments have largely focused on action plans. While state and provincial governments may have a positive role to play in dealing with ANS, the ability of species to spread within the region may indicate the need for the most serious efforts to come from the national and international levels.

Many studies of international environmental agreements use game theory to model potential outcomes, oftentimes looking at cooperation within a group of nations. (see Ecchia and Mariotti, 1998; Carraro and Siniscalco, 1998; Barrett, 1994). The potential for cooperation seems larger when fewer potential free-riders exists, such as in the current situation involving only two countries. However, the U.S. and Canada may have different values for the costs and benefits of ANS risk, and thus will not pursue the socially optimal outcome,  $r^*$ , unless they cooperate. If they do not cooperate, then an inefficiently low level of pollution control will result. Interestingly, since social net benefits are greater with cooperation, both could be better off by cooperating. This does not mean that cooperation will necessarily make each country better off. One country may gain more from risk reduction than the other country and may have to compensate the other country or compromise on the size of the risk reduction.

Endres and Finus (1999) identify three areas countries must agree on if they want to enter into an environmental agreement: a free-riding deterrent, an abatement target, and a rule for burden sharing. The US and Canadian governments have an incentive to work together and effectively address this problem, thus lowering the potential for free-riding. Cooperation between these two governments shares some similarities with a repeated prisoner's dilemma game<sup>3</sup>. In this case, non-cooperation by either country could have

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<sup>3</sup>In the Prisoner's Dilemma game, two prisoners are questioned separately and each given the option to either squeal on the other prisoner or say nothing. If neither prisoner says anything, they both receive short jail times, thereby optimizing their joint utility. If one prisoner does confess, he receives no jail time if the other prisoner does not confess. The second prisoner then receives a very lengthy sentence. However, if both prisoners confess, they both get long sentences. Depending on the potential sentences, prisoners in one period games have the incentive to confess and maximize their utility, but in repeated games where retribution is possible, then cooperation (i.e., silence by both prisoners) will be the prisoners best strategy.

significant deleterious effects on both countries, thereby lowering the benefit that either country has from free-riding. The ANS externality does not limit itself to any particular political boundary. Unless both countries work to lower the probability of ANS introductions, the lack of cooperation will limit the ability of any one country to lower the probability of introduction. As for an abatement target, this may take a fair amount of consideration on both sides about the acceptable trade-offs between abatement and cost, particularly the cost to the national shipping industries and the industries dependent on shipping. It would seem that both countries would seek fairly similar abatement targets since they each have experienced the considerable costs of ANS introductions, indicating that a low abatement target might appeal to neither. Of course, the political process of selecting an abatement target may lead either or both countries away from their similar efficient levels of abatement. The conflict over the rules for burden sharing will likely vary directly with the estimated administrative and monitoring costs. Presently, the administrative and monitoring costs are not excessive, and the US and Canadian governments have shown a willingness to police this problem together (Reeves, 1999). While potential subjects of international environmental agreements deserve a careful review under Endres and Finus' (1999) three conditions, a cursory review of the pollution problem and the countries involved suggests that fertile ground exists here for a mutually beneficial agreement.

## Chapter Three

### Analysis of Economic Policy Options

#### I. Introduction

In Chapter 2, I discussed the potential role for government intervention when the marginal costs of ANS introductions outweigh the marginal benefits. In order to develop economically efficient or cost-effective policies to deal with the introduction of ANS, three things need to be known (*a*) the available policy options, (*b*) an understanding of the specific design issues associated with the various options, and (*c*) a determination of the options that can cost-effectively deal with the situation. Indeed, a number of policy options are available, but the suitability of each option may vary. Even those options that may be suitable may not be very cost-effective unless they are designed appropriately to best deal with the problem. The economic literature on pollution control addresses these issues, largely by answering the following three questions: who to target, how to define and measure compliance, and lastly, how to induce changes in production and pollution control practices to improve environmental quality (Shortle and Horan 2001). Each of these questions needs to be answered in order to formulate cost-effective ANS pollution policies.

#### *Who to target?*

The question of who to target involves specifying the person or group towards whom policies are directed. This involves identifying the potential targets, analyzing which groups pose the most significant threat, and determining if there is a cost-effective way to target these groups. In the case of ANS the potential targets are all groups and individuals

that affect ANS introductions in the Great Lakes. The vectors of introduction include ballast water, solid ballast, canals, ship fouling, deliberate releases, aquariums, bait fish releases and accidental introductions. Rather than consider all vectors of introduction and the many groups which affect them, we focus on ballast water, since this vector is responsible for most of the recent introductions. As we indicate below, focusing on only one group limits efficiency. But targeting groups with little impact on pollution generates costs without producing substantial offsetting gains. Indeed, a focus on ballast water can reduce program start-up and administrative costs and provide greater benefits in the near term, at least relative to a program that tried to do too much and spread its administrative resources too thin. This focus is consistent with other pollution control programs that began by mainly focusing on large point sources and ignored smaller point sources and also non-point sources. Over time it may be beneficial to include other potential sources of ANS as well. The present list of potential targets then includes all ships loaded with ballast entering the Great Lakes, ships without ballast water entering the region (NOBOB's), ships that sail exclusively on the Great Lakes, and ports. The threat posed by these potential targets varies. For instance, ocean going ships that carry ballast differ in respect to such factors as whether and how thoroughly they exchanged ballast on the open ocean, the amount of sediment in the ballast tanks, the last port in which the ship loaded ballast, and physical characteristics.

*What is the basis for compliance?*

Compliance is the basis on which the instruments are applied. Generally, policies may be based on emissions, proxies of environmental performance, management practices,



input usage, or ambient pollution levels. For instance, in conventional pollution problems, the government can subsidize abatement, reductions in the use of polluting inputs, or the adoption of environmentally friendly technologies. Here, abatement, inputs, and technologies represent different policy bases. The nature of the particular sort of pollution problem will determine the cost-effectiveness of the policy basis. Identifying an effective compliance measure for a particular problem narrows the field of potential policy instruments, focusing attention on the most promising policy instruments.

An appropriate basis is one which is easily measured, monitored, and correlated with the environmental outcomes, in addition to being affected by firms' choices. Moreover, a firm must understand how its actions affect the compliance measure for the incentives to induce improved environmental outcomes.

Emissions are often viewed as an ideal policy basis, due to their high correlation with environmental damages. However, policies based on emissions require the ability to accurately monitor the amount of pollution emitted from various sources. An inability to obtain accurate emissions measurements limits the use of emissions as a policy basis. In the case of ANS, emissions of nuisance species are not easily observed at reasonable cost. Therefore, another basis for policy must be chosen.

Performance proxies are normally emissions estimates which are derived using information on firms' management practices and input use. In the ANS case, a performance proxy might be an estimate of the likelihood or risk of an ANS invasion, based on information such as whether a ship exchanged ballast water, the last port it entered, along with the technologies and ballast management practices it utilizes.

Every firm uses inputs in its production process. Inputs may include physical goods, technologies, and management practices, and certain inputs may contribute to the production or abatement of pollution. For instance, the use of chemical biocides to treat ballast water is an abatement input. Therefore, policies can be based on the use of inputs affecting pollution. Existing ballast water regulation largely focuses on dealing with inputs. For instance, the U.S. mandates that ships entering the Great Lakes perform an open-ocean ballast exchange (management practice), Argentina requires ships calling in Buenos Aires to chlorinate their ballast tanks (physical good), and Panama prohibits the dumping of ballast in the Panama Canal (management practice) (Perakis 2001).

The final policy basis is ambient pollution, or the overall level of pollution in the environment. In the case of ANS, the number of new organisms in the region would be a good indicator of the ambient pollution level. A regulatory agency would monitor the region for the presence of a new species. Once the regulatory agency detects a new ANS, the group of potential contributors would be identified based upon the estimated time of introduction, and a penalty would then be imposed on these potential contributors.

#### *How to induce changes?*

The third question from the pollution management literature which relates to ANS management is how to induce changes in production and pollution control practices to improve environmental quality. At least four avenues can be used to induce the desired changes: economic incentives, regulations (i.e. mandates or command-and-control policies), marketable permits, and educational/voluntary programs (Baumol and Oates, 1988). Which of these methods will most effectively induce the desired changes in production and

pollution control practices depends on the design of the policy, the amount of desired change, and the targeted firms, since policies can vary in effectiveness across firms.

Generally, the policies considered here are analyzed with respect to their ability to produce an economically efficient outcome, however, some policies can produce positive change, but are incapable of effecting economically efficient outcomes. This section contains a broad overview of the policy options. More detailed discussions of some specific instruments will follow.

Command-and-control measures are rules or mandates to which a firm must adhere (or else face a high penalty). These measures can effectively promote the adoption of practices and technologies that enhance environmental quality when enforcement and penalties exist. Rules can be structured so that polluters have more or less freedom in achieving policy goals. Rules can control either outcomes (performance-based rules) or processes (design-based rules). Design-based rules impose inflexible restrictions on polluters, such as a limit on certain inputs. As described above, this is the predominant approach of existing policies. In contrast, performance-based rules mandate that the polluter lower pollution by a given amount and allow the regulated party to find the most cost-effective way to meet the requirements.

Economic incentives most often come in the shape of taxes or subsidies, but they can take many other forms. Economic incentives vary in their applicability to different scenarios, as we describe below, but they all work under the same principle: to create an opportunity cost of engaging in activities that pose environmental risks. As described in Chapter 2, free markets do not create a price for using the Great Lakes as a waste receptacle for biological pollution. Since environmental risks are an externality of the shipping industry

and, in the case of ANS, these risks pose no cost for firms, firms will create too many risks. Economic incentives make it costly for firms to create risks, and so they will engage in fewer risky activities.

Economic incentives have been used around the world to induce better economic outcomes. For instance, many countries in the European Union utilize such economic incentives as fertilizer and pesticide taxes (Hanley, 2001). Environmental protection programs in the U.S. have also used economic incentives to a degree. For instance, the *Conservation Reserve Program* pays farms to keep land out of production (a subsidy) to decrease soil erosion and increase water quality and the *Environmental Quality Incentives Program* shares the cost (a subsidy) of approved measures that target environmental concerns (Ribaudo, 2001). Economic incentives have addressed such areas of pollution as industrial pollution, brownfields, municipal sewage plants, and agricultural pollution (Hanley, 2001; NCEE, 2001; Ribaudo, 2001). Table 3.1 lists a number of different economic incentives and examples of their use.

As noted above and in table 3.1, a number of pollution control initiatives use taxes as the policy instrument. Baumol and Oates (1971) demonstrate the ability of tax on emissions to produce an efficient outcome. Generally, taxes increase the opportunity cost of polluting by applying a charge to the polluter which can be based on emissions or a proxy, inputs, management choices or ambient pollution levels. Subsidies work in a similar manner to taxes, but rather than applying a charge, subsidies provide payments to those firms who take steps to reduce their environmentally risky behavior. Both taxes and subsidies have potential to cost-effectively lower the probability of ANS into the Great Lakes. The following section

more closely analyzes each of these policy instruments and their applicability to the ANS situation.

Marketable permits have displayed potential as a method of solving specific pollution problems (see Table 3.1). Hanley *et al.*, (1997) draw on the work of Montgomery (1972) and Tietenberg (1984) to demonstrate the least-cost properties of marketable permit systems. While marketable permits have performed well in certain cases, they are restricted in the situations in which they can help. As with all other regulatory instruments, marketable permits require the identification and measurement of a good such as an emission or input. A regulatory agency will then assign polluters the right to use or produce a specified amount of the targeted good. The specified amount will depend on what level of abatement policymakers hope to achieve. Individuals or firms may then sell all or part of their right to produce or use the good. The scarcity of the permits along with the ability to trade creates incentives for firms to reduce their emissions at least cost. An important hurdle exists for the efficient operation of this economic incentive; marketable permits require goods to be targeted that can be relatively inexpensively traded and monitored. Ballast water, possibly the most obvious option for marketable permits, would work well were it not for certain characteristics of the problem: the number of organisms can vary significantly among equal quantities of ballast water, and the introduction of only a few organisms may be a sufficient base for a population. ANS prevention policies seek to minimize the risk of new ANS introductions, and marketable permits need an appropriate target to effectively minimize the risk of ANS introductions. Marketable permits, if targeting a good that increases the probability of ANS introductions, could shift the usage of the good to the ships with the highest marginal cost of abatement, thus cost effectively lowering usage of the good.

Minimizing ANS introductions require that the targeted good corresponds with the probability of ANS introductions.

Cross compliance pollution control measures have been enacted to deal with the ANS situation in the Great Lakes, e.g., Public Act 114 (Sikkema, 2002). Cross compliance measures work by tying the behavior of a firm to its eligibility to participate in a government program. In the ANS context, shipping firms which pose a high risk of introducing ANS would lose their eligibility to receive subsidies unrelated to ANS control. Cross compliance measures basically operate as a binary instrument, either the firm retains eligibility for the entire subsidy or it loses eligibility to receive the subsidy. As such, firms face slightly different incentives, either abate to the smallest degree possible to retain eligibility for the subsidy, or do not decrease emissions at all. Cross compliance measures do not affect the marginal cost of polluting, which creates the aforementioned incentives that may not produce socially optimal outcomes. Although cross compliance measures may not produce socially optimal outcomes, they do have the potential to inexpensively lower the probability of ANS introduction, which in effect means that this tool can target firms with low abatement costs and those that might abate otherwise, i.e., the ‘low-hanging fruit’.

Liability can create a ‘strong incentive’ for firms to curb the pollution damages they cause (NCEE, 2001). Liability rules have been used successfully in the U.S. in the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). Holding firms liable for pollution implies that they have the responsibility to pay for the pollution damages they create. Different forms of liability exist and we discuss them below. Segerson (1995) identifies three types of liability rules that may have the potential to address different environmental problems: strict liability, liability under negligence, and a joint and several

liability standard. Strict liability holds the polluter responsible for all damages caused by the pollution, while liability under negligence only holds a polluting firm responsible if it did not exercise due care (Segerson 1995). That party would then bear full responsibility for all the pollution with the right to pursue other contributors. An introduction of a new ANS is a binary event. Either the species exists in the Great Lakes or it does not. Additionally, there is no practical method for determining if a ship ever dumped a particular non-indigenous species into the Great Lakes. Under a joint and several liability standard, the identity of only one party who contributed to the pollution need be ascertained; this party can then be held responsible for all the pollution damages, and has the right to then seek compensation from the other contributors (Segerson 1995). Again, the impossibility of proving that a firm ever dumped a particular species into the Great Lakes lessens the potential effectiveness of this liability measure. For these reasons, liability rules do not seem to have the ability to provide a significant incentives for firms to abate. Because liability would only be applied when ANS have been discovered in the Great Lakes, liability is similar to a tax on ambient pollution levels. The ‘Ambient Pollution’ section below more thoroughly analyzes this situation and the reasons neither ambient pollution nor liability can slow the introduction of ANS.

The following economic incentives and other sorts of policy instruments have limited potential to effectively address the ANS situation. Nonetheless, each of the following policy instruments have effectively dealt with other environmental problems (see Table 3.1) and, each will receive a brief analysis of its operation and the attributes which would likely limit its effectiveness in the ANS situation.

Deposit-refund systems have worked well in many states with beverage containers. This economic incentive is tied to a good, and attempts to promote recycling of that good.

Deposit-refund systems work by requiring the consumer to make a deposit on a product at the time of purchase. That person can then return the product for recycling and receive the deposit when he no longer has any use for it. A study by the National Center for Environmental Economics (NCEE, 2001) notes that deposit-refund systems basically amount to an initial product tax coupled with a recycling subsidy. This study also notes the potential for high administrative costs with deposit refund systems. In the case of beverage containers, the consumer will pay a deposit of five or ten cents for each bottle or can purchased. Each beverage container can then be exchanged later for the refund. An important question when considering a deposit-refund system is to what good will the refund be tied? The ANS situation does not provide a good answer to this question. Due to the lack of a suitable target, a deposit-refund system is not a promising economic incentive for the ANS problem.

Reporting requirements mandate that firms report their emissions. Assumably, the reporting requirements induce firms to abate more in order to avoid the negative publicity of causing pollution. Konar and Cohen (1997) report that reporting requirements can in fact give firms an incentive to reduce emissions. However, in the case of ANS, firms have the ability to report the amount of ballast water they release, but not the number of new ANS they have introduced. The correlation between the two varies, a fact which would limit the effectiveness of reporting requirements as a policy instrument for decreasing the probability of ANS introductions. Reporting requirements have been used with ballast exchange, a behavior believed to reduce the risk of ANS introduction. Ballast exchanges did become more common, and were later made mandatory when possible by the US. Generally, reporting requirements can act as inexpensive incentives to lower pollution damages if the



good being reported is correlated with pollution damages, which in this case are ANS introductions. Additionally, while reporting requirements do increase the opportunity cost of polluting, the opportunity cost they impose could be smaller than the costs of additional abatement for some producers. This may be due to the high cost of abatement technologies or the low opportunity cost of reporting.

Education and moral suasion, along with the potential for more stringent rules, caused most ships to increase open ocean ballast exchange before it became a government mandate. Additionally, the Lake Carrier's Association, which represents U.S. ships operating exclusively in the Great Lakes, has voluntarily adopted practices to slow the spread of ANS in the Great Lakes (possibly to ward off additional rules). While these efforts do reduce the likelihood of ANS transportation, they do not require substantial investments. However, further reductions in the probability of ANS introduction may require significant investments in technology. Ribaudo and Horan (1999) review the effectiveness of education with regard to agricultural pollution and conclude that it does not provide a significant incentive to undertake measures that improve environmental quality unless those measures also increase profitability. Given that additional reductions in the risk of ANS introductions could decrease profitability, education alone is unlikely to effectively lower the probability of ANS introductions. Ribaudo and Horan (1999) note that education can increase the effectiveness of other policy instruments, particularly performance-based instruments, by helping firms to understand the pollution they cause and how to lower the relevant pollution measurements or proxies.

Voluntary programs, such as the Laker Carrier's Association's members' voluntary adoption of practices aimed at slowing the spread of ANS, have the potential to reduce

pollution damages. As their name indicates, voluntary programs do not mandate participation. Voluntary programs share many similarities with education, and educational programs are normally voluntary in nature. Additionally, voluntary programs and education can easily be coupled together. It can be argued that voluntary programs are to a degree economic incentives, since participation can result in good publicity for firms, thereby increasing the marginal benefits of abatement. As with education programs and reporting requirements, voluntary programs may work well when the costs of abatement are small or the probability of more costly regulations is very high, but real changes will involve significant costs that firms cannot be expected to incur voluntarily. In a competitive economy, incurring the substantial abatement costs will imperil a firm's profitability and competitiveness. For this reason, voluntary programs perform poorly in the presence of high marginal costs of abatement. Voluntary programs are also susceptible to uncertain levels of participation as table 3.1 notes. Overall, voluntary programs and education are effective and inexpensive methods of lowering pollution damages in certain instances. However, when participation lowers profits, such as in the ANS case where expensive technologies may be necessary to decrease the risk of pollution damages, then voluntary programs have only limited usefulness.

While education and the various economic incentives mentioned above do have merits as pollution control instruments, this chapter can more fruitfully narrow focus to consider how government mandates, taxes, subsidies, cross compliance measures and marketable permits operate with different policy bases to control pollution. The following sections go into greater detail in examining these instruments and consider how they can be combined with different policy bases in order to analyze how well the different instruments

address the ANS situation with regard to targeting, measuring compliance, and inducing change.

## **II. Economic Incentives and Command-and-Control Measures**

I begin this section by focusing on two classes of pollution control instruments described above: command-and-control instruments and economic incentives. Economic incentives receive a significant amount of attention for their potential to harness the power of the market to address environmental problems, however, they do not necessarily have a distinct advantage over government mandates in achieving optimal environmental outcomes. After providing general descriptions of particular policies in these two instrument classes, this section then elaborates upon particular design issues with respect to the different policy bases.

### *Command and Control Measures*

#### *Government Mandates: General Properties*

Government rules attempt to limit risk by mandating changes in behavior. The mandated changes can be design-based or performance-based, although for now I focus on performance-based measures for ease of exposition.

Figure 3.1 illustrates a government mandate that limits a firm's risk proxy and the associated economic impacts. The risk proxy, denoted by  $r$ , is most accurately understood as similar to the probability of an ANS introduction (this is explained in further detail below). A firm's profits indirectly depend on the value of  $r$ : if  $r$  is restricted then the firm must alter its production choices, incurring costs (forgoing profits) to meet this restriction. In the

absence of any environmental policies, a profit-maximizing firm will choose the level of  $r$  (through its production and pollution control decisions) such that the firm's marginal profits from an increase in  $r$ , denoted  $M\pi$ , equal zero. At this point, a further increase in  $r$  has no positive impact on profit levels. The associated value of  $r$  is  $r_0$ , and the firm's profits are given by the area below the  $M\pi$  curve from 0 to  $r_0$ .

A limit on  $r$  generally prevents a firm from producing at  $r_0$ . Suppose  $r$  is set at a value of  $r^*$ , which may or may not be the socially optimal level,  $r^*$  (i.e., the point at which the marginal social benefits from an increase in the proxy equal the marginal social damages; more on this issue below). The firm will then make production and pollution control choices so that  $r = r^*$ , and its profits will equal the area under the  $M\pi$  curve between zero and  $r^*$ . The limit forces firms to forego the profits represented by the area under the  $M\pi$  curve between  $r^*$  and  $r_0$ . This area also corresponds to the amount of abatement costs that a limit causes a firm to incur. Depending on the magnitude of the required abatement, the effects of the regulations could extend further. The limit essentially increases the cost of production, which could lead to a decrease in the production of the good (shipping) and possibly some firms exiting the industry. At the market level, the price of shipping would increase.<sup>4</sup> The increased price would hurt consumers but would generally benefit firms that remain in the industry. Similarly, some industries and workers dependent on the shipping industry may be adversely affected, although those remaining in the market could benefit

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<sup>4</sup>Reeves (1999) alludes to the idea that some in the shipping industry worry that a small price increase will cause consumers to make a complete switch to other modes of transportation. Some substitution will occur, but a complete switch will not occur. As demand for other modes of transport is increased, suppliers of alternative transport will generally face increased marginal costs of providing transport. Accordingly, the market price for rail and other modes will rise. An equilibrium will therefore arise involving shipping and other transport industries.

from higher prices. Finally, limits might be a good idea when pursuing a safety-first goal because they would not give firms any flexibility to create risk in excess of the desired levels.

### *Economic Incentives*

Economic incentives work by creating an opportunity cost of engaging in activities that pose environmental risks. To be most effective, economic incentives should differentiate between polluters by the risk they impose when creating an opportunity cost. This means that for very risky activities the opportunity cost should be sufficiently high to reduce the occurrence of that activity, and for activities with a lower risk the imposed opportunity cost can be correspondingly lower. In the ANS case, the referred to risk represents the probability of ANS introduction, and targeting activities highly correlated with this risk is a serious challenge in policy design. Potential targets include volume ballast water, time in the Great Lakes, ballast exchanges, presence of filters and origin of the ship. All of the economic incentives mentioned require some sort of target, or policy basis, to operate. In some cases, promising bases for certain policies have been identified, thus raising the interest in these policies. Conversely, suitable bases have not been found for otherwise promising policies, thereby dampening enthusiasm for their present use.

### *Taxes*

Taxes raise the opportunity cost of creating risk by applying a charge to a firm based on a certain policy basis. The terms “charges” and “taxes” are used separately in table 3.1, but both imply a fee to be paid by the polluter. Taxes vary by magnitude of the charge they impose on firms, the amount of monitoring they require as well as the different bases they

utilize (e.g., a risk proxy, input, or ambient pollution level). The size of the tax will directly affect the level of abatement as well as the incentive for tax evasion (Biber, 1999). The challenge for effectively utilizing a tax in the ANS situation will be to select a target highly correlated with ANS damages.

Figure 3.2 graphically demonstrates the operation of a tax based on a risk proxy. The tax rate is represented by the horizontal line  $t$ . In the ANS case, a tax will create an opportunity cost for each additional unit of risk that a firm creates. A firm will produce up to the point where its marginal pre-tax profit equals the tax. Producing units beyond this point results in negative marginal post-tax profits. Optimally, the tax would be set at the point where  $M\pi = MD$ , at  $r^*$ . Other values of  $t$  will result in less efficient outcomes. Producing units beyond this point results in negative marginal post-tax profits. As set in figure 3.2, the tax rate  $t$  has the same efficiency properties as a limit set at  $r^*$ . That is, both generate the same level of social net economic benefits. The distributional effects of taxes are slightly different than regulations. For instance firms realize smaller profits under a tax, which equal the area between the  $M\pi$  curve and the tax line from 0 to  $r^*$ . An additional effect of taxes is to increase government revenue, which equals the area under the tax line between 0 and  $r^*$ . This transfer of rent from firms to the government has no effect on the overall level of social welfare. As the size of the tax grows, so too will societal gains from abatement and government revenues from tax collection while firms' profits decrease. As firms' profits shrink, certain firms may exit the industry, driving the price higher. Ultimately, the elasticity of demand for shipping and the elasticity of the supply of substitute forms of transport will determine the amount of shipping firms supply.

Finally, taxes may be seen as less-than-desirable in the short run when pursuing a safety-first goal to limit risk at a pre-specified level because taxes give firms the option of increasing their risk levels if it becomes profitable for them to do so. If this is viewed as a possibility, then the taxes might have to be set at higher rates to compensate for the likelihood that such an event would arise.<sup>5</sup> In the long run, however, taxes may provide more incentives than standards to develop new technologies that would allow firms to reduce their risk even more at low cost (Hanley et al., 1997).

### *Subsidies*

Environmental subsidies work in much the same manner as taxes in that they raise the opportunity cost of creating the risk of ANS introductions. However, rather than penalizing firms that pollute, they reward firms for limiting their environmentally risky activities and for engaging in environmentally friendly activities. Subsidies are generally favored by firms and communities in which those firms operate (e.g., freshwater ports such as Duluth which rely on the shipping industry). A subsidy to reduce the risk proxy is of the form  $s(r_0 - r^*)$ . This subsidy has two parts: a lump sum payment ( $s \bullet r_0$ ) and a tax ( $s \bullet r$ ), although the lump sum payment more than offsets the tax so that the total payment is positive. As with taxes, subsidies vary by the size of the payment they give firms, their monitoring requirements, and policy bases. Additionally, abatement is a function of the size of the

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<sup>5</sup>The same issues arise when striving for an efficient outcome. In that case, the efficient level of expected damages will not be achieved if firms take advantage of the flexibility offered by a tax. However, the implicit view behind the adoption of a safety-first objective is that it is important that the objective be satisfied and maintained.

subsidy, and an effective subsidy should focus on the abatement a target with a strong impact on ANS damages.

Figure 3.3 graphically demonstrates the operation of a subsidy. As figure 3.3 shows, a firm will produce up to the point where its marginal profit equals the subsidy. Producing units beyond this point results in negative marginal post-subsidy profits. Figure 3.3 represents the subsidy as a horizontal line(s); the intersection of this line with the marginal cost curve shows the predicted level of production,  $r^*$ . Setting the subsidy rate and tax rate at equal levels will result in the same outcomes. Adjusting the subsidy level will affect the level of production and risk. The distributional effects of subsidies differ in important ways from both taxes and regulations. Subsidies allow firms to gain profits equal to the area under the  $M\pi$  curve between 0 and  $r^*$  plus the area under the subsidy line from  $r^*$  to  $r_0$ . The firm earns the same pre-subsidy profit from a subsidy as with a limit to the point where estimated risk equals  $r^*$ . In addition, the subsidy provides a payment equal to the area under the subsidy line from  $r^*$  to  $r_0$ . The subsidy has an additional advantage over taxes for firms because not only does a firm not get paid under a tax-based approach, it has to pay the tax bill.

To encourage firms to abate, the government must set the subsidy at least as high as the cost of abatement. Subsidies impose substantial costs on the government, because achieving the desired level of abatement necessitates spending an amount equal to the area under the subsidy line from  $r^*$  to  $r_0$ . Subsidies can encourage excess entry into the subsidized industry, in this case the shipping industry, which could increase the risk of pollution (Hanley et al., 1997). Additional subsidies may then be required to reduce that risk, potentially creating a cycle which adversely affects the government budget.



Policies that use subsidies reveal a particular implicit philosophy. Paying polluters to stop polluting connotes a belief that polluters have the right to pollute, and the infringement upon this right requires a payment to be made. Taxes and regulations come from a different set of beliefs. Rather than conveying an implicit right to pollute, policies that include taxes or regulations express the belief that society has the implicit right to a clean environment, and polluters that infringe on that right will be subject to sanctions. Recognizing the philosophical differences among the different types of policy instruments may aid in the selection of the appropriate instrument.

As with taxes, subsidies may provide firms with too much flexibility when a safety-first standard is applied, and so they might have to be offered at higher rates to compensate and ensure that the desired level of risk is maintained. However, a cost-share (a subsidy tied to a specific action) might be useful in combination with command-and-control approaches. But even in that case a subsidy will reduce a firm's average costs, which might encourage excess entry that would further increase the risk of an introduction.

### *Marketable Permits*

Marketable permits are a hybrid of governmental rules and economic incentives and have been useful in addressing certain environmental problems(see Table 3.1). Conventionally, establishing marketable permit system begins with a regulatory agency assigning permits that provide the right to emit a specified amount of pollution<sup>6</sup> or use a certain quantity of an input (a command-and-control measure or rule). The permits restrict

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<sup>6</sup>Since ANS emissions are unobservable, emissions will not serve as a basis for a permit system, although a proxy that estimates the risk of emissions might work.

environmentally risky activities or outcomes, thereby creating scarcity. This permit can then be bought and sold by different firms. Firms with high marginal abatement costs (MAC) will benefit since they can buy permits from firms with lower MAC. Firms with the lower MAC will decrease their risk of emissions because they can sell their permits and increase profits. The scarcity of the permits along with the ability to trade creates incentives for firms to reduce their risk of emissions at least cost (Hanley *et al.*, 1997; Perman *et al.*, 1999).

As will all policy instruments, marketable permits need a base, or more specifically a tradeable good. In the case of ANS, this question has no good and obvious solution. Trading the right to emit ballast water could raise safety issues, and the ships with the highest MAC, who would buy the permits, would not necessarily be those who pose the lowest risk. Worth noting is the fact that marketable permits cannot target capital investments, since capital investments can not be traded. Thus, an effective policy basis for use with marketable permits will necessarily involve variable inputs or variable measures (e.g., a risk proxy or the amount of ballast water dumped). An ideal policy basis (the tradeable good) will have a strong relationship with the risk of introduction. However, marketable permits will allow the firms with the largest MAC to retain a high level of risk, thus hindering the ability of the marketable permits to lower the probability of introduction. In practice, the price of permits works as a sort of tax, where each firm must pay a certain amount for its risk, and risk levels will vary according to the marginal benefits of risk to each particular firm in accordance with economic efficiency.

Figure 3.4 graphically illustrates the operation of a marketable permit system. An estimate of risk of emissions is on the horizontal axis, while dollars are on the vertical axis. The two downward sloping lines represent the marginal profit curves of two different firms.

It is assumed that the firms have already received permits to create risk. Given the existence of supply and demand forces in a functioning market for the permits, an equilibrium price,  $P$ , will emerge. Each firm will buy or sell the permits so that the amount of permits they hold will allow them to create risk up to the point where its  $M\pi$  curve intersects  $P$ . However, the firms have different  $M\pi$  curves. This means that the cost benefits of emitting, or operating at a high level of risk, are greater for certain firms than for others. So, firm one will produce at the level where its risk of emissions equal  $r_1$  and firm two will produce up to  $r_2$ . While permits do induce all firms lower their risk level, the level of risk will still vary among firms.

Because a permit system combines elements of limits and incentives, tradeable permits may be desirable when the goal is to limit risk according to a safety-first criterion. The reason is that the permits, since they are a form of limit, place an upper bound on the aggregate level of risk. Firms then use the market to reallocate this risk in a least cost fashion.

### *Cross Compliance*

The Michigan legislature recently passed a bill, PA 114, aimed at decreasing the introductions of ANS by focusing on ballast water releases in Michigan waters. This bill operates as a cross compliance measure<sup>7</sup>. It renders firms ineligible for Michigan Department of Environmental Quality aid money if their ships did not dispose of or treat the ballast water in an acceptable manner (Sikkema, 2002). Cross compliance pollution control measures act as a binary instrument, either a firm totally loses eligibility for a

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<sup>7</sup>Public Act 114 also contains a reporting requirement.

government aid program, or it retains full eligibility. This is similar to a lump sum instrument, implying that firms do not have the incentive to abate at the margin. Cross compliance measures definitely give firms an economic incentive to abate, but not cost-effectively. Figure 3.5 graphically demonstrates the operation of a cross compliance measure with two firms with different levels of risk. On the horizontal axis is the estimated level of risk that a firm creates for the introduction of a new ANS. Dollars are on the vertical axis. The two downward sloping lines represent the marginal profit curves of two firms. The cross compliance measure is assumed to be set at  $r^*$ , the socially optimal level of risk of emissions. If a firm chooses to produce at a level of risk greater than  $r^*$ , then it loses eligibility for government aid, which equals the area equal to the box entitled cross compliance. If the area under the  $M\pi$  curve from  $r^*$  to  $r_0$  is smaller than the cross compliance box for either firm, then that firm will choose lower its risk to just below  $r^*$ . As figure 3.5 shows, firm one would choose not to abate, while firm two would choose to abate. This means that the firm which originally posed the greatest risk for introductions has not decreased its risk at all, while the ship that posed less risk has reduced its risk. The size of the compliance measure box can be changed to induce more or less abatement, and since the firms which pose the most risk lower their risk for a significant drop in the probability of introduction to occur, the value of the compliance measure will have to be quite large. Alternatively, the acceptable level of risk could be increased, meaning  $r^*$  moves to the right, an action which would get more of the firms with greater risk to reduce their risk. As Figure 2.3 demonstrates, pollution control measures need to target the firms with the greatest risk, otherwise the overall probability may not decrease greatly. So then, unless cross compliance measures have a very large penalty attached to them, they will not induce a significant

reduction in risk among the firms which already pose the greatest risk. However, cross-compliance may be a good idea when used in conjunction with other policies.

### *Compliance Bases and Options*

Policy instruments, such as incentives and standards, require policy bases. Options for policy bases include emissions proxies, ambient pollution levels and management choices (inputs) that influence the likelihood of emissions. Policy bases are the standards by which compliance with a policy is measured. For instance, a policy that uses an input as its basis would be judged on how well it affects input usage and thus pollution levels. Although a number of options exist, the unique nature of the ANS quandary will likely limit the effectiveness and efficiency of many of the policy bases, as discussed below.

### *Emissions and Proxies*

Intuitively, emissions seem to be an obvious basis for policy<sup>8</sup>. However, for the ANS problem, measuring actual emissions at a reasonable cost is not a feasible option. Risk proxies offer a promising alternative to emissions. Risk proxies are normally estimates of emissions or the likelihood of emissions, which are defined as a newly introduced species in this case. For a particular species, an introduction is a binary event, it will either occur or it

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<sup>8</sup>Griffin and Bromley (1982) showed that policies based on emissions proxies can produce an efficient outcome if the proxy is assumed to perfectly estimate emissions, and there are no stochastic variables. However, Shortle and Dunn (1986) indicated that proxies cannot perfectly measure emissions when stochastic factors influence emissions. Thus, the proxy only provides incentives to control mean emissions. But expected damages are influenced by the variance of emissions as well as the mean, and so the outcome can not be efficient. While not efficient, emissions proxies can still be usable. The usefulness will depend on how well correlated the proxy is to actual emissions.

will not. Accordingly, the estimate for any single specie lies between one and zero, although actual emission can lie outside this range. Since species introductions do not come in fractions, the risk proxy is most accurately understood as similar to the probability of an ANS invasion. The characteristics of a firm and its management decisions could be input into a computer simulation model to derive such estimates. The quality of the estimate depends on the comprehensiveness of the model as well as the degree of randomness in the variables. Due to random factors, proxies can not perfectly model risk, but they are a useful tool when relevant inputs can be measured. In the case of aquatic nuisance species, risk proxies can be based on a host of inputs and behaviors. These inputs and behaviors may include the origin of the ballast water, the cleanliness of the ballast tanks, whether or not a ballast exchange occurred, the length of the voyage or the presence and use of ANS prevention technologies. Proxies have been used in other contexts, such as in the control of nonpoint pollution. Marketable permit systems involving point and nonpoint sources work by allowing point sources who wish to increase their own emissions to pay nonpoint sources to make an offsetting reduction in their emissions. This is not a straightforward task however, because nonpoint source emissions are unobservable. This difficulty is overcome by using the estimate of these emissions as the basis for trades (Horan and Shortle, 2001).

A policy based on a risk proxy policy basis is performance rather than design-based, meaning that the policy focuses on the probable outcome as opposed to the process, ideally providing individual polluters an incentive to seek to lower their proxies in the most cost-effective way possible. Every policy basis has a certain set of conditions under which it maximizes efficiency; risk proxies are no different. Utilizing a risk proxy as a policy basis necessitates having the ability to measure the variables that affect the risk of ANS invasions.

In addition, a knowledge of how these variables contribute to emissions aids in constructing a model with which to produce useful emissions estimates. Unfortunately, the list of affecting variables can become lengthy. Thus, in order to lessen the burden of gathering information, a subset of the most relevant variables must be chosen. This subset will optimally contain the variables with the largest impact on ANS invasions. Both cost and the reporting burden need to be considered, consequently tradeoffs may arise between accuracy and cost, i.e., better specifying the risk proxy measure increases its cost and vice versa.

Firms need to understand the model that estimates their risk proxy and the variables over which they have control in order to respond rationally to mandates or incentives. The government will presumably take responsibility for constructing a model which produces the proxy. Polluting firms then need to be educated on the actions they can take to lower their risk proxy. Polluters may be aware of their emissions, but that does not imply that they know the steps they can take to limit those emissions. Firms and individuals responsible for the pollution need to have some control over the offending inputs and behaviors for risk proxies to be an efficient policy basis. The effectiveness of risk proxies as a policy basis relies on the polluters' comprehension of how to lower emissions and control the inputs and management practices that cause them, otherwise polluters will not know how to respond to the incentives.

Ideally, policies that utilize risk proxies (e.g., economic incentives or command-and-control measures) would be firm-specific since firms may create different expected marginal damages. Of course, firm-specific policies would increase administrative costs relative to policies that target firms uniformly, although they would also increase efficiency. The suitability of these two types of policy approaches, firm-specific and uniform, depends on

whether or not the expected marginal damages vary among firms. In the ANS case, it is not reasonable to assume that all firms have identical marginal expected damages.

### *Ambient Pollution Levels*

Ambient pollution is the overall level of pollution in an environment. In the context of ANS in the Great Lakes, ambient pollution can be defined as the number of non-indigenous species in the Great Lakes region. A policy based on ambient pollution levels works by monitoring ambient pollution measurements (number of ANS); if the measurements decrease, then general abatement is assumed, and vice versa. In the ANS case, introductions are binary events, either they have or have not occurred, thus the corresponding ambient measurements would be one and zero for any given species.

Ambient pollution does offer certain advantages as a basis for pollution control. Most importantly, it is often easier and less expensive to monitor than input use or emissions. Rather than monitor many firms, the regulator would only have to monitor the ambient level of pollution in the environment.

Along with the benefits of an ambient pollution policy basis exists disadvantages and a number of challenging design issues. An important disadvantage of ambient pollution as a policy basis is its ineffectiveness in dealing with all forms of pollution<sup>9</sup>. Skillfully designing policies based on ambient pollution may overcome these deficiencies to a degree, but limitations do exist. For instance, ambient pollution measures are subject to time lags. In the case of ANS, these lags can be years, and the ships responsible for the emissions may

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<sup>9</sup>The covariance between marginal damages and marginal ambient pollution needs to equal zero for all firms and all inputs for an optimal tax rate based on ambient pollution to exist (Horan *et al.*, 1998).



never be known or receive the consequences. Time lags can produce a situation where firms are held responsible for established ANS populations to which they did not contribute. Additionally, stochastic factors affect the actual level of ambient pollution, meaning that firms do not have assurance that their risk reductions will lower the ambient pollution levels. Altogether, ambient pollution has definite weaknesses as a policy basis, particularly in the ANS case.

Tax and subsidy schemes based on ambient pollution concentrations have been proposed for efficiently reducing nonpoint and other pollution problems (Segerson, 1998). This discussion on ambient-based instruments will focus entirely on economic incentives<sup>10</sup> (e.g. taxes, subsidies, and liability). As noted above, ambient pollution-based policies monitor ambient pollution measurements (number of ANS), and if the measurements do not increase, then general abatement is assumed and firms are either not taxed or receive a subsidy. The presence of new ANS would indicate that firms have not abated (i.e. reduced their risk of ANS introduction), and then firms are either subject to taxes or loss of a potential subsidy. The advantages of an ambient-based policy include the low monitoring costs, low administrative costs, and the incentive all firms have to abate when the opportunity cost of not abating is sufficiently high (i.e. large taxes or subsidies). In the case of ANS major disadvantages also exist such as the time lag between the introduction of a new species and its identification as well as large economic incentives necessary to deter

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<sup>10</sup>Governmental mandates that limit pollution do not function well when the basis for policy is ambient pollution. A disconnection exists between the mandate and the required actions of polluters. Polluters may know that they are required to lower the ambient pollution level, but not knowing the actions of other polluters, nor necessarily how the ambient pollution requirement relates to a change in individual firm action, they do not have enough information or a compelling reason to comply. Hence, regulations do not generally produce cost-effective outcomes when compliance is based on ambient pollution.

free-riding which raise equity issues. Additionally, policies based on ambient pollution have a unique set of design issues, explored below, which limit the forms of policies available, and the types of pollution that can be addressed with this policy basis.

Polluters need to understand how their actions and choices affect ambient pollution for ambient-based incentives to work. Unless they understand the impact of their choices on ambient pollution, basing policies on ambient pollution can not work. This means that firms which do not believe their choices have an impact, as well as those firms which do not understand their impact may not respond to incentives, in which case incentives may need an adjustment. Policies need to be constructed in such a way that firms benefit from their reductions in pollution, otherwise a freeriding situation can evolve. Conventionally, all polluters contribute to the level of ambient pollution in an environment, and so ambient pollution measures compliance by a group, not individually. However, in the ANS case, a perfect correlation does not exist between the risk of ANS introduction and the expected damage from ANS invasion due to the random natural forces shown in Figure 2.1. This can create a tendency toward freeriding which may potentially pose an equity dilemma as firms which reduce their risk will not necessarily change the actual environmental outcomes (i.e, ANS invasions). However, effective deterrence of freeriding can result from large opportunity costs of polluting. If the government sets an ambient tax high enough, no firm will consider polluting to be profit-maximizing, and thus all will reduce their level of risk. Admittedly, the level of the tax or other penalty necessary to achieve this may be quite high. The solution to freeriding of creating extremely large opportunity costs may cause some firms to cease operations or decrease their level of risk beyond the socially optimal level.

### *Liability Rules and Ambient Pollution*

Liability rules are a form of ambient-based incentive, since suits normally result from the damages caused by the level of ambient pollution in the environment. In general, liability rules do provide polluting firms with the incentive to abate. Liability rules have been discussed as a potential policy for the Great Lakes before (Larsen 1995, Foster 2000). In fact, laws already on the books may allow for liability suits in the ANS situation (Foster 2000). Policies that incorporate liability rules often use an emissions basis. In the case of ANS, emissions cannot be measured, and introduced species cannot be traced back to individual ships. This creates an incentive for firms to abate as little as possible, since no one will likely trace their ANS introductions back to them. When a joint and several liability standard is used, an ambient pollution basis might allow for the entire industry to be held liable for the level of ambient pollution, which in this case is the number of introduced species. A joint and several liability rule may have more potential with regard to the ANS situation than either strict liability<sup>11</sup> or negligence under liability<sup>12</sup> due to its focus on the number of firms to have contributed to pollution damages.

“The term “joint and several liability” means that if the government can identify just one party out of many that contributed wastes to a site, then that one party can be held responsible, potentially, for all cleanup costs. In turn, any potentially responsible parties that have been identified by the government may seek to involve other potentially responsible parties (NCEE 2001).”

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<sup>11</sup>A firm is held responsible for all the damages it creates under a strict liability standard.

<sup>12</sup>A firm is held responsible for its damages if it did not take due care to avoid damages.

Under a joint and several liability standard, all ships that have introduced ANS are potentially responsible for all the damages of the particular species they may have introduced, even if they were not the first. This characteristic conventionally gives joint and several liability standards a better chance to recoup cleanup costs. However, this standard of liability would still require the ability to trace the introduction of an ANS to a specific ship, thus sharing the same limitation as the other types of liability. Unless this obvious limitation of the different forms of liability in the ANS case can be overcome, liability rules will not likely play a significant role in preventing ANS introductions.

A relevant consideration with regard to the ANS problem is the importance of the initial introduction. Once a species has entered the Great Lakes and established a population, the introduction of a few additional members of that species does not have a significant impact. The problem can be compared to throwing a rock through the window in that the first rock does the damage. Additional rocks may exacerbate the problem, but the value of the window fell the most with the first rock. So then, a joint and several liability standard holds all the rock throwers responsible for the first introduction.

Particularly in the ANS situation, liability rules have distinct weaknesses. Liability rules introduce an additional degree of randomness in enforcement which may cause polluters to lower their expected liability from ANS introductions. A liability rule would afford society with the right to bring suits against firms for the damage caused by ANS introductions. Two features of liability rules that reduce effectiveness are the uncertainty regarding whether or not a firm will actually face a lawsuit for the ANS introductions it is responsible for and the possibility that not every lawsuit will result in a polluting firm having

to pay damages. For these reasons, while liability rules do have the potential to deter polluters from emitting, they would not result in a first-best outcome in the ANS situation.

### *Inputs and Practices*

Policies based on inputs attempt to alter the use of those inputs or practices that affect the level of pollution; in other words, to change the biosecurity choices firms make. For example, farmers can limit pesticide runoff by decreasing pesticide use, or ships can decrease the probability of introducing an ANS by using biocides or filters. To decrease input usage, marginal costs (normally the price) associated with using the input should be raised. Increasing the usage of certain inputs may lower the probability of introduction, indicating that the marginal costs should be lowered. So then, changing the price of an input can change its usage and affect emissions levels, or risk levels in the ANS case. In the long run this tendency is magnified since technologies are developed to use expensive inputs sparingly and expand usage of inexpensive inputs (Hayami and Ruttan, 1985). In the ANS case, many of the inputs, such as water filters and ultrasound systems, are not used at all, and the policy challenge is to introduce these new inputs into the production process.

Chapter two described how the economically efficient level of production occurs at the point where the marginal social benefits of production equals the marginal damages. The idea of economic efficiency can be applied to the analysis of the efficient level of inputs, assuming that responsibility for pollution and profits can be divided among inputs. A tradeoff between social benefits (e.g., profits, the produced good) and social damages (e.g., pollution) exists with the use of inputs. Society maximizes its welfare when the marginal

benefits and expected marginal damages of input usage equal. Policies that utilize inputs as a policy basis attempt to lower the expected marginal damages caused by input usage.

Policies based on input usage can be shown to be economically efficient in some cases. An efficient policy that utilizes an input basis would target all relevant inputs in a firm-specific manner equal to the expected marginal damage or benefit created by each input. In the case of input-based incentives, for example, each risk-increasing input would have to be taxed and each risk-reducing input subsidized, and the tax/subsidy rates would vary by firm. For example, a policy based on input usage that utilizes economic incentives might subsidize filtration and ultrasound systems while taxing the deballasting of untreated ballast water in coastal areas. Achieving economic efficiency requires changing input usage individually for scores of inputs and firms in order to equalize the marginal benefits and marginal damages of each input for each polluter. Needless to say, any such policy will create enormous monitoring and administrative costs, effectively negating the efficient nature of the policy.

Targeting all the pollution-contributing inputs can be an onerous and expensive task, so it may be optimal to only focus on those inputs that are both easily observable and highly correlated with risk. Eliminating certain inputs from consideration reduces the regulatory burden that would otherwise be established for polluters and bureaucrats to navigate through, thereby creating excessive costs. This leads to a familiar tradeoff; the larger the targeted subset of inputs and practices, the greater the transaction costs imposed on all parties. However, a smaller targeted set of inputs results in less control over environmental outcomes. If a safety-first criterion is adopted, then an input-based strategy that targets only a subset of inputs might allow for excessive levels of risk to emerge, depending on which

inputs are not targeted. Alternatively, the regulator might have to compensate for the non-targeted set by increasing the stringency of policies directed at the targeted set, such as by encouraging or mandating the adoption of expensive technologies that are highly effective at significantly reducing risk and that leave little room for adverse impacts from choices involving non-targeted inputs.

Inputs are defined as both current and potential inputs and management practices. Using this definition, all of the ANS prevention technologies mentioned in Chapter One fall into the input category, along with the other physical inputs and management practices such as ballast water and ballast exchange. For certain inputs, the quantity of an input can vary greatly (i.e. biocides or ballast water), while for other inputs, such as filtration systems, the quantity employed will be either one or zero. An understanding of the feasible input quantities is necessary when formulating policy goals in order to provide incentives that promote feasible input use decisions.

Government mandates or rules are one potential instrument that can work with policies based on input usage. Mandates could work in two ways, depending on whether the policy is designed to increase or decrease input usage. Rules that seek to decrease the use of an input, work by restricting the amount of the input each particular ship could employ, or limiting the supply of that input for the industry overall. Increasing input usage would require imposing lower limits on the amount of an input each polluter can use. Input restrictions that attempt to lower input use would more heavily penalize the firms with a greater reliance on the input. Mandates that seek to increase input use would reward firms that heavily use the input at the present time, requiring that they make a relatively small change in their production process.

Rules that mandate introduction of a new technology into the production process require a binary change. Firms must switch from not having, to both possessing and utilizing a certain technology; water filters for ballast tanks offer a perfect example of this. Monitoring whether firms possess the mandated technologies does not pose a great regulatory burden. However, the transaction cost of enforcement and monitoring whether and to what degree firms use these technologies may be prohibitively high; biocides provide a good example since the marginal cost of using biocides is constant and greater than zero. So then, if the monitoring and enforcement of an input with significant marginal costs of use such as a water heater or biocide is overly expensive, mandating or encouraging the use of a technology such as a filtration could produce better environmental results than the use of technologies with which regulated parties have an incentive to minimize usage.

Economic incentives can cause changes in input usage. Economic incentives operate by changing the marginal costs of an input and thereby altering its usage. Taxes and subsidies are the most familiar economic incentives. Both taxes and subsidies hold some promise for use with policies based on input usage. Taxing an input should cause its use to decrease, while a subsidy should do just the opposite. The size of the change in usage will depend on the magnitude of the tax or subsidy, and the change in input usage will produce a change in emissions<sup>13</sup>. As mentioned above, economic incentives could potentially be tied to inputs, such as the subsidization of chemical treatments or filtration systems or the taxation

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<sup>13</sup>It is worth noting that economic incentives have a unique relationship to binary inputs. While they do try to change their usage, it is only from zero to one or vice versa. This implies that taxes and subsidies operate as non-varying penalties and grants which either take effect or do not, implying that unless they are large enough to change input usage (from zero to one or vice versa), they have no effect at all. This being the case, the operation of taxes and subsidies on binary inputs shares some similarities to cross compliance measures.



of ships that deballast without having exchanged ballast on the open ocean or that do not have approved ANS control technologies (e.g., filters, UV systems, biocides, etc.).

In the case of Aquatic Nuisance Species which enter the Great Lakes, an obvious input to target is ballast water. Unfortunately, there exists no good substitute for ballast water, so taxing or restricting the use of ballast water could have severely deleterious effects on the shipping industry. However, many physical inputs and management practices do have the ability to lower the probability of ballast water introducing ANS. Many of the inputs and practices reviewed in Chapter One lie in the category of inputs which decrease the danger from ballast water. Utilizing inputs as a policy basis offers an effective way to reduce emissions if policies target inputs that are highly correlated with emissions.

## Chapter Four

### Conclusion

Aquatic Nuisance Species invasions have caused significant economic damages both in the Great Lakes region and globally, primarily by altering ecosystems and disrupting industries. ANS invasions are certainly a significant pollution problem, and human activities such as commercial shipping provide opportunities for ANS invasions. For instance, ships may carry species in their ballast tanks and release them into a new environment when they take on or exchange ballast water in the Great Lakes. Individual ship owners and operators do not consider the potential external costs of their ballast management practices (in terms of a potential ANS invasion), and thus they have no incentive to adjust their behavior to reduce this threat. The result is a need for public policy to induce ship owners and operators to make more socially efficient biosecurity choices. However, the types of policy approaches that are commonly used to address more conventional forms of pollution do not apply here. Economists typically promote emissions-based policies because such policies are closely related to external damages and because such ‘performance-based’ instruments give firms the flexibility to reduce their emissions in the most cost-effective way they can find. But emissions of ANS are not directly or indirectly observable, and so emissions-based policies are infeasible in the ANS context.

Many of the general types of instruments used in other pollution contexts, such as taxes and standards, can work to help reduce the threat of ANS invasions. These instruments will have to be applied to a compliance measure other than emissions (which are unobservable). Good policies will be positively correlated with the likelihood of invasion,

and will also provide vessels with flexibility to look for ways to further reduce costs and/or improve effectiveness.

In this paper, I have used a framework for policy evaluation that focuses on two facets of good policy design: the basis, the measure to which the policy is applied, and the instrument, which is the policy tool used. An effective policy will use an appropriate basis and instrument. While a variety of policy bases and instruments exist, the design of the policy and its suitability to the particular problem require special consideration. I have analyzed a number of different bases and instruments. Some have desirable properties, although none represents a panacea for the ANS dilemma. In the following paragraphs I review the three bases considered in this paper to show how some potential policies may be formed to lower the threat of ANS invasions. These three policy bases are biosecurity choices, risk proxies, and ambient pollution levels.

The term 'biosecurity choices' refers to the choices regarding input usage and management practices that a firm makes which affect the likelihood of ANS invasions. For example, chemical treatment of ballast water would be considered here as a biosecurity choice. Using specific biosecurity choices as a policy basis implies that the policy will target the process by which risk is produced rather than the outcome. Taxes, subsidies, government mandates, and cross-compliance measures are policy instruments that could work with biosecurity choices as the policy basis. The magnitude of the tax, subsidy, or cross-compliance measure will affect the degree to which firms change their biosecurity choices. In principle, input-based policies can be efficient. However, the design of such instruments is so complex (e.g., targeting all potential biosecurity choices with vessel-specific rates) as to make efficient input-based policies infeasible. More practical approaches involve

targeting only certain choices with fairly uniform policy instruments across certain vessel classes. The effectiveness of lowering ANS invasions will depend on how closely the input or biosecurity choices are correlated with the likelihood of invasions as well as the correlation between non-targeted inputs or biosecurity choices and the likelihood of invasions.

Risk proxies are computer-generated estimates of the likelihood of ANS invasions produced by a model that utilizes the available data. Hence, risk proxies are a measure of performance. Firms that face policies based on these measures will have incentives to choose the most cost effective approach for reducing risk. The same list of policy instruments as above, as well as possibly marketable permits, could be paired with risk proxies to create an ANS prevention policy. The accuracy of the risk proxy is important to provide firms with the incentive to take actions highly correlated with the likelihood of ANS invasions, thereby lowering the threat of ANS invasions. Increasing the accuracy of the risk proxy involves correctly specifying a model and gathering accurate data, the latter of which can become expensive. Again, as with biosecurity choices, assuming the policy basis is highly correlated with the likelihood of ANS invasions, the effectiveness of the policy will depend on the size of the incentive provided by the policy instrument. It is worth noting that, because risks will not be uniform across firms, every policy will ideally be firm-specific and will provide the optimal level of incentive for each firm. However, financial and time restraints render this ideal quite impractical.

Finally, policies could be based on ambient pollution levels -- the overall levels of pollution in an environment, which in the ANS context means the number of species which have invaded the Great Lakes region. This basis does not measure the risk any one firm

poses, but rather the damage already caused. So if an invasion does occur, then all firms that contributed to the risk of invasion would be held accountable. The hope is that ambient-based instruments will provide firms with ex ante incentives to reduce the risk of invasion. It is natural to consider a liability rule as a potential ambient-based policy instrument, particularly since it is impossible to accurately assign responsibility for any particular invasion to a firm. But for this same reason and also other reasons, ambient-based policies may not provide the proper incentives when used alone. The problem is that for these instruments to work, firms would have to understand how their choices combine with the choices of other firms to affect the overall risk of invasion. This is too much information for the typical firm to process. If a firm thinks its risk contribution is negligible relative to others, then the firm may not have incentives to change its actions. The only way to encourage a risk-reduction response in this case is to drive up the penalties to a point where some firms will go out of business. This implies that any policy using this basis will be relatively ineffective in lowering the risk of ANS invasions without destroying the responsible industry, shipping in this case.

From an economic standpoint, there is no perfect policy instrument to reduce the risk of ANS invasions. But there are some approaches that make more economic sense than others – that is, some approaches can result in risk-reduction goals being achieved at low cost relative to other approaches. The next step is to gather more information about the costs and effectiveness of various approaches and use this information to empirically analyze specific types of policy tools that in theory hold promise.

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Table 1.1—Selected Non-indigenous Species with Origins, Date of Entry, and Introduction Vectors  
(Source: Mills *et al.*, 1993)

<i>Species</i>	<i>Origin</i>	<i>Date of Entry</i>		<i>Vector(s)</i>
Eurasian Watermilfoil	Eurasia	<1952	R(AQ), S(F)	
<i>Glugea bertwigi</i>	Eurasia	1960	R(F)	
Zebra Mussel	Eurasia	1988	S(BW)	
Coho Salmon	Pacific	1933		R(D)
Brown Trout	Eurasia	1883	R(A)	
Ruffe	Eurasia	1986	S(BW)	
White Perch	Atlantic	1950		C
Alewife	Atlantic	1873	C, R(F)	
Sea Lamprey	Atlantic	1830's		C, S(F)
Chinook Salmon	Pacific	1873		R(D)
Common Carp	Asia	1879	R(D)	
<i>Aeromonas salmonicida</i>	Unknown	<1902		R(F)
Purple Loosestrife	Eurasia	1869	C, S(SB)	

Table 1.2—Effects of Selected Non-indigenous Species (Adapted from Mills *et al.*, 1993, for additional information refer to Leach *et al.*, 1999)

<p><u>Zebra Mussel</u>-its biofouling and filter-feeding negatively effects the Great Lakes ecosystem. Large concentrations(which is normal) of zebra mussels increase water clarity and hurt native Anand clam populations. The species imposes millions of dollars of cleanup costs on water treatment facilities.</p>
<p><u>Alewife</u>-destroyed habitat of more favored fish and birds(Emery 1985). Supports a small commercial fishing industry and is a forage food for commercial fish.</p>
<p><u>Ruffe</u>-carnivorous fish, presently relatively concentrated, with great potential for affecting the Great Lakes ecosystem.</p>
<p><u>Sea Lamprey</u>-induced the decline of the native lake trout populations, resulting in millions of dollars of lost fishing revenues. Also adversely affected burbot populations.</p>
<p><u>Purple Loosestrife</u>-competes with native plants, marsh animals, and waterfowl for habitat.</p>
<p><u>Glugea bertwigi</u>-this protozoan parasite reduced the rainbow smelt population in the 1960s and 1970s, but such infestation has not occurred since.</p>
<p><u>Eurasian Watermilfoil</u>-this plant can change water temperatures, poses difficulties for recreational and industrial water uses, and competes with native plant species.</p>
<p><u>Coho and Chinook Salmon</u>-popular in the sport fishing industry and help control alewife populations.</p>
<p><u>Aeromonas salmonicida</u>-this gram-negative bacterium causes furunculosis, trout and gold fish ulcer disease, common carp erythrodermatitis, and other infections.</p>
<p><u>Common Carp</u>-destroyed habitat of more favored fish and birds(Emery 1985).</p>
<p><u>White perch</u>-sport and commercial fish.</p>

Table 1.3—Selected Ballast Water Treatment Technologies and Behavioral Methods  
(Source: Oemcke, 1999)

Physical
Filtration
Cyclonic Separation
Ultraviolet Irradiation
Heat
Ultrasound
Magnetic Fields
Electric Fields
Chemical
Chlorine
Other Halogens(Bromine and Iodine)
Chloramine
Chlorine Dioxide
Ozone
Hydrogen Peroxide
Organic Compounds
Copper Ions
Copper + Silver Ions
Ionizing Radiation
Photochemistry
Oxygen Deprivation
pH Adjustment
Salinity Adjustment
Tank Coatings
Behavioral
Ballast Exchange
Ballast Retention
Ballast Water Micromanagement

Table 1.4—Descriptions of Selected Ballast Water Treatment Technologies  
(Sources: Buchholz *et al.*, 1998; Mackey *et al.*, 2000; Oemcke, 1999; Pollutech, 1992)

Filtration and cyclonic separation. Filtration has received a great deal of attention for its potential as a primary ballast water treatment and as a stand alone ballast water treatment (Pollutech, 1992). A number of different filtration methods exist, including rapid sand filtration, screening, cloth screens/filters, precoat filtration and membrane filters (Oemcke, 1999). “The Great Lakes Ballast Technology Demonstration Project concluded that filtration with automatic back-flush screen filters was feasible with existing technology down to about 50 microns (Mackey *et al.*, 2000).” Filtration was also shown to be 95-99% effective against zooplankton and 60-80% effective against smaller planktonic organisms (Mackey *et al.*, 2000).

Ultrasound. Ultrasound works in ballast water by producing small vibrations that cause “microscopic gas bubbles to quickly form, expand, and implode (Buchholz *et al.*, 1998).” This process can “rupture cell membranes, free particulates from solid surfaces, and destroy particles and organisms through particulate collisions or by forcing them apart (Buchholz *et al.*, 1998).” Ultrasound is often mentioned as a secondary technology whose effectiveness increases with pre-treatment. While this is true, ultrasound can still effectively treat ballast water. Ultrasound can kill or inactivate 100% or larger organisms and achieve a 99.9999-99.99999% reduction in bacterium and viruses. Using this technology does require significant costs, one 600-gpm unit costs \$250,000 to purchase and requires electricity in the range of 40 kW/hr(1,000 gpm) to 294 kW/hr (7,350 gpm)(Buchholz *et al.*, 1998). Additionally, ultrasound systems require very little maintenance, approximately once every 12,000 hours.

Ultraviolet Radiation. Ultraviolet radiation is considered a very promising secondary treatment option. UV radiation causes a “photochemical reaction of cellular nucleic acids” (Buchholz *et al.*, 1998) which either kills organisms or renders them unable to reproduce. The effectiveness of this treatment increases as water clarity, exposure period, and radiation energy increase (Buchholz *et al.*, 1998). Primary treatment options such as filtration increase the effectiveness of UV radiation by removing larger organisms from the ballast water which may block the UV rays. Estimates of the costs for an Ultraviolet radiation unit vary along with the volume of water they can handle, from \$10,000 -\$545,000. Additionally, UV units impose operating costs of around \$2,200-\$4,000 a year and require regular maintenance (Buchholz *et al.*, 1998).

Heating ballast tanks. Using heat to treat ballast water has received renewed attention largely because of the possibility of using waste heat from the ships engines. While this measure would likely lower the operating costs, it would also impose high costs for refitting the plumbing. Heat treatment of ballast water works by “denaturing cellular proteins and/or increasing metabolism beyond sustainable levels (Buchholz *et al.*, 1998).” Heat treatment affects different organisms at different temperatures, for example, less complex organisms generally do not succumb to heat as quickly as more complex organisms. The cost of a boiler to heat water varies with the volume it can handle, from \$60,000 for a 1,200 gpm unit to a 12,000 gpm unit for \$600,000. As the size of the boiler varies, so does its oil consumption. Additionally, heat treatment systems can impose a safety hazard for crew members with the hot water it produces.

Table 1.5–Selected International ANS Prevention Policies (Source: INTERTANKO, 2002)

<u>Country</u>	<u>Date Enacted</u>	<u>Policy</u>
Australia	1992	Voluntary ballast water exchanges and mandatory reporting.
Argentina- <i>Buenos Aires</i>	1990	Mandatory chlorination of ballast water for ships arriving from areas with cholera.
Israel	1994	Mandatory ballast exchanges in open ocean for all ships destined for Israeli ports.
New Zealand	1998	Mandatory mid-ocean ballast water exchange.
United Kingdom- <i>Orkney Islands</i>	<1998	Mandatory ballast discharge to onshore water treatment plant.

Table 1.6—Selected Policies, Legislation, and Actions Relating to ANS Invasions in the Great Lakes (Source: Reeves, 1999)

*August 1998*—Great Lakes Fishery Commission and the International Joint Commission request ballast water regulations for ships entering Great Lakes.

*May 1989*—Canadian Coast Guard sets forth Voluntary Guidelines for the Control of Ballast Water Discharges from Ships, advocating ballast exchange.

*November 1990*—Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA 1990) passed, directing U.S. Coast Guard to issue voluntary and mandatory guidelines, six months and two years respectively after the act.

*April 1993*—U.S. Coast Guard issues regulations, as directed by NANPCA 1990, that require ballast exchange or alternative measures on all ships entering the Great Lakes.

*November 1993*—Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges, which urges ballast exchange, is adopted by the International Maritime Organization General Assembly.

*October 1996*—United States passes the National Invasive Species Act of 1996 (NISA 1996), directing the U.S. Coast Guard to set forth national voluntary guidelines one year after act and mandatory policies three years later, if the voluntary guideline prove ineffectual.

*October 1998*—With the passing of the Shipping Act, Canada authorizes the government to issue mandatory regulations for ballast water management in Canada.

*May 1999*—U.S. Coast Guard issues an interim rule including national ballast water exchange guidelines and mandatory reporting requirements.

*August 2001*—Michigan enacts Public Act 114 which requires ships to report their ballast water management and ties eligibility for state grants, loans and awards to satisfactory ballast water treatment.

Table 2.1—Quadrants of Risk, Profit, and Recommended Action

<u>Expected Marginal Damage</u>	<u>Marginal Profit Level</u>	
	<u>High</u>	<u>Low</u>
<u>High</u>	Intermediate reduction of risk	Large reduction of risk
<u>Low</u>	Small reduction of risk	Intermediate reduction of risk



Table 3.1—Uses of Economic Incentives (Source: NCEE 2001)

Incentives	Examples	Pros & Cons
Pollution Charges & Taxes	Emission charges Effluent charges Solid waste charges Sewage charges	Pros: stimulates new technology; useful when damage per unit of pollution varies little with the quantity of pollution  Cons: potentially large distributional effects; uncertain environmental effects; generally requires monitoring data
Input or Output Taxes & Charges	Leaded gasoline tax Carbon tax Fertilizer tax Pesticide tax Virgin material tax Water user charges CFC taxes	Pros: administratively simple; does not require monitoring data; raises revenue; effective when sources are numerous and damage per unit of pollution varies little with the quantity of pollution Cons: often weak link to pollution; uncertain environmental effects
Subsidies	Municipal sewage plants Land use by farmers Industrial pollution	Pros: politically popular, targets specific activities Cons: often weak link to pollution; uncertain environmental effects
Deposit-Refund Systems	Lead-acid batteries Beverage Containers Automobile bodies	Pros: deters littering; stimulates recycling Cons: Potentially high transaction costs; product must be reusable or recyclable
Reporting Requirements	Proposition 65 SARA Title III	Pros: flexible, low cost  Cons: impacts may be hard to predict; applicable only when damage per unit of pollution does not depend on the quantity of pollution
Voluntary Programs	Project XL 33/50 Energy Star	Pros: low cost; flexible; many possible applications; way to test new approaches Cons: uncertain participation
Liability	Natural resource damage assessment Nuisance, trespass	Pros: provides strong incentive  Cons: assessment and litigation costs can be high; burden of proof large; few applications
Marketable Permits	Emissions Effluents Fisheries access	Pros: provides limits to pollution; effective when damage per unit of pollution varies with the amount of pollution; provides stimulus to technological change Cons: potentially high transaction costs; requires variation in marginal control costs

Figure 1.1–ANS Taxonomic Groups in the Great Lakes (Source: Mills *et al.*, 1993)

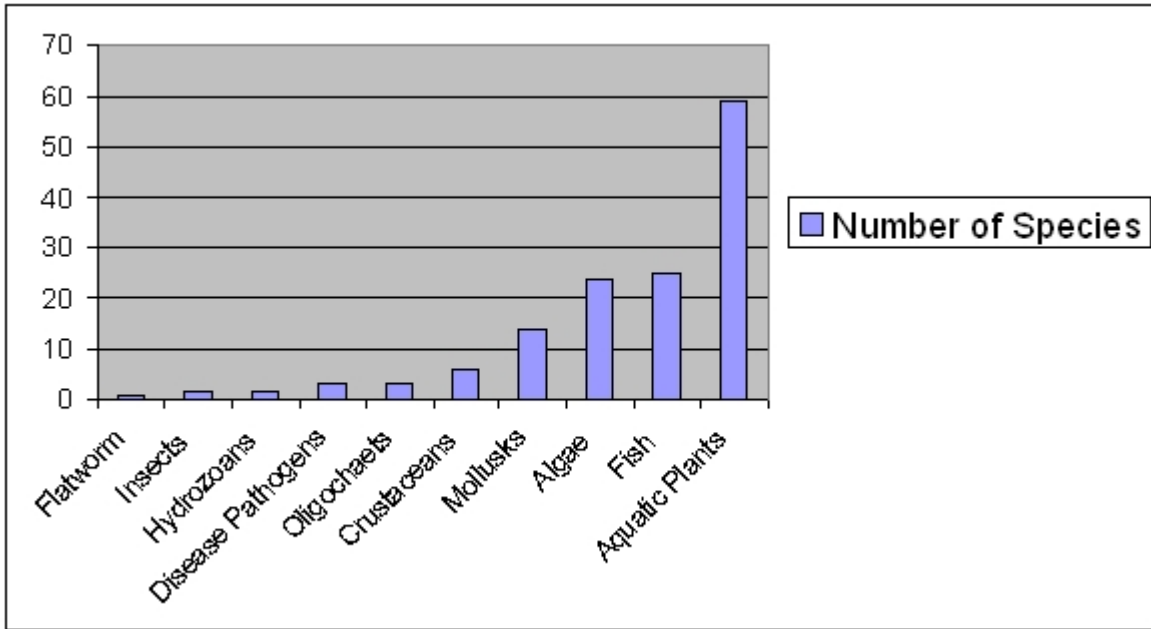


Figure 1.2–ANS Introduction Vectors Over Time (Source: Mills *et al.*, 1993)

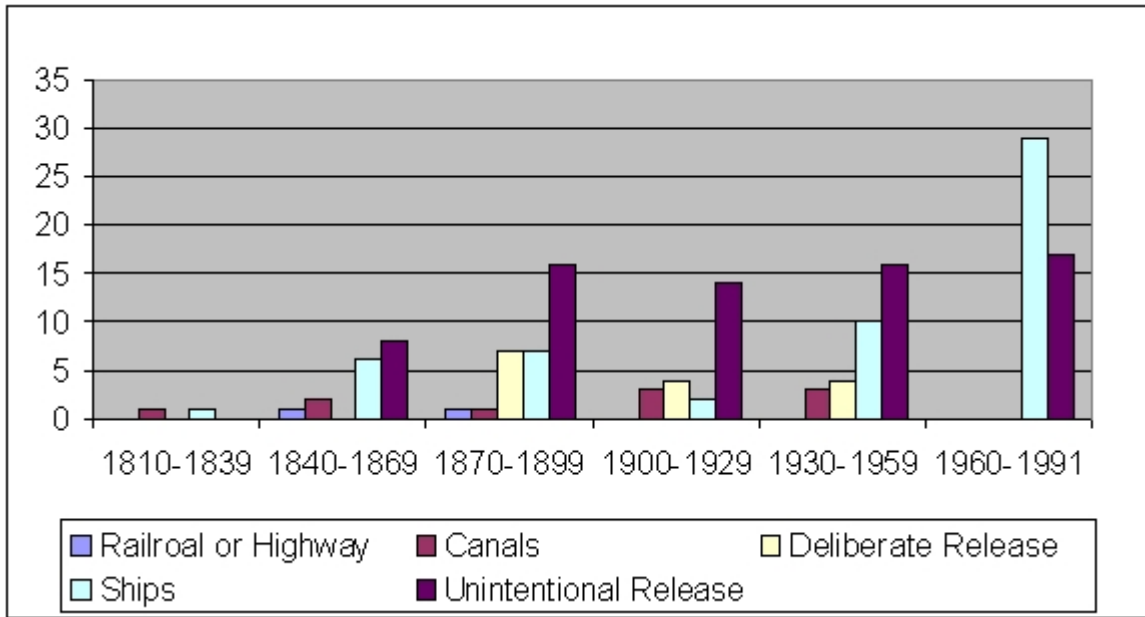


Figure 1.3–Diagram of Ballast Water Management Options (Source: Oemcke, 1999)

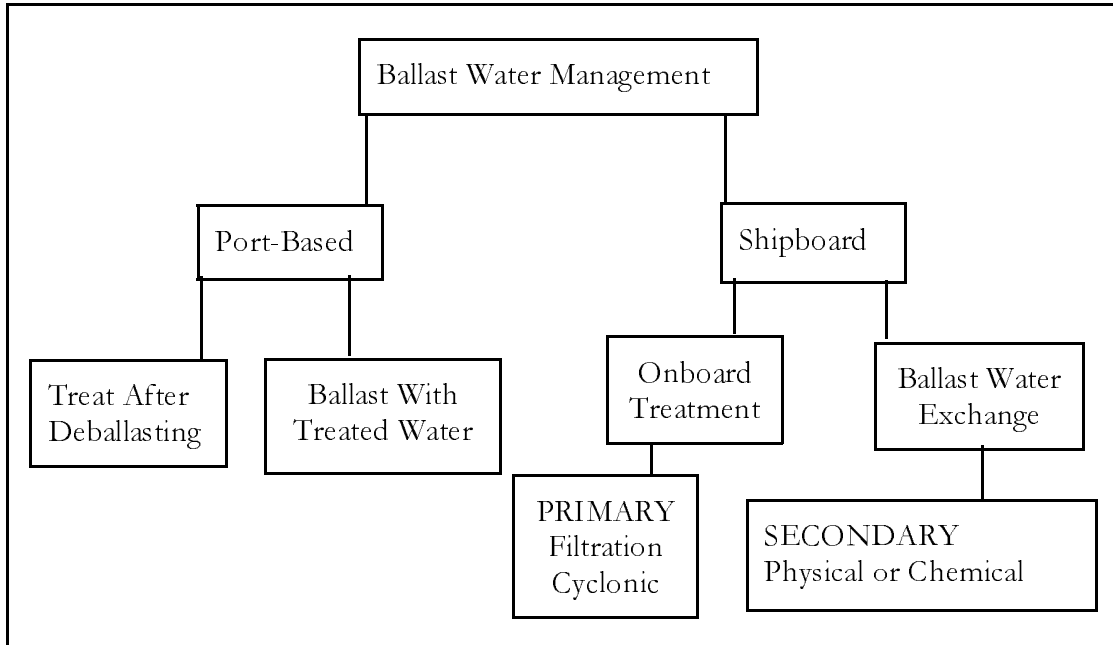


Figure 2.1–The ANS Invasion Process

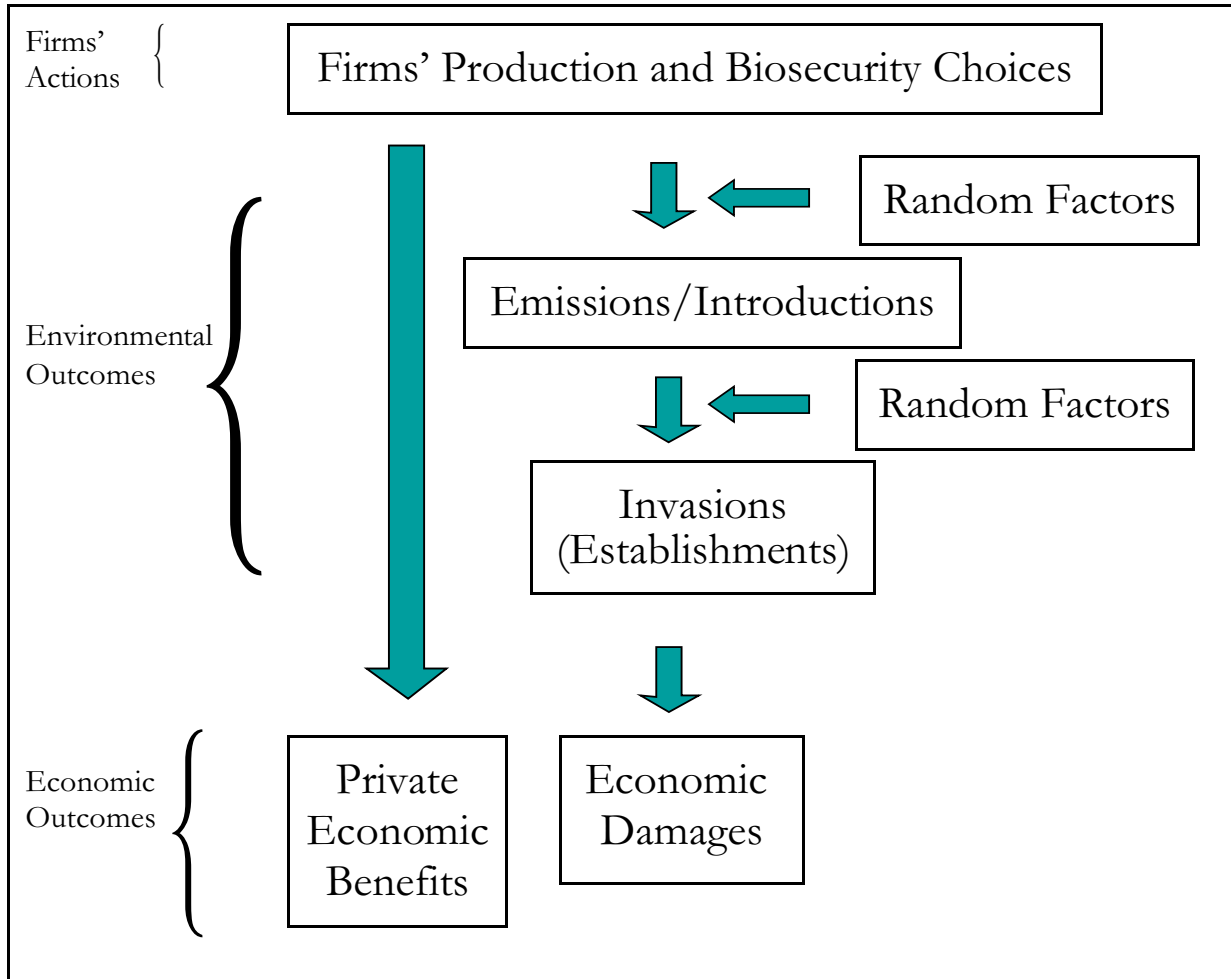


Figure 2.2–Social Welfare

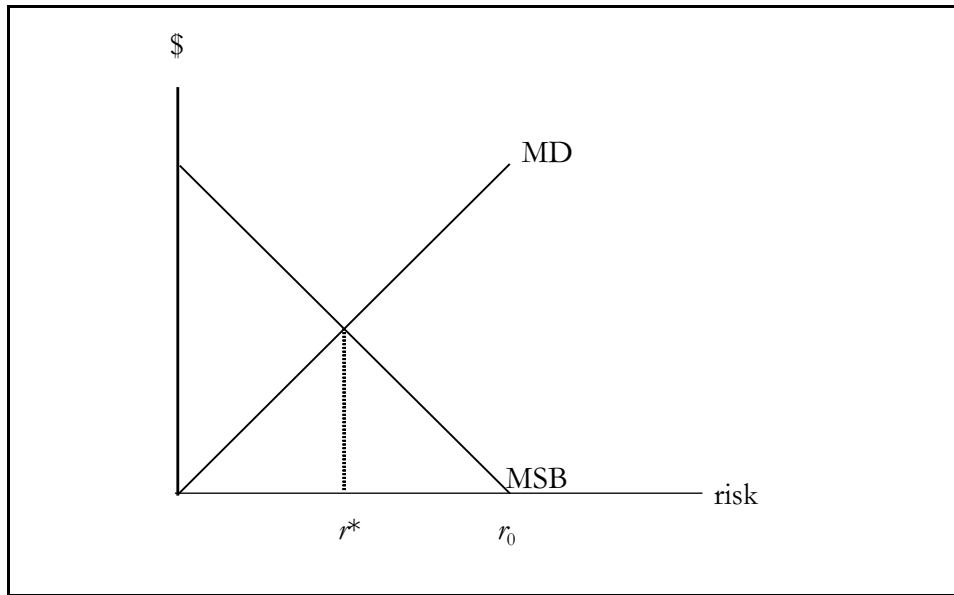


Figure 2.3–Different Marginal Demand and Profit Curves

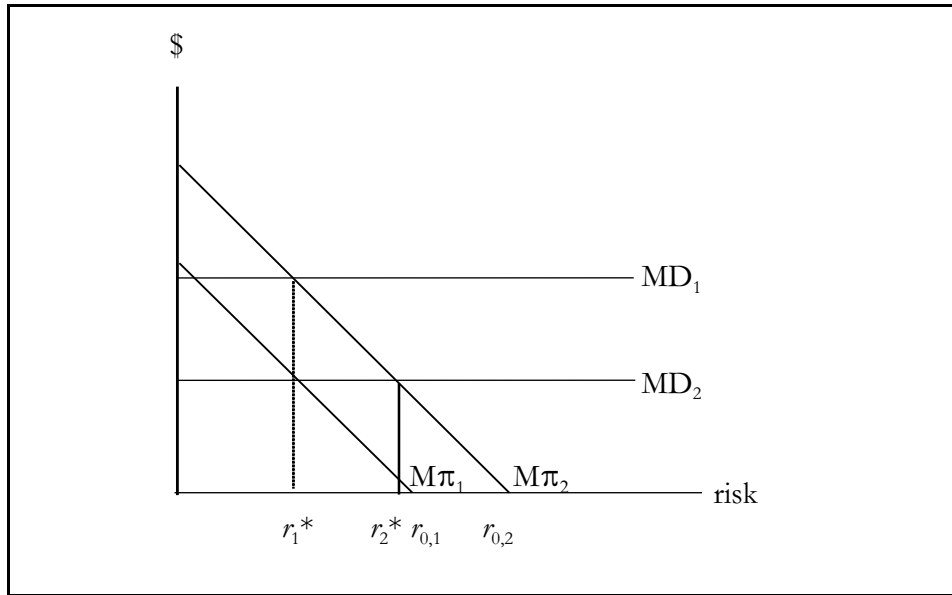


Figure 2.4—The Incentives the Firm Faces

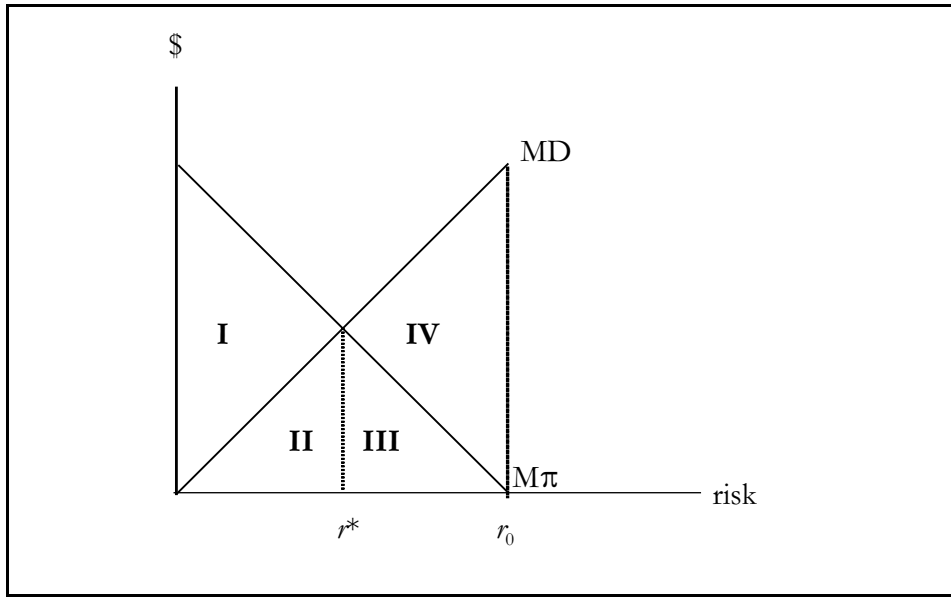




Figure 3.1–Government Mandated Limit

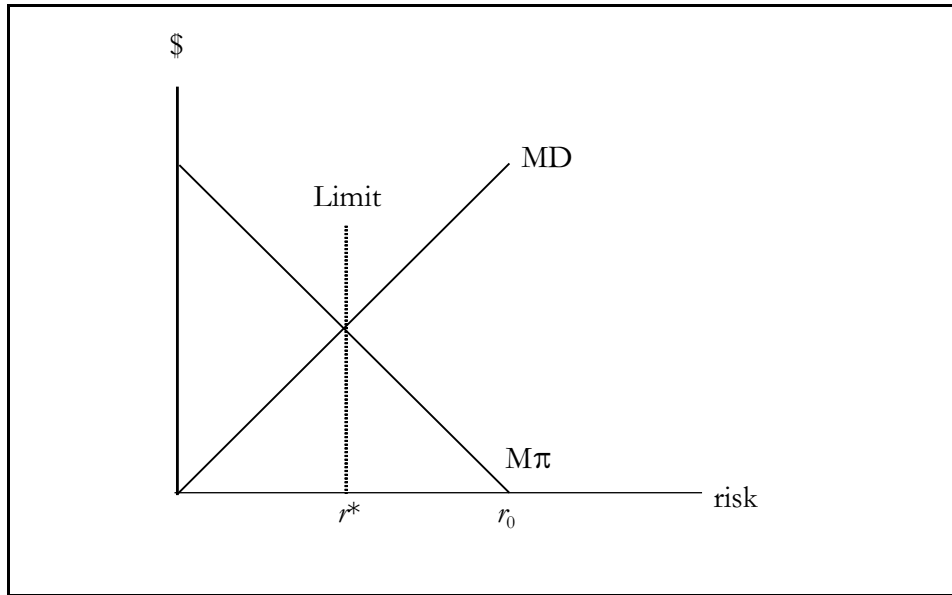


Figure 3.2–Tax

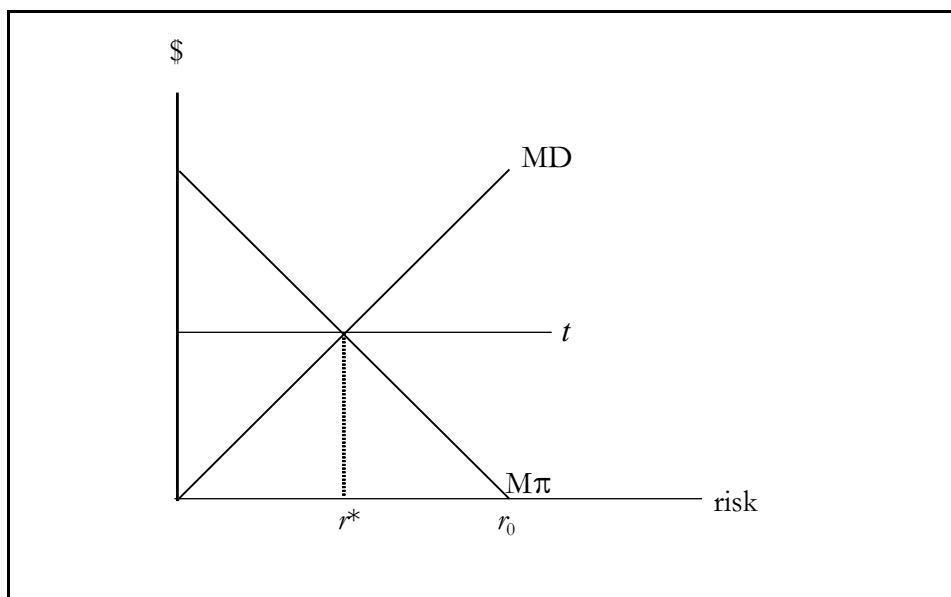


Figure 3.3–Subsidy

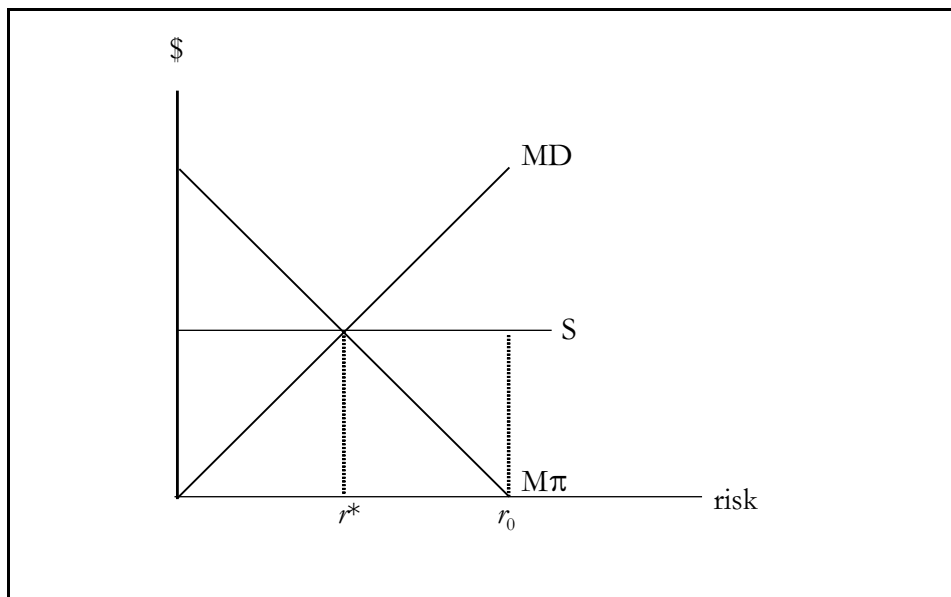


Figure 3.4—Marketable Permit

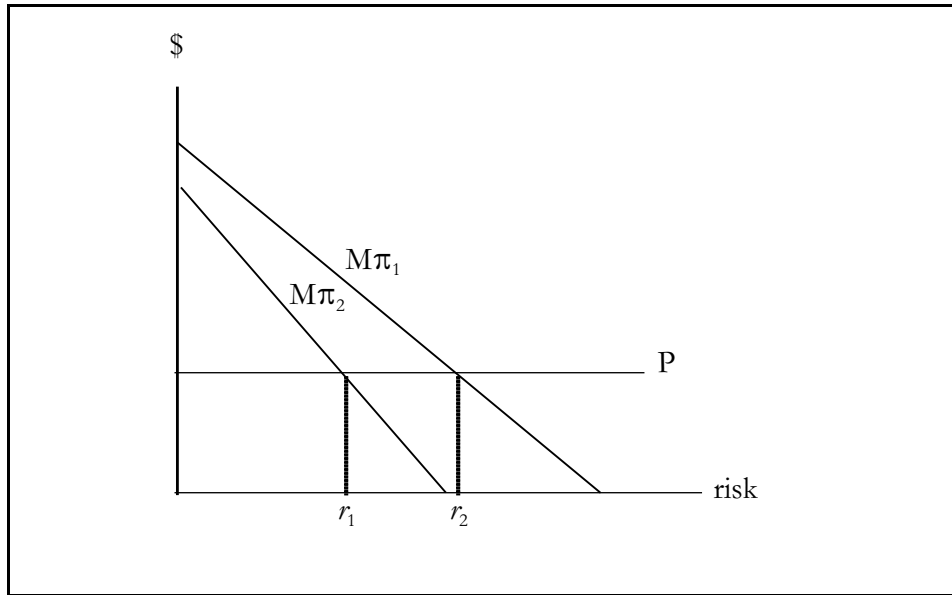


Figure 3.5–Cross Compliance Measure

