A STUDY ON EMISSION CONTROL AREA FOR REDUCING AIR POLLUTION FROM SHIPPING

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ABSTRACT

Several countries are considering establishing Emission Control Areas (ECAs) to reduce air pollutants from shipping operations. An ECA is a policy prepared by the International Marine Organization. This paper uses a basic model to analyze how a country might determine the optimal boundary of an ECA. The model deduces an optimization condition for ECA size. The area is optimal where the social benefit of a reduction of air pollutants from a ship equals the sum of the unit cost of installing a unit of capital input for removing air pollution and the unit cost of goods to use for such capital. This condition is different from the total benefit to cost ratio (B/C) of implementing an ECA. A high value of B/C does not necessarily indicate that the size of an ECA established by governments is optimal. This paper considers the case of the North American ECA and shows the possibility of improving the B/C by diminishing the size of this ECA.

Keywords: Air Pollution, Shipping, Emission Control Area

1. BACKGROUND

Although technological progress in automobile anti-air pollution devices such as the catalytic converter reduces air pollution from road transportation, air pollution from shipping has worsened because worldwide economic development and international specialization have caused a large increase in marine transport. Buhaug et al. (2009) indicated that air pollutants, such as nitrogen oxide (NOx), sulfur oxide (SOx), and particulate matter (PM), from shipping have increased from 1990 to 2007. Air pollution causes negative health effects, such as chronic respiratory illness and bronchial asthma, when pollutants are inhaled. Corbett et al. (2007) showed that shipping-related air pollution is responsible for 19,000 to 64,000 annual cardiopulmonary and lung cancer deaths worldwide.

The International Marine Organization (IMO) adopted the International Convention for the Prevention of Pollution from Ships (MARPOL) annex IV with the goal of reducing air pollution from shipping. The IMO approved a revised version in 1997. The annex entered into force in 2005. Because the air pollution regulations in MARPOL annex IV contained only technologies available as of 1997, the IMO reviewed the regulations for air pollution within five years of their coming into force. Accordingly, in July 2005, the Marine Environment Protection Committee (MEPC) began a review of the levels of air pollution set by regulations in annex IV in MEPC 53. After three years of work on revisions for further reducing air pollutants from shipping, the IMO decided to adopt more stringent regulations for air pollution, which included the global sulfur cap for SOx, "Tire II" and "Tire III" emission limits for NOx. MEPC 58 adopted these regulations, which appear in the revised annex IV. They entered into force on July 1, 2010.

The revised annex IV contains articles not only on technological regulation but also on spatial regulation. The spatial regulation is called an Emission Control Area (ECA). A country or countries hoping to establish an ECA in a nearby ocean can submit proposal documents to the MEPC. The MEPC will deliberate the merits of establishing an ECA. If the MEPC accepts the proposal, then the country or countries can establish an ECA in their ocean. An ECA is one of the international systems intended to reduce shipping-related air pollution in coastal sea areas.

As several countries discussed and evaluated whether to establish ECAs in their sea areas, it is valuable to discuss the optimal size over which an ECA should be established. Depending on an ECA's size, the amount of shipping activity captured will change. The area size also affects the reduction of air pollutants. This implies that the benefit and cost of implementing an ECA can fluctuate depending on the size of the ECA. That is, the value of the benefit to cost ratio (B/C) differs according to an ECA's size. How then might we decide the area size of an ECA? Descriptions to decide the size of an ECA in recent proposal documents on ECAs are ambiguous, then they should be clear to set better size of an ECA.

This paper uses a basic model to analyze how we might delineate the optimal boundaries of ECAs. The rest of this paper is organized as follows. The next section provides an overview of existing ECAs. This section discusses the United States and Canada's ECA proposal and also reviews discussions on establishing an ECA in Japan. Furthermore, it focuses on ECA area size, a topic on which there have been no detailed discussions. Section 3 describes the model for analyzing optimal ECA size. Section 4 simply evaluates the size of the North American ECA on the basis of the results from Section 3. The paper concludes with a summary in Section 5.

2. OVERVIEW OF EMISSION CONTROL AREAS

Emission Control Area is defined in IMO (2008) as follows:

> *Emission Control Area* means an area where the adoption of special mandatory measures for emissions from ships is required to prevent, reduce and control air pollution from NOx or SOx and particulate matter or all three types of emissions and their attendant adverse impacts on human health and the environment.

There are two broad categories of ECAs: ECAs for SOx and PM emissions and ECAs for NOx emissions. The Baltic Sea and the North Sea have been designated as ECAs for SOx since May 2006 and November 2007 respectively. The United States and Canada jointly submitted an ECA for all three pollutants.

Once a sea area is designated as an ECA, all ships traveling through the area must be equipped with regulation-compatible engines and/or use regulation-compatible fuel. Specifically, after 2015 ships may not sail in sea areas designated as ECAs for NOx without engines that reduce 80% of NOx pollutants compared to the level of 2005 regulation. Note that some types of ship are excluded from ECA regulation based on exceptions. Ships may not sail in sea areas designated as ECAs for SOx without using sulfur-free fuel.

If a country or countries would like to designate some sea area as an ECA, they first need to submit proposal documents to the MEPC. The MEPC surveys the documents pursuant to eight criteria written in APPENDIX III of the revised annex VI. The eight criteria required for designation of an ECA are as follows: (1) a clear delineation of the proposed area of application; (2) the type or types of emission(s) that is or are being proposed for control; (3) a description of the human populations and environmental areas at risk from the impacts of ship emissions; (4) an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts; (5) relevant information on meteorological, topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts; (6) the nature of the ship traffic in the proposed ECA; (7) a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NOx, SOx and particulate matter emissions; and (8) the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade. Finally, if the MEPC approves the proposal as valid, then it revises annex VI to designate the proposed area an ECA.

2.1 Establishment of the North American ECA and its area

In 2009, the United States and Canada jointly submitted the proposal for an ECA in MEPC 59. The proposal mentioned that the area of this ECA would contain waters adjacent to the Pacific coast, the Atlantic coasts, and the eight main Hawaiian Islands, and that it would extend up to 200 nautical miles (nm) from those coasts. This ECA is for all three air pollutants, as noted earlier. The proposal documents included descriptions of the required eight criteria. MEPC 59 confirmed the validity of the proposal and added it to the revised annex VI. The North American ECA was designated in August 2012.

The proposal submitted by the United States and Canada demonstrated the validity of setting an ECA in North America based on numerical projections generated by computer simulation of the effects of shipping on air pollutants. The documents showed the then-current situation and the future forecasts of the environmental effects of emissions in the United States and Canada according to eight criteria IMO required. The documents prepared two scenarios, the 2020 Current Performance case and the 2020 with ECA case, to estimate air pollutants. It also enforced diffusion simulation to reveal the effects of each air pollutants. The proposal mainly focused on two air pollutants: PM2.5 and Ozone (O_3). The simulation showed that establishing an ECA could reduce over 15% of PM2.5 and 1% of O_3 in North America. The ECA could also reduce air pollutants in inland areas. In Canada, implementation of an ECA lowered 5% to 10% of PM2.5 emission in the Pacific area and over 2% to 5% in the Atlantic area. It also reduced within 5% of O_3 emission in Pacific and over 2% in Atlantic area.

The final part of the document calculated the cost of implementation of the proposed ECA. It used the WORLD model to estimate the cost of low-sulfur fuel, accumulated refinement costs for shipping equipment, and usage costs of exhaust-gas treatment equipment and low-sulfur fuel. This estimation showed that the additional costs of establishing an ECA in 2020 would be $3.2 billion. The Environmental Protection Agency (EPA) (2010) revealed the benefit of implementing an ECA in the North America. Almost all the benefits of applying an ECA derive from health improvements, such as improvement of rate on early death by air pollutants and reduction of urgent patient care caused by air pollution. The EPA estimated the benefit at $47 billion to $110 billion.

On the other hand, the documents did not discuss the area size of the proposed ECA. They mentioned adverse effects on human health and the environment due to air pollutants from shipping as far away as 200 nm. There was no description of why the two countries set 200 as the size of the ECA, and no discussion of any other possible size. From the documents, we can extrapolate several important factors in the size of the ECA, for example, the number of residents, the population density within range of the air pollutants, weather conditions, and the transfer coefficient of air pollutants. Because the size of an ECA is related to the benefit and cost of implementing the ECA, as mentioned before, one would hope that the proposal documents would contain detailed analysis of the size of the ECA.

There were two other issues with the proposal. First, although the proposal calculated the monetary benefit and cost on health impact, it did not estimate another external cost of air pollution: air pollution causes several social costs other than health deterioration. Such costs should have been included. Second, establishing an ECA carries logistics cost in the United States. The proposal did not estimate the effect of implementing an ECA on cost of living or the domestic economy. These changes should have been estimated.

2.2 Proposed Japanese ECA and its area

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) started the reviewing process for establishment of an ECA in Japan in 2010. The MLIT scrutinized the necessity of a Japanese ECA according to the eight required criteria. It developed a simulation model of the relationship between air pollutants from shipping and the density level of air pollutants to calculate how much an ECA would reduce air pollution from shipping operations.

The simulation model used a basic scenario, which was based on data from 2005, to estimate the amount of NOx and SOx emissions in 2020. This scenario reflects only changes in air pollution regulation implemented by IMO until 2020. The results of the simulation model estimation show that air pollutants from shipping operations in 2020 would not radically change the density level of air pollution on the mainland. Forty harbor areas and the surrounding areas, which might be strongly affected by air pollution from ships, were selected and observed for specific changes in density levels of air pollutants. SOx emissions from shipping were projected to increase in density almost 15% of in these areas. Such change in all areas, however, would not violate Japanese ambient standards. The density level of NOx emissions from ships would also increase, but, like the Sox emission results, this increment would not violate ambient standard in these areas. Moreover, although MLIT forecasted increases of PM2.5 and O_3 emissions by 2012 using simulation models, these levels also would not violate ambient standards in all forty areas. The conclusion from the simulation results was that air pollution from shipping operations would largely not affect density levels of air pollution on the mainland. These results are quite different from results in the proposal submitted by United States and Canada.

MLIT did not scrutinize the area size of the proposed ECA because the simulation results showed that stepwise strengthening regulation by IMO would effectively reduce air pollutants from shipping operations, thus eliminating the need to introduce an ECA, which is a policy to additionally reduce air pollution. On the other hand, the National Maritime Research Institute calculated and estimated cost of establishing an ECA. It used the assumption “200 nm” from the coastline as the size of the ECA for its cost estimation. This implies that there was no discussion of the size of the Japanese ECA because air pollution simulations showed a low possibility of establishing such an ECA.

3. MODEL ANALYSIS FOR OPTIMAL ECA SIZE

Both the North American proposal and the discussion in Japan reveal a lack of consideration of ECA size. As mentioned before, the size of an ECA affects the B/C of its implementation. This suggests the following question: what is the condition for setting the optimal size of an ECA?

3.1 Existing literature

Although there are several studies of cost-benefits or cost-effectiveness on ECAs (Wang et al, 2007; Wang and Corbett, 2007; Tzannatos, 2010), no study has focused solely on optimal ECA size. On the other hand, spatially external diseconomy, like air pollution, in urban areas have been analyzed by Stull (1974), Miyao, Shapiro, and Knapp (1980), and Parker (2007), to name a few. Specifically, Henderson (1977) and Kanemoto (1987) constructed spatially continuous models and analyzed the effects of air pollution on rent in urban areas. Henderson (1977) assumed an industrial area in a central business district (CBD) and a residential area in the outer city to scrutinize cases of external diseconomy in which industry emits air pollutants in residential areas. In this study, the level of air pollution in residential zones was calculated only after industry emissions were summed up at the industrial-residential boundary. This formulation of dispersion of air pollutants caused discontinuity of rent at the industrial-residential boundary. Kanemoto (1987) reviewed the results of Henderson (1977) and presented another model of density level of air pollution with two zones. Kanemoto (1987) also determined the optimal distance of the industrial-residential boundary from a CBD. He asserted that for the boundary to be optimal, the social benefit of marginal extension at the boundary would have to equal the social cost at the boundary. Because he settled identity formulas of social benefits and costs and treated the two zones symmetrically, his model showed no discontinuity at the industrial-residential boundary.

Naito (2003) focused on area license schemes (ALS), which are used to alleviate air pollution and congestion in urban areas. ALS is a policy to charge fees for vehicles that enter designated areas. Naito (2003) used a linear city to compute the optimal tax and optimal size of an ALS to maximize social net welfare, which is defined as the difference between consumer surplus and external diseconomy caused by congestion and air pollution. To deduce the optimal size of an ALS he mentioned social net welfare according to additional extension of ALS equated zero. That is, the marginal social benefit of extending ALS is equal to marginal social cost.

This study uses the model of Kanemoto (1987) to develop a simple model for analyzing the optimal ECA size.

3.2 Model for Analyzing Optimal ECA Size

3.2.1 Assumptions

Consider a linear city. Let x denote the distance from the center of the linear city. The linear city is located at $[-\underline{x}, \underline{x}]$ ($\underline{x} > 0$). Residents live in the linear city in density $N^r(x)$. Non-residential areas, $(-\infty, -\underline{x})$ and $(\underline{x}, \infty)$, are located on the outer sides of the linear city (Figure 1). These are sea areas. Shipping companies operate in the seas. The density of the companies in the sea areas is defined by $N^f(x)$. The ships emit air pollutants. Assume that residents, however, do not emit any air pollutants.

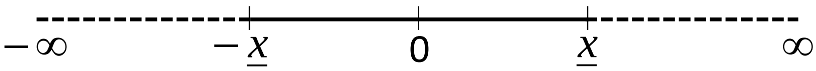

Figure 1 – Linear city and sea area

3.2.2 Model of Shipping Operations

All ships have the same production function $F(N, K_1)$, where N and K_1 are the labor and capital inputs. Ships emit air pollutants and change their amount of emissions depending on the location of the sea area. That is, all ships have the same emission function $e(N, K_1, x')$, where x' indicates location of sea area, $x' \in (-\infty, -\underline{x})$ or $x' \in (\underline{x}, \infty)$. All vessels have same equipment to reduce air pollutants from their operation. The amount of air pollution reduced can be written as $h(s, K_2, x')$, where s and K_2 are goods and capital input for removing air pollutants generated by operations. x' in the function $h(s, K_2, x')$ is used with an indicator of whether the ships enter an ECA or not. The net amount of air pollutants is written as $e(N, K_1, x') - h(s, K_2, x')$. We denote $e(x') - h(x')$ as a short version of $e(N, K_1, x') - h(s, K_2, x')$. The air pollutants in x', $E(x')$, can be shown as

$$E(x') = (e(x') - h(x')) \cdot N^f(x').$$

The price of shipping services is p . All ships face the net profit function

$$\pi = pF(N, K_1) - w_1 N - r_k(K_1 + K_2) - c_f(|x'| - |\underline{x}|) - w_2 s,$$

where w_1 is wages, r_k is the rental price of capital inputs, c_f is the fuel price, and w_2 indicates the price of goods s.

3.2.3 Model of Residents

All city residents have the same utility function $u(z, h, a)$, where z and h are the composite quantities of consumer goods and residential land, and $a(x)$ is the density level of air pollutants. The density level of air pollutants depends on the amounts of emission from shipping operation in the sea areas, i.e., $E(x')$. The density level depends on the distance from emitters because air pollutants diffuse according to distance from emitters (Ishizuka et. al., 1978). In addition, the pollution level in a location on the mainland x depends on the contribution function of pollution from the sea area, $g(E(x'), x', x)$. An increase in emissions increases the density level of pollution, i.e., $\partial g/\partial E > 0$. A greater distance x decreases the pollution density level on the mainland at a given level of emissions, i.e., $\partial g/\partial x' < 0$.

3.2.4 Model of ECA

Suppose the government imposes a symmetrically boundary of an ECA, x^E , in the sea areas, i.e., $x^E \in (\underline{x}, \infty)$ and $-x^E \in (-\infty, -\underline{x})$. Then area of the ECA is set as $(-x^E, -\underline{x}) \cup (\underline{x}, x^E)$ (Figure 2).

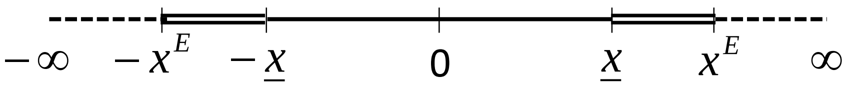

Figure 2 – Setting ECA area in sea

If ships sail in the ECA area, they must activate equipment K_2 to reduce the air pollutants from their operations. After implementing the ECA, the amount of air pollution in x' , $E(x')$, can be expressed in two ways:

$$E(x') = e(x') \cdot N^f(x') \qquad (x' \notin (-x^E, -\underline{x}) \cup (\underline{x}, x^E))$$

$$E(x') = (e(x') - h(x')) \cdot N^f(x') \qquad (x' \in (-x^E, -\underline{x}) \cup (\underline{x}, x^E))$$

Next, the density level of air pollutants after implementing the ECA, $a^E(x)$, can be written as

$$a^E(x) = \int_{-\infty}^{-x^E} g(e(x') \cdot N^f(x'), x', x)\, dx' + \int_{-x^E}^{-\underline{x}} g((e(x') - h(x')) \cdot N^f(x'))\, dx'$$
$$+ \int_{\underline{x}}^{x^E} g((e(x') - h(x')) \cdot N^f(x'))\, dx' + \int_{x^E}^{\infty} g(e(x') \cdot N^f(x'), x', x)\, dx'.$$

The social benefit to residents of reduced pollution emissions in x' , based on Kanemoto (1987), is written as

$$B^E(x') = \int_{-\underline{x}}^{\underline{s}} \frac{\partial U / \partial a}{\partial U / \partial z} N^r(x) \frac{\partial a^E(x)}{\partial E(x')} dx.$$

We deduce the optimal size of the ECA to compare the social benefit to residents of a reduction in air pollutants with the social cost of reducing air pollutants generated by shipping operations. This paper uses a strong assumption for the density of ships in the sea area, $N^f(x)$, to simplify the analysis. That is, the density of ships, $N^f(x)$, does not change even after the ECA is implemented.

We focus on the boundary of the ECA x^E . To compute the optimal size of the ECA, we marginally extend the boundary of the ECA to the outside by Δx . The amounts of air pollutants at $x' \in [x^E, x^E + \Delta x]$ can be reduced to extend the ECA as follows:

$$\{e(x') - (e(x') - h(x'))\} \cdot N^f(x') = h(x') N^f(x').$$

We can obtain the social benefit to residents by extending ECA, B^S , to multiply the amount of the reduction by the benefit of reduction of air pollutant density levels on the mainland, $B^E(x')$. That is,

$$B^S = B^E \cdot h(x') \cdot N^f(x').$$

On the other hand, the social cost of implementing the ECA can be written as

$$C^{ECA} = (r_k K_2 + w_2 s) N^f(x').$$

This formulation shows that all ships in $x' \in [x^E, x^E + \Delta x]$ need to activate anti-air pollution equipment because they are within the ECA.

The social benefit of a marginal increase in ECA size must equal the social cost for the ECA boundary to be optimal. This implies $B^S = C^{ECA}$ at the optimal boundary. Then,

$$B^E(x') \cdot h(x') = r_k K_2 + w_2 s$$

is the optimal condition to decide the optimal boundary of the ECA. The ECA boundary is optimized where the social benefit of a reduction of air pollutants from a ship equals the sum of the unit cost of installing a unit of capital input for removing air pollution and the unit cost of goods used such capital. Note that the above discussion is appropriate in $x' \in [-x^E - \Delta x, -x^E]$.

The condition for optimal ECA size shows that the condition depends on the amount of air pollutants at the boundary and the adverse effects of these air pollutants. If air pollutants are emitted closer to the mainland, the adverse effects on residents are higher. This implies $\partial B^E / \partial x' < 0$. Moreover, distance x' in the function $h(x')$ is associated with the indicator, which represents whether a ship is in the ECA or not. The level of $h(x')$ is not directly affected by x'. We can assume $h(x')$ is constant in $(-\infty, -\underline{x})$ or $(\underline{x}, \infty)$. This indicates that $B^E(x') \cdot h$ is a function of downward-sloping curve for increasing x'. Although $r_k K_2 + w_2 s$ is not related to x', government can point x^E in sea areas compared with downward $B^E(x') \cdot h$ and constant $r_k K_2 + w_2 s$. Note that the optimal boundary does not necessarily decide only one point.

Although the above model assumes a linear city, we can expand such a model to a monocentric city by rotating a city centered on point zero.

4. DISCUSSION OF THE ANALYTICAL MODEL FOR ECA

Based on the proposal for the North American ECA and EPA (2010), the value of B/C of this ECA surpassed ten. That is, the North American ECA is a cost effective policy to reduce air pollution.

However while the value of B/C is high, the size of the North American ECA is not optimal. Because air pollution emissions close to the mainland have more adverse effects than emissions far from the mainland, it is possible that the value of $B^E(x') \cdot h$ at 200 nm is under $r_k K_2 + w_2 s$ (Figure 3). Dead weight loss arises where the value of $B^E(x') \cdot h$ is located beneath the $r_k K_2 + w_2 s$ line. If dead weight loss occurs, net benefit can turn positive because area between $B^E(x')\cdot h$ and $r_k K_2 + w_2 s$ from 0 nm to point where $B^E(x')\cdot h$ equals $r_k K_2 + w_2 s$ is larger than area between $r_k K_2 + w_2 s$ and $B^E(x')\cdot h$ from the point to 200 nm in Figure 3. In addition, the B/C of applying an ECA can exceed the one because area beneath $B^E(x')\cdot h$ from 0 nm to 200 nm is bigger than area beneath $r_k K_2 + w_2 s$ from 0 nm to 200 nm.

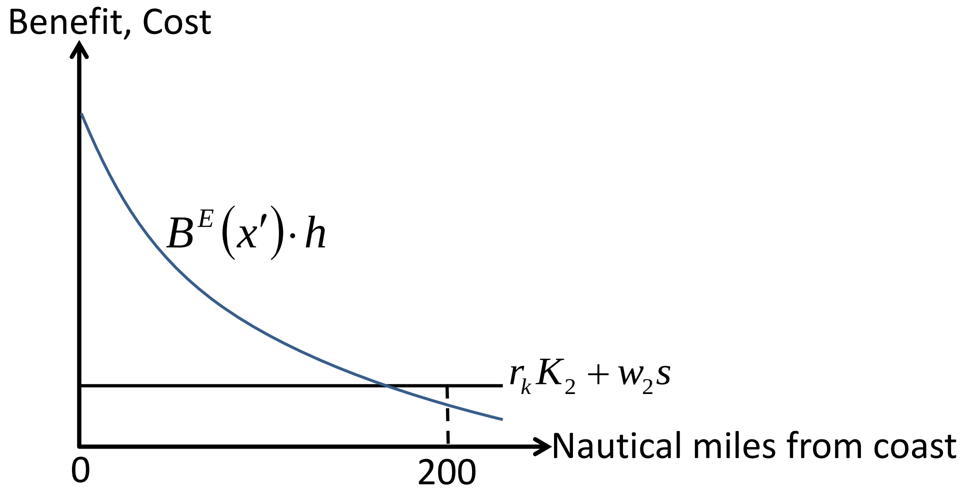

Figure 3 – Simple evaluation of ECA in USA and Canada

It is thus necessary for the United States and Canada to consider decreasing the area of the North American ECA. Decreasing the area of the ECA has the potential to improve the B/C tradeoff. Other countries considering establishing ECAs should prepare alternative proposals with different area sizes to ensure an optimized policy for reducing air pollutants from shipping operations.

5. CONCLUSION

This paper analyzes how we might determine the boundary of an optimized ECA through a basic model. The area is optimal where the social benefit of a reduction of air pollutants from a ship equals the sum of the unit cost of installing a unit of capital input for removing air pollution and the unit cost of goods used for such capital. This condition is different from the total B/C of implementing an ECA. A high value of B/C does not necessarily indicate that the size of an ECA established by the government is optimal. This paper considers the case of the North American ECA. It shows a possibility of improving the B/C by diminishing the size of this ECA.

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