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A RISK/COST FRAMEWORK FOR PUBLIC POLICY EVALUATION: THE HAZARDOUS WASTE TRADE

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ABSTRACT

The management of hazardous waste disposal operations is extremely complex involving a multitude of environmental, engineering, economic, social, and political concerns. As costs for domestic hazardous waste disposal have risen, waste generators and handlers have been encouraged to consider the disposal of wastes outside the country of origin. This article proposes a framework for policy makers to assist them in the evaluation of trade policies. A spatial general equilibrium-based policy evaluation model is developed to calculate risk, cost, and risk-equity tradeoff curves. This framework provides policy makers a tool with which they can relate resulting patterns of trade and their associated risk, cost, and equity attributes to original policy goals.

INTRODUCTION: CONTEXT AND SIGNIFICANCE

The management of hazardous waste disposal operations is extremely complex, involving a multitude of environmental, engineering, economic, social, and political concerns. Public scrutiny over the siting and operation of hazardous waste facilities has always been a source of controversy and confrontation. As noted by Warmerdam and Jacobs [1], it is unlikely that the hazardous waste stream will diminish significantly in the short term. In 1986, the total hazardous waste stream generated was on the order of 800 million tons [2].

As costs of domestic hazardous waste disposal have risen, a result of stringent environmental regulations, waste generators and handlers have been encouraged to consider the disposal of wastes outside the country of origin. The average cost of hazardous waste disposal in Africa is approximately $40 per ton, in Europe it costs between $160 and $1000 per ton, and in the United States it ranges from $450 to $1500 per ton [3]. In addition to disposal cost, the decision to trade in hazardous waste across countries is influenced by:

- diminishing capacity for disposal of certain types of waste in the home country;
- existence of an appropriate disposal facility in a foreign country which is closer than a similar facility in the home country;
- existence of a disposal facility which may serve several countries; and
- potential future liability for any damages caused by waste disposed of in the home country.

Even in the most simple, deterministic case, optimal trade patterns based on minimum costs may unnecessarily expose people and the environment to risks associated with possible accidents. The trade in waste involves potential transfer of risks of damage to human health, environment, and ecology to both the transit and recipient countries; these risks result from accidents, improper handling, or disposal. To some extent, the existing waste trade is based on uninformed decisions; the recipient countries seem to be unaware of the risks involved [3]. In recent years, hazardous waste trade has expanded to include developing countries; in fact, developing countries outnumber developed countries as importers of hazardous wastes [3]. This has touched off a controversy over the pros and cons of international trade in hazardous waste [4, 5]. It should also be noted that developing countries face a problem with the management of hazardous waste even without the presence of international trade in waste. Anandalingam and Westfall [6] discuss and present recommendations for addressing this problem.

The widespread concern over the transfrontier movements of wastes manifested itself in the Basel Convention on Transboundary Movements of Hazardous Wastes and their Disposal (1989), sponsored by the United Nations Environmental Programme (UNEP). The convention formulated guidelines for regulating the movement and disposal of hazardous wastes, and the treaty obligates the contracting parties to take measures to prevent illegal trade practices.

Typically, environmental policy decisions are driven by a combination of economics, political concerns, and risk calculations. As the Environmental Protection Agency [7] has indicated that it considers the reduction of risk to be the most important goal of any environmental policy, it is reasonable to assume that environmental policy decisions should be greatly influenced by the level of risk posed by the environmental problems.

Generally, it is difficult at best to address and quantify the risks involved in the transportation, treatment, and disposal of hazardous waste. It would be ideal to use the actual risks; however, these are rarely known and policy makers must rely on calculated risks or perceived risks. A risk/cost framework for the hazardous waste management system must include an assessment of the risks due to transportation, treatment, and disposal. In many cases, the methodology for the assessment of risks from transport and disposal of hazardous waste are similar; although the factors differ, the overall objective is to quantify risk as an expected cost in the event of an undesired release.

Another factor which deserves significant emphasis in the debate over the international trade in hazardous waste is the issue of equity. Equity is often measured by the largest impact per unit population (e.g., fatalities per thousand persons) or the difference between the largest and smallest of these.

In developing policy regarding the international trade in hazardous waste, we must consider the two main players in the system: the waste generators and the policy makers. Each of these stakeholders controls a different set of variables. Specifically, the government controls policy variables, i.e., the trade restrictions, while the generators control the selection of final disposal methodologies and sites. Both the government and the generators behave according to their own objectives, i.e., social welfare and profit maximization, respectively. Policy makers face a two-part problem: they must predict the response of the generators to policy decisions and then choose among various alternatives to maximize their policy goals. Policy makers are essentially trying to answer the questions: what is the cost, risk, and risk equity associated with various policies, and how do these levels correspond to our global environmental goals? In this vein, we need to consider potential siting of new disposal and transfer facilities in addition to determining the optimal route for wastes.

We contribute to the hazardous waste trade literature in the development of a hazardous waste trade policy evaluation framework to determine the optimal trade patterns for hazardous waste under multiple objectives. This framework will provide decision makers with a tool with which they can relate original policy goals with resultant patterns of trade.

The article is organized as follows: in Section 2 a brief review of relevant models of the international trade in hazardous waste is presented; in Section 3 the policy evaluation framework is presented. We end the article in Section 4 with concluding remarks.

INTERNATIONAL TRADE IN HAZARDOUS WASTE

There is an extensive literature on international externalities. Dean provides a comprehensive survey of the existing literature on the interactions between trade and the environment [8]. Merrifield briefly discusses the literature on trade models with transnational pollution [9].

The literature on international externalities can be divided into three major categories:

- pollution generated in one country spills into another;

- pollution generated in one country is confined to the same country but industries migrate from one country to another following a change in domestic environmental regulations, or tax/trade policy; or
- neither pollution generated in one country spills onto another nor do industries migrate but wastes in one country are transported to other countries [10].

This research falls into the third category.

In comparison to the vast literature on the interaction between trade and the environment, the literature on trade in hazardous waste is relatively small. However, there have been numerous incidents of legal and illegal trade in hazardous waste reported in newspapers and magazines. A review of the literature reveals that there are only a handful of contributions to the literature on international trade in hazardous waste. The main contributions to the literature are Sullivan [11], Copeland [10], Oates [12], Asante-Duah et al. [13], Kohn [14], and Rajamani [15].

Sullivan evaluates three second best policies for dealing with the illegal disposal of hazardous wastes in a partial equilibrium context [11]. These three policies include a laissez-faire policy, a policy subsidizing legal disposal, and a policy encouraging expanded enforcement. He determines the conditions under which each policy is superior to others. Copeland uses a general equilibrium framework to investigate the welfare effects of international trade in waste disposal [10]; specifically, he addresses the question of whether or not trade restrictions should play a role in the control of the externalities associated with waste disposal. Copeland ignores the costs due to transportation and assumes that it is the waste itself which causes the externality. He does not consider the externalities resulting from illegal or improper disposal or those associated with storage or transport. Oates outlines a research agenda for needed work in open economy environmental economics, one being the international treatment and disposal of hazardous pollutants [12]. Asante-Duah et al. propose a framework for the evaluation of hazardous waste programs [13]. In this work, they develop a risk-cost-benefit framework for the evaluation of the trade in hazardous waste. Kohn uses a Hechscher-Ohlin-Samuelson model to demonstrate that a Pigouvian tax on untreated wastes can correct for attendant externalities [14]. Kohn argues that when each country imposes a tax on the hazardous waste stored within its boundaries at a rate equal to the expected marginal damage to its citizens, and subsequently distributes the tax revenue among its citizens in such a way that each household is fully compensated for the resultant toxic risk, then all citizens in all countries benefit from the free trade in hazardous waste. Rajamani investigates the patterns of legal trade in hazardous wastes through fixed effects tobit models [15]. This study investigates whether the patterns of trade in hazardous waste are consistent with the predictions of a model of efficient trade. Specifically, she considers how the political economy can affect trade patterns.

Thus far, the literature on hazardous waste trade has focused on the development of economic-based models of trade. In addition, most models have focused on one aspect of the system: Kohn focuses on waste storage [14]; Copeland does not consider the externalities associated with storage or transport [10]; and Sullivan focuses on illegal disposal [11]. Asante-Duah et al. provide the first practical framework for the assessment of the hazardous waste trade system [13]. This research falls into the later category and develops a framework which can be utilized for policy evaluation and development.

Several limitations on the scope of this research should be noted. We are interested in the assessment of risks and costs due to hazardous waste transportation, treatment, and disposal; we do not consider risks and costs associated with waste generation. For the purposes of this research, risk focuses on risk to human populations. Although it is noted that ecological risks are important, these factors are considered outside our scope. For modeling purposes, it is assumed that all trade in wastes will be legal; the costs of enforcement will not be included in the model.

POLICY EVALUATION FRAMEWORK

This section presents the policy evaluation framework for the international waste trade. The impetus for this model is the need for the evaluation of policies for the international trade in hazardous wastes. Solutions to the model allow policy makers to evaluate the effects of various trade policies through resulting patterns of trade. This evaluation framework is broken down it two steps: the behavioral model for waste generators is presented; and then the evaluation module is presented—this includes the derivation of expressions for risks and costs associated with the hazardous waste management systems.

Prior to outlining the details of each of the steps, it is helpful to provide a brief overview of the components and goals of the model. A schematic diagram of the Policy Evaluation Framework is presented in Figure 1. The policy evaluation model consists of two distinct modules or sub-models: the behavioral model of the waste generators and the evaluation module for the assessment of the risks and costs of each scenario. The behavioral model describes the resulting actions of the waste generators to regulatory constraints imposed by the policy-makers; solutions to the model provide routes and disposal sites for all generated hazardous waste. The evaluation module calculates the resultant costs and risks associated with the output from the behavioral model; solutions to the behavioral model are evaluated for their risks, costs, and equity-tradeoff curves are derived.

The policy evaluation model is a linear, network model of the international waste trade system; both network and planar measures are used to develop the objectives. Figure 2 presents a graphical representation of a hypothetical network. The multiple objectives in the model include risk minimization, cost minimization, and risk equity. Solutions to the model will produce routes and disposal sites

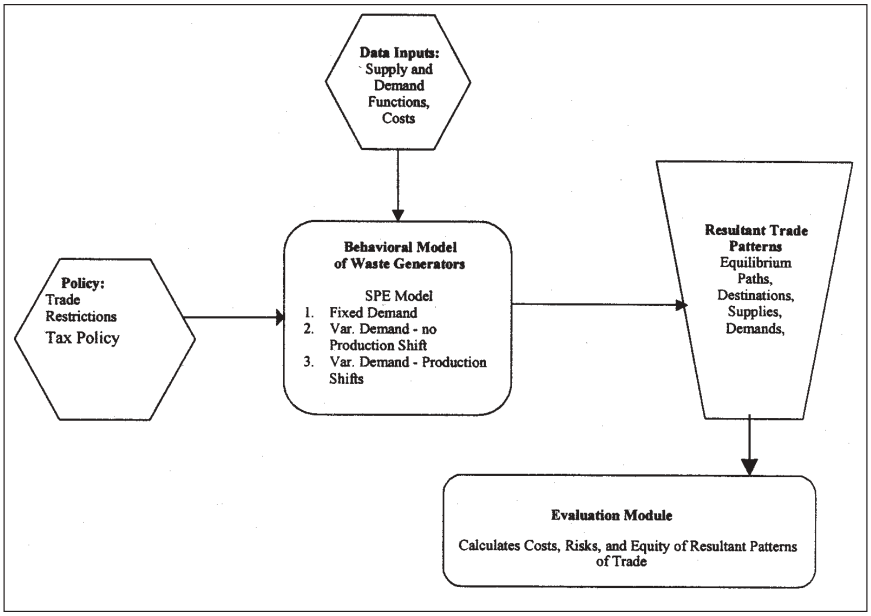

Figure 1. Model 1—Policy Evaluation Model.

for all generated hazardous waste; solutions will be evaluated for their risks and costs and tradeoff curves will be derived.

Model Formulation

As mentioned above, the model developed in this phase consists of two parts: a behavioral model and an evaluation module. The combined model is utilized to evaluate policy scenarios and to develop cost-risk tradeoff curves for resulting patterns of trade. When used together, the two models provide a vehicle for the evaluation of policy scenarios and the development of risk-cost tradeoff curves.

For modeling purposes, costs and risks are estimated on a total as well as zonal basis. As shown in Figure 2, the study area is divided into zones; the total cost and risk exposure for each zone is a function of the routes, facilities, and transfer stations selected in each solution. One simplifying assumption in the model is that the estimate of the risk in each zone will be based upon the risk experienced at one central location in the zone. As the number of zones in the system increases, the error due to this assumption will decrease as the computational complexity increases. Another approach which could be utilized is that the model can be run to identify potential "hot spots" for risk. These sensitive zones could then be broken down into smaller areas to fully calculate the risks to these zones. This type of an

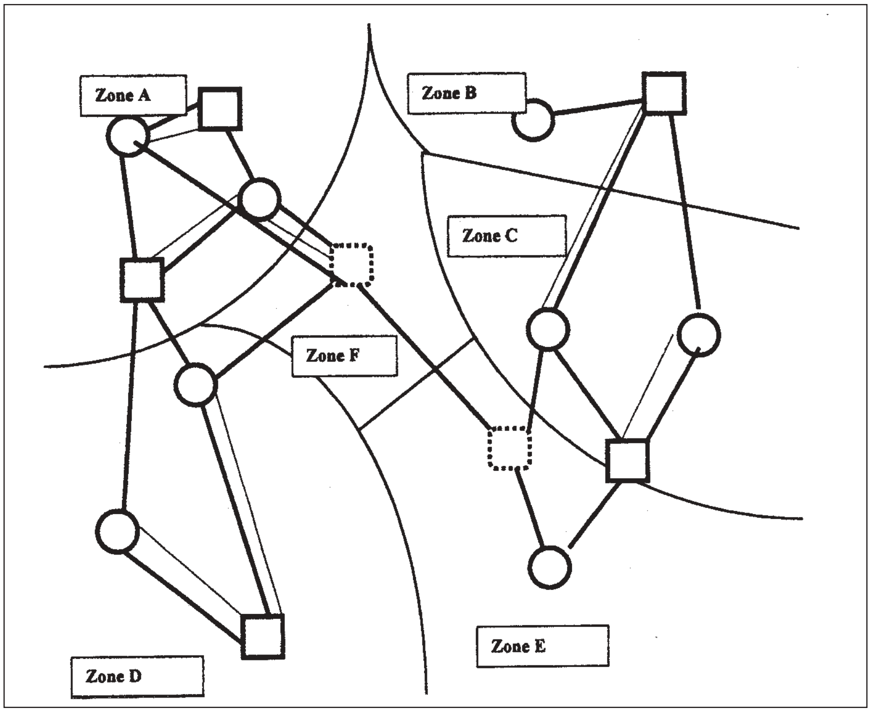

Figure 2. Representative network.

approach to risk assessment allows us to evaluate the equity of risk distribution in each solution. This type of an approach is used by List and Mirchandani in their combined routing and siting model for hazardous materials [16].

Behavioral Model

The behavioral model describes the reaction of the waste generators to trade restrictions imposed by the policy makers. The output of this model is the resulting pattern of trade including final paths and destinations of all generated hazardous waste. In this system, waste generators act independently from each other. Each generator chooses their paths and destinations based upon maximizing their utility; in this case, the generators make decisions based upon minimizing their overall cost of disposal.

A network equilibrium approach is taken to model this system. The model simultaneously solves the problem of routing waste from the generator to the disposal site and assigns generators (or a portion of the waste generated) to a specific disposal facility.

As one of the issues we are attempting to model is the equity of trade patterns, or the distribution of waste throughout the system, the system of international trade in hazardous waste has a very distinct spatial component. It is for this reason that a spatial price equilibrium model is chosen as the modeling tool for this research.

For modeling purposes, we need to view the hazardous waste trade system in a unique manner. The waste generators "demand" treated waste and the waste processors "supply" treated waste. Therefore, the flows in the model are from waste processor to waste generator; flows in the "real" system will actually go in reverse (i.e., material will flow from the generators to the treatment facilities with payments being made to the waste processors).

Treated waste is a commodity which is produced and consumed at each of several spatially separated markets. When a particular market experiences excess demand, demand greater than that which it can supply, it will seek to import quantities of treated waste from other markets. Similarly, a market with excess supply will seek to export quantities of treated waste to other markets. Importing and exporting adjustments go on until an equilibrium is reached for which the local market price is exactly equal to the price of any import, at the latter's market of origin, plus the unit cost of transportation between the two markets. To describe this situation mathematically, it is first necessary to make the following definitions:

i, j, k, l = nodes of the network
a = arcs of the network (all arcs are directed)
p_{kl} = set of available paths between node k and node l
p = a path between node k and node l ($p \in P_{kl}$)
h_p = the flow of treated waste on path p
fa = the flow of treated waste on arc a
δap = 1 if arc a is on path p (i.e., $a \in p$)
0 otherwise
$fa = \Sigma\ \delta\ ap\ hp$
k: waste generator "demands treated waste"
l: waste processor "supplies treated waste"

With the above definitions, we may describe the equilibrium of interest in the following form:

(i) nonnegativity of flows and prices

$$h_p \geq 0 (\forall i,j\ p \in P_{ij})$$

$$\pi_i \geq 0 (\forall\ i)$$

(ii) equality of delivered process and local prices for nontrivial flows

$$hp > 0 \rightarrow \pi_k = \pi_l + c_p \text{ flow from l to k}$$

(iii) trivial flows for delivered prices which exceed local prices

$$h_p = \phi \rightarrow \pi_k < \pi_l + c_p$$

(iv) conservation of flow at all markets

$$\Sigma\,\Sigma\, h_p - \Sigma\,\Sigma\, h_p = S_l - D_l$$

flow out of k   flow into k

Any solution (π, h) which satisfies conditions (i)–(iv), is referred to as a spatial price equilibrium. These conditions are analyzed and discussed in greater detail in Jara-Diaz and Friesz [17] and Tobin and Friesz [18]. As discussed in Tobin and Friesz [18], this SPE problem can be solved using an equivalent optimization problem (EOP).

Evaluation Module

We assume that any region of interest can be divided into a set of Z nonoverlapping zones on which a transportation network {N, A} can be superimposed. Each zone $z \in Z$ experiences cost and risk impacts due to: (i) material and waste being shipped over nearby links; and (ii) wastes being processed at nearby treatment facilities.

The evaluation module calculates the risk, cost, and risk equity of trade patterns for the international trade in hazardous waste. The inputs to this model are the output, or resulting trade patterns, from the behavioral model described above. This module gives policy makers a tool with which they can compare the effects of resultant trade patterns with original policy goals. Based upon the calculated risk, cost, and equity values, tradeoff curves are developed.

It is important to note the distinction between flows of hazardous waste in the system and flows of waste services. For the purposes of this research, all flows in the system are flows of waste treatment services from the treatment/disposal facility to the waste generator. The waste generator pays the treatment/disposal facility for services. In reality, this translates to an actual waste flow from the generator to the treatment/disposal facility.

The following are the outputs of the behavioral model:

x_{ij} = flow of waste services from node i to node j
D_l = demand for waste service in region l (i.e., amount of waste produced in region l)
S_i = supply of waste service in region l (i.e., quantity of waste treated in region l)
π_1 = price of waste service in region l

Cost

CD_l = Cost for disposal and transportation in each region
$CD_l = D_l{*}\pi_l$

TCD_l = Total cost of disposal and transportation
$TCD_l = \sum_l CD_l$

Revenue

RV_l = Revenue from supply of waste disposal services in each region
$RV_l = S_l{*}\pi_l$

TRV_l = Total revenue from supply of waste disposal services
$TRV_l = \sum_l RV_l$

Risk—Risk assessment involves estimating the frequencies and consequences of undesirable events and then evaluating the associated risk in quantitative terms. As noted above, each zone $z \in Z$ experiences cost and risk impacts due to: (i) material and waste being shipped over nearby links, and (ii) wastes being processed at nearby treatment facilities.

Each arc has associated with it a function $c_{ij}(z, x_{ij})$ which computes the per person impacts for each zone given shipment volume x_{ij} passing over arc ij. Abkowitz and Cheng [19] present an impact model for gas dispersion which illustrates this idea. Similarly, each treatment site is associated with a function $c_l(z, X_l)$ which computes the per-person impacts on zone z from volume X_l of waste processed at location l.

For each zone, combining the impact distributions for all arcs and treatment locations, generates a cumulative impact distribution (Figure 3). This can then be translated into the risk perceived by the people living in zone z. We can define a function $RISK(c_{ij}(z, x_{ij}), c_l(z, X_l))$, which creates a scalar risk measure, like a (dis)utility function, from the fatality, and injury projections provided by the individual impact components. As the derivation of such a function is extremely data intensive, we will use the per-person impacts (i.e., $c_{ij}(z, x_{ij})$ and $c_l(z, x_l)$) as surrogates for risk. The development of these risk functions is left for future research. The chain of relationships involved is shown in Figure 4.

Transportation risk

TR_{ijl} = per person transportation impact in region l from material transported on arc ij

TR_{ijl} = $x_{ij}{*}LEN_{ij}{*}(DIST_{ijl})^{-2}\ ARR_{ij}$

where:

LEN_{ij} = length of arc ij

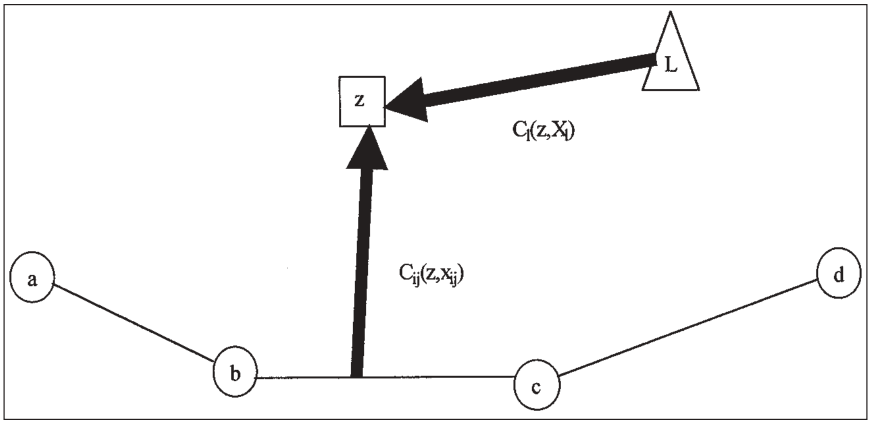

Figure 3. Schematic to indicate effects (bold arrows) of an incident on link segment s due to transporting volume x_{ij} from node b to node c, and from treating volume X_l at site L.

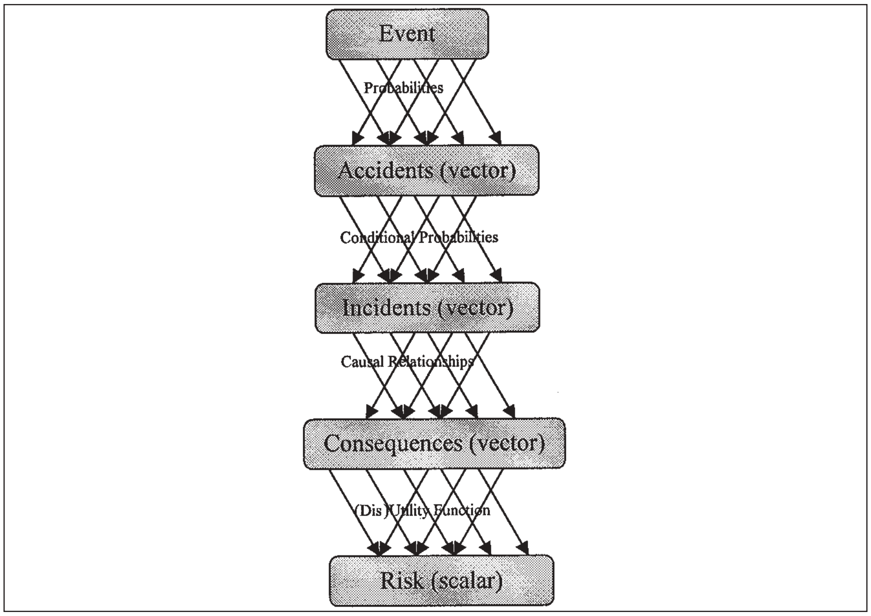

Figure 4. Serial relationship among incidents, accidents, consequences, and risk.

$DIST_{ijl}$ = distance from arc ij to region l
ARR_{ij} = accident release rate for arc ij

Note: The per-person impact is inversely proportional to the square of the distance between the arc and the region of consideration and proportional to the volume of material transported over the arc. The square of distance was chosen to reflect the fact that as the distance between bodies increases, the relative impact they have on each other decreases at an increasing rate (e.g., gravitational pull).

TTR_l = total per person transportation risk in region l
$TTR_l = \sum_i \sum_j TR_{ijl}$

$TOTTR_l$ = total transportation risk in region l
$TOTTR_l = \mathrm{TTR}_l * POP_l$

where:

POP_l = population in region l

Disposal risk
DR_{kl} = per person disposal risk in region l from material treated in region k
$DR_{kl} = S_k * (RDIST_{kl})^{-2} * TRTYPE_k * DRR_k$

where:

$TRTYPE_k$ = treatment technology in region k
$RDIST_{kl}$ = distance from region k to region l
DRR_k = accident release rate for region k
TDR_l = total per person disposal risk in region l
$TDR_l = \sum_k DR_{kl}$

$TOTDR_l$ = total disposal risk in region l
$TOTDR_l = TDR_l * POP_l$

Total risk
$TOTRISK_l$ = Total risk in region l from resultant trade pattern—weighted sum of transportation and disposal risk
$TOTRISK_l = w_{tr} TOTTR_l + w_{dp} TOTDR_l$

Equity—In the past decades, society has become increasingly conscious that the waste products of its advanced technology can pose danger to the health of citizens and to the viability of the ecosystem on which all depend. This concern has given rise to a number of salient policy issues centering on how to best minimize those dangers in efficient and equitable ways. The inclusion of risk equity in hazardous materials routing and siting models has increased recently [20-22]. In addition to its place as a modeling objective, there is a large literature in risk and cost equity in many sociology, political, and geography journals [23-26]. There are numerous methods to characterize risk equity: minimizing the maximum per-person risk in a region; minimizing the difference between the minimum and maximum regional risks; minimizing the differences in relative risk among regions. We use relative risk to characterize the risk equity of resultant patterns of trade.

$RELRISK_{kl}$ = absolute value/$(TOTRISK_k - TOTRISK_l)\backslash/TOTRISK_k$

CONCLUSIONS

Given the high cost of disposal in developed countries, it is likely that the market for trade in hazardous wastes will continue to be attractive. As a result, we need to develop a framework within which policy makers can make informed decisions.

We have developed a framework through which policy makers can evaluate proposed policies. Our framework models the resultant patterns of trade for a proposed policy; this is combined with an overall risk-cost tradeoff analysis to assist decision makers in the determination of appropriate policy decisions. This framework marks a significant improvement over the current practice of after-the-fact analysis. We take into account the varied interests of the multiple stakeholders involved in the development and implementation of a policy regarding the transboundary movement of hazardous waste as well as considering the multiple objectives of cost, risk, and equity.

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