Analysis and Design of a Regional Pollution Discharge Tax Rate: An Economic-Environmental Input-Output Approach

By
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Abstract

This article develops a model system to analyze and design environmental policy, and to determine a pollution discharge tax rate, under the restrictions of environmental quality and economic demand. This model system, combining input-output analysis and mathematical programming approach, sets up the relation between the economic sector and the environmental sector with an economic-environmental input-output model, while it analyzes and designs a pollution discharge tax by using a mathematical programming model. This model system is lastly applied to a regional area located in the northeast of China. The analysis results of the application show that it is an acceptable and effective tool for assessing economic and environmental impact and for formulating environmental policy.

1. Introduction

A basic feature of economic activity is the extraction of materials from the environment and the release of pollutants into the environment. As we know, most environmental resources render both production and consumption services to a variety of users in a largely non-exclusive manner. Since many users share these services provided by environmental resources that are not subject to private ownership, and thus are available at zero price, the quality of these environmental services has deteriorated to a certain degree. If the quality of the shared benefits of environmental resources is to be maintained, usage must be restricted to a level below the assimilative capacity of the environment. Hence environmental issues suggest a number of theoretical problems: how do positive and negative externalities impact the economic system? How fast should the economy grow when faced with environmental concerns? What policies should be adopted to assure economic growth and environmental quality while addressing environmental concerns? These questions have gained increasing importance among policy makers and are likely to assume even more prominence in the

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coming years, particularly in rapidly developing countries.

The traditional approach is to frame environmental issues as problems of externalities and to investigate alternative mechanisms that allow society to correct, partially or fully, for the allocated distortions caused by externalities. Although there are a variety of solutions, economic analysis stresses the role of policy tools operating through the price system. A handful of programs that utilize some or all of the elements of an environmental charge approach have been implemented in a number of countries. Germany, Hungary, Czechoslovakia, France and the Netherlands use different versions of effluent charges for water and air pollution control. Singapore has implemented a central area road pricing system. Japan and Malaysia are exploring road user charges in order to reduce transport congestion. In the USA, Oregon, Michigan, Massachusetts, New York, Vermont and Maine have established beverage container deposit programs. China has also implemented a system of imposing pollution emission charges since the 1980s.

To deal with the environmental charges, material balance and value balance models are often used, especially the CGE (Computable General Equilibrium) model and the economic-environmental input-output model. CGE models were pioneered by Arnold Harberger (1962) and Leif Johansen (1973). In essence, a CGE model is an operationalization of neoclassical microeconomic theory and welfare economics, i.e., the Walrasian paradigm. The most common use of CGE models is first to calculate an initial equilibrium, ensuring that the model reproduces the benchmark data set which formed the basis for its construction. Next, some exogenous variable, usually a policy parameter such as a tax rate, is changed, and a new "counterfactual" equilibrium is calculated. A comparison of the two equilibriums reveals the impact of the policy change.

The vast majority of applications to date have been in the areas of tax policy, development policy, trade policy and environmental policy. CGE models address environmental problems by recognizing explicitly that even when a change in environmental policy has a direct impact on only one sector of the economy, there are always indirect impacts on other sectors. Economic agents respond to incentives; laws and regulations change these incentives, and CGE models take these responses into account. It is apparent that many of the recent CGE models have dealt with policies designed to reduce emissions of CO_2, SO_2 and NOx, etc., and have gained increasing acceptance as appropriate tools for modeling environmental policy (Nathan Wajsman, 1995). Most of the CGE models, however, follow the idea that the economic system is the main system while the environmental system is an external subsystem. Therefore, the main equilibriums in a CGE model are firstly set up according to the economic system, environment-related equilibriums based on the output of the economic system. For this reason, with CGE models it is difficult to internalize the "externalities" of environmental problems effectively. In addition, CGE models need the data of the fourth quadrant of the input-output table, data which is usually not collectable. Hence, environmental input-output models are often employed.

Input-output analysis can be extended into a complex system with economic and environmental factors to describe interdependence among economic sectors and environmental sectors. Such models were developed by Cumberland (1966), Daly

(1968), Isard (1968), Ayres and Kneese (1969), Leontief (1970) and Victor (1972), etc. in different forms and for various applications. The environmental input-output models developed so far can be classified into three categories (G. H. Huang, W. P Anderson and B. W. Baetz, 1994).

The first category of models is the economic-ecological model which represents an ambitious attempt to integrate an analysis of the input-output flows within and between the economic system and the ecological system. In this structure, the total system is divided into its human and non-human sectors. Therefore, a non-human sector is added into the input-output table in row and column, respectively. The comprehensiveness of this idea lies in the fact that flows of material resources from the environment to the economy make possible the production of goods, and the flows of pollutants from the economy to the environment affect the environment's ability to regenerate those environmental resources which were initially withdrawn to the economy (Isard, W., 1968). However, this category of models includes too many ecological factors associated with the complex web involved in the ecological system. Due to the lack of data regarding the ecological process, this category of models was gradually adapted to form the second category of models called commodity-by-industry model.

The commodity-by-industry model adopts some of the conventions established by Isard (1968), but greatly reduces model complexity and data requirements. The model includes both economic and ecological commodities. Ecological commodities are those things that are input from, or output into, the environment by economic sectors. The Economic commodities are those things exchanged between economic sectors or consumers (Victor, 1972). Recognizing the data problem inherent in the ecological interaction matrix of Isard's model mentioned above, Victor eliminated this matrix and focused on the linkage between economy and environment. Although Victor's approach allows the extension of the basic input-output table to the ecological sector, it is still a framework taking into consideration large-scale materials balance, and with this approach, too, it is difficult to analyze effectively pollution abatement activities in terms of internality.

The third category of models is a pollution generation-elimination model that is widely known as the augmented Leontief model. Leontief introduces extra rows into the input-output table to illustrate the flow of pollutants from the economy to the environment, and extra columns to illustrate anti-pollution sectors which with given quantities of inputs from economic sectors can remove a technologically determined level of pollution. Expanded in this manner, the model can be used to determine the level of production activity necessary for each sector in the economy in order for it to meet the requirements of final demand. The basic principle followed in these models is that economic activities create pollution as a byproduct and the level of this pollution may be reduced, at some cost, through payments to a pollution abatement sector. In order to avoid the problem of multi-output of industries, this structure considers the pollution problem as industry activity in columns and considers the same problem in terms of commodities in rows, i.e. the environmental sectors were added into the input-output table as different characteristics in rows and columns. Therefore, this model makes it difficult to permit industries to internalize the cost of pollution abatement (Johnson and Bennett, 1981), and it is also difficult effectively to reflect the internality of the pollution abatement process. However, as this framework has considered pollution abatement as a kind of industry activity, it provides a suitable basis for the economic-environmental input-output model developed in this paper.

This paper, following the augmented Leontief (1970) model, assumes that pollution abatement activities are performed by environmental industries possessing the same production characteristics as conventional economic sectors producing abated pollutants as their goods. Such environmental industries are added into the traditional input-output table. Then, setting up a balance relation between the two types of industries not only in terms of volume but also in terms of unit value, we can develop an economic-environmental input-output model. By introducing the environmental policy parameter, this model can be developed into a model system to be used for analyzing and designing a pollution discharge tax rate. The second section of this paper will give a simple introduction of the framework of an economic-environmental input-output model. Section 3 discusses policy parameters involved in the framework. In Section 4, a pollution discharge tax rate analysis and a design model will be developed. By applying the models developed in this paper, Section 5 will presents a case study of a regional area located in the northeast part of China. Finally, observations will be summarized in the conclusion.

2. Economic-Environment Input-Output Model

2.1. A Framework of Economic-Environmental Input-Output Table

Suppose that there are n economic industries and m environmental industries. Following Li and Ikeda (2001), the economic-environmental input-output table could be expressed as Table 1.

In Table 1, A_1, X_1, Y_1, V_1 are the coefficients associated with economic sectors only, and define the traditional input-output table, where

$x2_j$: total pollutant eliminated by environmental industry j;

$y2_j$: pollutant eliminated for final consumption by environmental industry j;

$a2_{ij}$: input from economic industry i to environmental industry j when j is eliminating unit pollutant;

$b1_{ij}$: pollutant eliminated by environmental industry i for economic industry j when j is producing unit product;

$b2_{ij}$: pollutant eliminated by environmental industry i for environmental industry j when j is eliminating unit pollutant;

$g1_{ij}$: pollutant i generated by economic industry j when j is producing unit product;

$g2_{ij}$: pollutant i generated by environmental industry j when j is eliminating unit pollutant;

$g3_j$: pollutant j generated by unit final demand;

Table 1: A Framework of an Economic-Environmental Input-Output Table

	Economic Industries 1, 2, …, n	Environmental Industries 1, 2, …, m	Final Demand	Total Products
Economic Industries 1, 2, …, n	$A_1 = \{a1_{ij}\}$	$A_2 - R = \{a2_{ij} - r_{ij}\}$	$Y_1 = \{y1_i\}$	$X_1 = \{x1_i\}$
Environmental Industries 1, 2, …, m	$B_1 = \{b1_{ij}\}$	$B_2 = \{b2_{ij}\}$	$Y_2 = \{y2_i\}$	$X_2 = \{x2_i\}$
Basic Input	$V_1 = \{v1_j\}$	$V_2 = \{v2_j\}$		
Total Products	$X_1 = \{x1_i\}$	$X_2 = \{x2_i\}$		
Pollution Generated 1,2, …, m	$G_1 = \{g1_{ij}\}$	$G_2 = \{g2_{ij}\}$	$G_3 = \{g3_j\}$	

$v2_j$: fixed asset depreciation, labour payment and profit of unit product in environmental industry j.

Clearly, the products needed by the environmental industries in the process of pollution elimination depend on the technology (fixed asset) taken in this process. Therefore, $A_2 - R$ is a technical coefficient matrix. The pollutants generated from economic and environmental industries also depend on the technology (fixed asset) being used, so G_1 and G_2 are also technical coefficient matrices. The pollutants generated from the final consumption depend on both the production structure and consumption style of the nation. Hence, G_3 possesses socio-cultural characteristics and is also defined as a technical coefficient matrix. The pollutants eliminated, however, depend on the regulation of environmental policy, so we call B_1 and B_2 policy coefficient matrices, and this will be discussed in detail in Section 3.

Table 1 differs from other environmental input-output tables in two important ways. Firstly, environmental industries are added into the input-output table in terms of economic activity in rows and columns. Environmental industries possess the same production characteristics as economic industries if we take the eliminated pollutant as their product. This not only makes the required data for the environmental sector tangible and collectable, but also allows us to deal with externality of environmental problems in terms of internality. Secondly, environmental policy parameters can be effectively introduced into the input-output model, which makes possible environmental policy analysis and design. This will be discussed in detail in Section 3.

Regarding to the economic products recycled in the process of pollution elimination, we introduce a technical coefficients matrix:

$$R = \{r_{ij} \mid i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m\},$$

where r_{ij} specifies the product of economic industry i recovered by environmental industry j when j is eliminating unit pollutant. Therefore, R should be taken from A_2, assuming the form of "$-R$".

2.2. Balance Relations in the Economic-Environmental Input-Output Table

A series of balance equations including both volume and value relations are discussed here. The volume relations can be set up by row equilibriums and the value relations can be set up by column equilibriums in the input-output table.

According to the usual principle of input-output analysis, the volume balance can be constructed, based on the defined notations, as follows:

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \left[I - \begin{pmatrix} A_1 & A_2 - R \\ B_1 & B_2 \end{pmatrix} \right]^{-1} \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} \tag{1}$$

Let $P_1' = \{p1_j \mid j = 1,2,...,n\}$, $P_2' = \{p2_j \mid j = 1,2,...,m\}$ refers price vectors of economic industry and environmental industry, respectively. The value balance can be formulated, based on the defined notations, as follow:

$$\begin{pmatrix} P_1 \\ P_2 \end{pmatrix} = \left[I - \begin{pmatrix} A_1' & B_1' \\ A_2' - R' & B_2' \end{pmatrix} \right]^{-1} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix} \tag{2}$$

Conventional input-output tables are usually set up in two different forms, the physical unit form or the value unit form. In Table 1, B_1, B_2 and R are always defined as physical forms. Therefore, in equation (2), when the basic conventional input-output table takes a physical unit form, P_1 represents the price of the product of economic industries. When the basic conventional input-output table takes a value unit form, $P_1 = \left\{ 1 + \frac{\Delta p1_i}{p1_i} \right\}$ represents the unit value (price) change vector of economic industries. P_2 always represents the product price of environmental industries.

2.3. Definition on Pollution Generation and Elimination

Pollutants are generated in the process of economic production, pollution elimination and final consumption. Therefore, the total volume of pollution generated is defined as follows:

$$G = G_1 X_1 + G_2 X_2 + G_3 \sum_{i=1}^{n} y1_i \tag{3}$$

Since pollutants generated less pollutants eliminated equals pollutants discharged, we have

$$H = G - X_2 \tag{4}$$

The cost of pollution elimination can be calculated by the amount of pollutants eliminated and their price. This can be expressed as

$$C = P_2' X_2 \tag{5}$$

3. Policy Parameters and Environmental Policy Effect

In the market economy, economic industries are not willing to eliminate pollutants by on their own at the extra cost unless there is a regulatory policy forcing them to do so. In order to examine the effect of environmental policy, we introduce a pollution elimination ratio matrix β into our model as follows:

$$\beta = \{\beta_{ij} | \beta_{ij} = b_{ij} / g_{ij}; i = 1, 2, \cdots, m; j = 1, 2, \cdots, n\} \quad (0 \le \beta_{ij} \le 1)$$

Then, β is a policy parameter matrix. Now, let us consider this problem for the simplest case by assuming that there is only one economic industry and one environmental industry, and that no pollution is generated in the environmental industry. Under these conditions, there is only one element in each matrix or vector defined above, so that we use the lowercase symbols a_1, a_2, g_1, v_1, v_2 and β to represent the elements in the corresponding matrix or vector. According to equation (2), the price of pollution elimination can be simply expressed as

$$p_2 = \frac{a_2 v_1 + (1 - a_1) v_2}{1 - a_1 - a_2 \beta g_1} \qquad (6)^1$$

Formula (6) shows that the pollution elimination price p_2 increases with the pollution elimination ratio β. If a pollution discharge tax is introduced into the system, and the tax rate is set to T_r, then the pollution elimination behavior of the economic industry will change with the pollution discharge tax rate T_r. This can be illustrated by Figure 1.

In Figure 1, β^* corresponds to the intersection point of T_r and p_2. When $\beta = \beta_1 (\beta_1 < \beta^*)$, the pollution discharge tax rate is greater than the pollution elimination price, i.e. $T_r > p_{21}$, economic industry will choose the behavior of pollution elimination, paying the environmental industry to eliminate the pollutant, to increase β until $\beta = \beta^* (p_2 = T_r)$. And when $\beta = \beta_2 (\beta_2 > \beta^*)$, indicating that

[1]According to formula (2), the price of the product of economic industry and environmental industry may be formulated as $\begin{cases} a_1 p_1 + \beta g_1 p_2 + v_1 = p_1 \\ a_2 p_1 \qquad + v_2 = p_2 \end{cases}$. Therefore, equation (6) can be deduced.

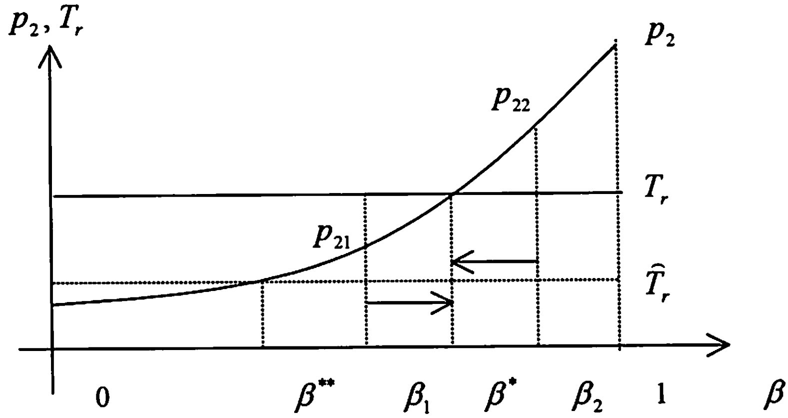

Figure 1: Pollution Discharge Tax and Pollution Discharge Behavior of Industry

the pollution elimination price is greater than the pollution discharge tax rate, i.e. $p_{22} > T_r$, the economic industry will choose the behavior of paying a tax for discharging the pollutant, to decrease β until $\beta = \beta^*$ ($p_2 = T_r$). Therefore, β^* is the optimal pollution elimination ratio of the economic industry related to the pollution discharge tax rate T_r. If the pollution discharge tax rate decreases from T_r to $\hat{T}_r$, then the optimal pollution elimination ratio will also decrease from β^* to β^{**}.

When there are a number of economic industries and a couple of pollutants involved, the conclusion that the price of pollution elimination is increasing with β_{ij} $(\forall i, j)$ can also be deduced, and the same result as above can be obtained. Therefore, the pollution elimination ratio β can be considered as a regulatory policy parameter related to a pollution discharge tax. In this way, we can analyze the volume and cost of pollution elimination at various policy levels.

4. Analysis and Design of Pollution Discharge Tax

In this section, mathematical programming models will be developed both to determine a reasonable pollution discharge tax rate which can sustain environmental quality and meet economic demand, and to estimate the pollution elimination ratio related to a given pollution discharge tax rate.

4.1. Environmental Quality Management Model

An environmental quality management model is developed to analyze what a reasonable pollution discharge tax rate would have be in order to sustain environmental quality and meet economic demand. The environmental quality criterion is often given in concentration standard and total amount of pollutant discharge standard. Since the concentration control is not adequate for reducing the total amount of pollutant discharged, the environmental quality control based on the total amount of pollutant discharged is usually adopted. Therefore, the environmental quality management model is also developed on the basis of the standard for the total amount of pollution discharged.

According to the analysis of the preceding section, if the pollution elimination price can be obtained for each environmental industry ($P2_i^*$) associated with the given environmental quality and economic demand, the pollution discharge tax rate can be easily determined by using the equation $Tr_i = P2_i^*$. Here, it is assumed that the TDP (Transferable Discharge Permit) trading is applied, compelling all industries to attain the minimum pollution abatement cost. Therefore, programming models to analyze the optimal pollution discharge tax rate may be set up as follows:

(1) Object function:

$$\text{Min} \quad C = C_1 + C_2$$

where

$$C_1 = \sum_{i=1}^{m} P2_i X2_i$$

$$C_2 = \sum_{i=1}^{m} Tr_i \left(\sum_{j=1}^{n} g1_{ij} X1_j + \sum_{j=1}^{m} g2_{ij} X2_j - X2_i\right)$$

C_1 is the cost for processing pollution and C_2 is the tax paid for discharging pollution.

As discussed above, the stable state of a pollution elimination system controlled by a pollution discharge tax can be realized only at $P2_i = Tr_i$; thus, the object function may be expressed as

$$\text{Min} \quad C = \sum_{i=1}^{m} p2_i \left(\sum_{j=1}^{n} g1_{ij} X1_j + \sum_{j=1}^{m} g2_{ij} X2_j\right)$$

where $p2$ denotes the pollution elimination price, and $X2$ denotes the pollutant eliminated. These can be calculated according to the volume balance and value balance of E-E I/O-Table as

$$\sum_{i=1}^{n} a1_{ij} p1_i + \sum_{i=1}^{m} \beta1_{ij} g1_{ij} p2_i + v1_j = p1_j \quad (j = 1,2,\cdots,n)$$

$$\sum_{i=1}^{n} a2_{ij} p1_i + \sum_{i=1}^{m} \beta2_{ij} g2_{ij} p2_i + v2_j = p2_j \quad (j = 1,2,\cdots,m)$$

$$X2_i - \sum_{j=1}^{n} \beta1_{ij} g1_{ij} X1_j - \sum_{j=1}^{m} \beta2_{ij} g2_{ij} X2_j = Y2_i \quad (i = 1,2,\cdots,m)$$

(2) Constraints:

Three kinds of constraints are taken into account: the economic demand constraint, the environmental quality constraint, and the environmental technology capacity constraint.

The economic demand constraint can be expressed as follows:

$$X1_i - \sum_{j=1}^{n} a1_{ij} X1_j - \sum_{j=1}^{m} a2_{ij} X2_j \geq Y1_i \quad (i = 1,2,\cdots,n)$$

where, $Y1$ is the final demand of economic sectors.

The environmental quality constraint can be given in two forms as follows:

$$\frac{X2_i}{\sum_{j=1}^{n} g1_{ij} X1_j + \sum_{j=1}^{m} g2_{ij} X2_j + g3_i \sum_{j=1}^{n} y1_j} \geq \bar{\beta}_i \quad (i = 1, 2, \cdots, m)$$

$$\sum_{j=1}^{n} g1_{ij} X1_j + \sum_{j=1}^{m} g2_{ij} X2_j + g3_i \sum_{j=1}^{n} y1_j - X2_i \leq \bar{e}_i \quad (i = 1, 2, \cdots, m)$$

where $\bar{\beta}_i$ denotes the environmental quality standard in terms of the average pollution elimination ratio, and $\bar{e}_i$ represents the environmental quality standard in terms of the total amount of pollutant discharge.

The environmental technology constraint can be expressed in terms of the maximum pollution elimination ratio as follows:

$$0 \leq \beta1_{ij} \leq \bar{\beta}_{ij} \quad (i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n)$$

$$0 \leq \beta2_{ij} \leq \bar{\beta}_{ij} \quad (i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, m)$$

where $\bar{\beta}_{ij}$ represents the maximum pollution abatement rate for pollutant i in industry j associated with present environmental technology.

In summary, the environmental quality management model may be given as follows:

$$\text{Min} \quad C=\sum_{i=1}^{m} p2_i(\sum_{j=1}^{n} g1_{ij}X1_j+\sum_{j=1}^{m} g2_{ij}X2_j)$$

$$\left.\begin{aligned} \text{s.t.}\ & X1_i-\sum_{j=1}^{n} a1_{ij}X1_j-\sum_{j=1}^{m} a2_{ij}X2_j \geq Y1_i \quad (i=1,2,\cdots,n) \\ & X2_i-\sum_{j=1}^{n} \beta1_{ij}g1_{ij}X1_j-\sum_{j=1}^{m} \beta2_{ij}g2_{ij}X2_j = Y2_i \quad (i=1,2,\cdots,m) \end{aligned}\right\} \quad (7)$$

$$\left.\begin{aligned} & \sum_{i=1}^{n} a1_{ij}p1_i+\sum_{i=1}^{m} \beta1_{ij}g1_{ij}p2_i+v1_j=p1_j \quad (j=1,2,\cdots,n) \\ & \sum_{i=1}^{n} a2_{ij}p1_i+\sum_{i=1}^{m} \beta2_{ij}g2_{ij}p2_i+v2_j=p2_j \quad (j=1,2,\cdots,m) \end{aligned}\right\} \quad (8)$$

$$\left.\begin{aligned} & \frac{X2_i}{\sum_{j=1}^{n} g1_{ij}X1_j+\sum_{j=1}^{m} g2_{ij}X2_j+g3_i\sum_{j=1}^{n} y1_j} \geq \overline{\beta}_i \quad (i=1,2,\cdots,m) \\ & \quad or \\ & \sum_{j=1}^{n} g1_{ij}X1_j+\sum_{j=1}^{m} g2_{ij}X2_j+g3_i\sum_{j=1}^{n} y1_j - X2_i \leq \overline{e}_i \quad (i=1,2,\cdots,m) \end{aligned}\right\} \quad (9)$$

$$\left.\begin{aligned} & 0 \leq \beta1_{ij} \leq \overline{\beta}_{ij} \quad (i=1,2,\cdots,m;\ j=1,2,\cdots,n) \\ & 0 \leq \beta2_{ij} \leq \overline{\beta}_{ij} \quad (i=1,2,\cdots,m;\ j=1,2,\cdots,m) \end{aligned}\right\} \quad (10)$$

Formula (7) represents the constraints of satisfying demand in each industry; formula (8) is a nonlinear equation for calculating the price of pollution elimination; formula (9) expresses environmental quality constraints in terms of the average pollution elimination ratio standard or the total amount of pollutant discharge standard; formula (10) gives the constraint of environmental technology.

In all of the programming models above, pollution elimination ratio β_{ij} is the programming variable. If β_{ij}^* expresses the solution of the programming model, the pollution elimination price of each environmental industry $P2_i^*$ corresponding to β_{ij}^* can be gotten according to restriction (8). Then the pollution discharge tax rate can be determined by letting $Tr_i = P2_i^*$.

4.2. An Effectivity Analysis Model of the Pollution Discharge Tax

An effectivity analysis model of the pollution discharge tax is developed for estimating the pollution elimination ratio in relation to a given pollution discharge tax rate. As discussed above, if pollution discharge permit trading is put into operation, all industries will regulate their pollution elimination behaviors to reach a state where the social average pollution abatement price is just equal to the given pollution elimination tax rate. Only under this condition will the total pollution abatement cost corresponding to the given pollution discharge tax rate reach its minimum. Based on such a consideration, a programming model for analyzing the effectivity of a pollution discharge tax can be set up as follows:

$$\text{Min} \quad C = \sum_{i=1}^{m} p2_i \left(\sum_{j=1}^{n} g1_{ij} X1_j + \sum_{j=1}^{m} g2_{ij} X2_j\right)$$

$$\text{s.t.} \quad X1_i - \sum_{j=1}^{n} a1_{ij} X1_j - \sum_{j=1}^{m} a2_{ij} X2_j \geq Y1_i \quad (i = 1, 2, \cdots, n)$$

$$X2_i - \sum_{j=1}^{n} \beta1_{ij} g1_{ij} X1_j - \sum_{j=1}^{m} \beta2_{ij} g2_{ij} X2_j = Y2_i \quad (i = 1, 2, \cdots, m)$$

$$\sum_{i=1}^{n} a1_{ij} p1_i + \sum_{i=1}^{m} \beta1_{ij} g1_{ij} p2_i + v1_j = p1_j \quad (j = 1, 2, \cdots, n)$$

$$\sum_{i=1}^{n} a2_{ij} p1_i + \sum_{i=1}^{m} \beta2_{ij} g2_{ij} p2_i + v2_j = p2_j \quad (j = 1, 2, \cdots, m)$$

$$p2_j \geq Tr_j$$

$$0 \leq \beta1_{ij} \leq \overline{\beta}_{ij} \quad (i = 1, 2, \cdots, m; \; j = 1, 2, \cdots, n)$$

$$0 \leq \beta2_{ij} \leq \overline{\beta}_{ij} \quad (i = 1, 2, \cdots, m; \; j = 1, 2, \cdots, m)$$

where Tr_j denotes the given pollution elimination tax rate for pollutant j. The pollution elimination ratio β_{ij} is also the programming variable here, and the solution will give the available pollution elimination ratio related to the given pollution discharge tax rate Tr_j.

Obviously, in the programming model, while the pollution elimination ratio equals zero $(\beta_{ij} = 0, \forall ij)$, the pollution elimination price does not equal zero

$(P2_j \neq 0, \forall j)$. This indicates that the initial investment and payment for labor for environmental protection have already taken place.

In addition, the effectivity analysis model of a pollution discharge tax developed here is set up from the point of view of industry, considering the pollution elimination process in terms of economic benefit. If pollution elimination efficiency is also emphasized by the government, other additional regulations regarding a pollution discharge tax and related constraints should be taken into account.

5. A Case Study of Heilongjiang Province in China

5.1. A General Introduction to the Studied Area

Located in the northeast of China, with a total area of 452.90 thousand square km, Heilongjiang is a large province. At the end of 1995, the population of Heilongjiang was about 92.96 million. In the past, the Chinese government has invested considerable financial resources for developing basic industry in Heilongjiang. Indeed, total products originating in Heilongjiang reached 2020 hundred million RMB in 1995.

Concomitant with heavy economic production, pollution has become a serious problem in the province. According to China's national statistical agency, large amounts of wastewater, waste gas, and residue were generated and discharged in Heilongjiang in 1995.

Wastewater discharge was 1287.17 million tons, with industrial wastewater accounting for 693.89 million tons, or 53.91% of the total. The industrial discharge of COD (Chemical Oxygen Demand) was 217 thousand tons, about 3% that of the whole country.

The total volume of waste gas emission was 5451 hundred million cu. m, with industrial waste gas at 4224 hundred million cu. m, 77.49% of the whole. The total industrial discharge of SO_2 (Sulphur Dioxide) was 245 thousand tons, about 2% that of the whole country. The total industrial discharge of TSP (Total Suspending Particles, including soot and dust) was 596 thousand tons, which occupies about 4% that of the whole country.

Heilongjiang province has made efforts to protect the environment. In 1995, it invested 182.79 million RMB on a total of 433 projects. The number of enterprises and organizations related to environmental protection has reached 360, with fixed assets of about 11.4 hundred million RMB. Further, regulations regarding a pollution emission charge have been effectively implemented in Heilongjiang province, which in 1995 imposed pollution emission charges of about 100 million RMB.

5.2. Pollution Emission Charge System in China

The provisional law on pollution emission charge was put in force in China on July 1, 1982. This law is rather unusual in the world in that it defines norms for the discharge of many pollutants on a nationwide scale. This system involves collecting a charge from individual firms according to the amount and type of pollutants they discharge into the environment. While the system was initiated in the belief that it would induce individual firms to reduce the amount of pollutants discharged at the pollution source through economic disincentive, in fact, the system does not seem to function very well.

First, since the standards of emission charge are calculated according to the concentration of pollutants, firms are allowed to dilute pollutants into large amounts of water to reduce the concentration level below the standard. In addition, if individual firms discharge more than one pollutant from the same overflow or stack, the amount of the charge is based only on the most poisonous material. This is not adequate as a measure to reduce the total amount of pollutant discharge.

Second, there are many inadequacies in the present emission charges system. A charge differs from a fine. The aim of the emission charge is to induce individual firms to save resources and to reduce the amount of pollutants discharged. Thus, it is assumed that the level of the charge should be set up slightly higher than the marginal pollution control cost of the average level of the society (Yang, 1981, Zhou, 1981). However, since it is difficult to measure the pollution control cost accurately, the aim of the emission charge regulation cannot fulfilled.

Therefore, the environmental protection agency of China has been conducting research on reforming the pollution emission charge system. Some cities, for example Shenyang, are considering the establishment of new systems of air quality control based on the total amount of pollutants discharged.

5.3. An Overview of the Application Problem

The models developed for the analysis of a regional pollution discharge tax will be applied to Heilongjiang Province, located in the northeast of China. In order to show the applicability of our model, we take a classification by aggregating the economic system into sixteen major sectors and considering three major pollution-processing industries. The total nineteen industries are as follows:

1. Agriculture
2. Mining industry
3. Food, beverage, and tobacco processing industry
4. Textile industry
5. Leather, furs, and related products industry
6. Papermaking and paper products industry
7. Production and supply of electric power, steam and hot water industry
8. Petroleum processing industry
9. Coking, gas, coal products industry
10. Chemical industry
11. Building materials and other nonmetal mineral products industry
12. Smelting and pressing of ferrous metals and nonferrous metals industry
13. Metal products industry
14. Machine building, electric equipment manufacturing industry
15. Other industry
16. Other trades

17. COD processing industry
18. SO_2 processing industry
19. TSP processing industry

The economic sectors generate COD, SO_2 and TSP in the process of production, with a certain generation rate G_1, and the environmental sectors eliminate COD, SO_2 and TSP, with pollution elimination ratio β related to a given pollution discharge tax rate.

5.4. Assumptions on Input Data

Data for the conventional elements of the input-output table were collected from several sources. A_1, D_1, W_1, V_1, Y_1 are drawn from a 33 sectors I/O-Table in the *Compilation of Statistical Material of Heilongjiang, (1952-1996)*; B_1 and G_1 were from the *Environmental Yearbook of China (1997)*, *Heilongjiang Statistical Yearbook (1997)* and other environment statistical references of Heilongjiang province. As discussed above, A_2 and R are technical coefficient matrices related to pollution elimination technology. These data could be provided by industrial technology process analysis or the associated experimental investigations. However, because of the unavailability of such expert data, we assume a zero recycle rate, i.e. $R = 0$, while A_2 was estimated based on *Economic and Technical Handbook of Wastewater Processing in China* (Wang Fukang, 1992), "Design and Implementation of a Pollution Emission Charge System in China" (Yang Jintian and Wang Jinnan, et al, 1998) and experimental studies in Heilongjiang province. Since there are no statistical investigations about pollution generated and eliminated in Agriculture and in the final demand sector, there is assumed to be no generation and no elimination in these sectors. In addition, since pollution generated and eliminated in the process of pollution elimination is very small, and since there are no statistical investigations about pollution generated and eliminated in this process, there is also assumed to be no generation and no elimination in this process.

In this way, the conventional input-output table with pollution generation and elimination relations for the studied area of 1995 can be set up as Table 2.

Following Li and Ikeda (2001), the economic-environmental input-output table for the studied area in 1995 can be set up as Table 3.

5.5. Calculating Results and Observation

Calculation and analysis are performed on the basis of the E-E I/O-Table shown as Table 3, and related reference data of the studied area in1995 that are given with the related calculation and analysis results.

In addition, according to present environmental technology conditions in the area studied, the maximum abatement rate for COD and SO_2 are set at 80%, and TSP is set at 95% in all industries.

Table 2: Conventional Input-Output Table with Pollution Relations

(Original Unit: Economic Sectors: 10^8 RMB, Environmental Sectors: 10^5 TON)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.10828	0.00034	0.39938	0.15228	0.08551	0.00275	0.01074	0.00007	0.00036	0.01774	0.00468	0.00047	0.00041	0.00036	0.43490	0.00512	0	0	0
2	0.00337	0.02406	0.00844	0.01802	0.00462	0.10170	0.20258	0.50949	0.31552	0.09969	0.13741	0.14996	0.01494	0.01826	0.04472	0.03472	0.150	0.160	0.083
3	0.08609	0.00034	0.11987	0.00248	0.02195	0.00103	0.00031	0.00164	0.00066	0.01641	0.00069	0.00052	0.00159	0.00180	0.00350	0.01942	0	0	0
4	0.00203	0.00168	0.00384	0.16342	0.25334	0.01197	0.00330	0.00036	0.00224	0.01338	0.00882	0.00162	0.00233	0.00198	0.00803	0.00619	0	0	0
5	0.00443	0.00330	0.00054	0.00295	0.11797	0.00163	0.00251	0.00068	0.00394	0.00185	0.00168	0.00202	0.00295	0.00216	0.00122	0.00448	0	0	0
6	0.00069	0.00305	0.01507	0.00641	0.00762	0.19970	0.00194	0.00057	0.00129	0.01029	0.01792	0.00173	0.01102	0.00788	0.00369	0.02364	0	0	0
7	0.00478	0.03604	0.00724	0.01867	0.00563	0.03077	0.00329	0.00697	0.02648	0.01762	0.05901	0.04377	0.01817	0.01884	0.00674	0.01305	0.097	0.098	0.062
8	0.02797	0.03200	0.00948	0.01420	0.00578	0.01429	0.06171	0.02905	0.02461	0.01237	0.04664	0.03639	0.01814	0.02036	0.00931	0.05425	0	0.082	0
9	0	0.00003	0.00015	0.00001	0	0.00015	0.00008	0.00001	0.00201	0.00066	0.00059	0.02795	0.00936	0.00118	0.00122	0.00011	0	0.024	0
10	0.08048	0.02862	0.01637	0.15217	0.07296	0.09770	0.03667	0.01793	0.03697	0.24651	0.09149	0.01743	0.03981	0.05496	0.04694	0.04246	0.135	0.157	0.024
11	0.00585	0.01582	0.00450	0.00135	0.00075	0.00456	0.00941	0.00192	0.00802	0.01462	0.03956	0.03078	0.01302	0.01354	0.00526	0.05326	0	0	0
12	0.00078	0.01143	0.00164	0.00135	0.00049	0.01731	0.00612	0.00177	0.01022	0.00617	0.02335	0.18800	0.29392	0.15515	0.02429	0.02796	0	0	0
13	0.00723	0.01342	0.00223	0.00366	0.01284	0.01010	0.00720	0.00187	0.01107	0.01334	0.01014	0.00748	0.05392	0.02682	0.00946	0.01384	0	0	0
14	0.01323	0.05271	0.00663	0.02046	0.00466	0.01452	0.07137	0.01522	0.05117	0.02488	0.06922	0.03527	0.02172	0.17011	0.01859	0.04286	0.049	0.055	0.021
15	0.00244	0.00492	0.00042	0.00027	0.00590	0.00181	0.00094	0.00004	0.00420	0.00054	0.02520	0.04499	0.00556	0.00202	0.00403	0.00069	0.039	0.029	0.010
16	0.06639	0.05613	0.06599	0.18320	0.13779	0.14283	0.16115	0.01571	0.16636	0.10857	0.17822	0.15193	0.19890	0.18025	0.07718	0.19022	0.210	0.260	0.140
17	0	0.00072	0.00198	0.00129	0.00011	0.03148	0.00115	0.00023	0.00269	0.00087	0.00019	0.00120	0.00013	0.00037	0.02918	0.00011			
18	0	0	0.00002	0.00002	0	0.00004	0.00118	0.00001	0	0	0.00010	0	0	0	0.00005	0			
19	0	0.00235	0.00260	0.00628	0.00075	0.03780	0.04549	0.00020	0.01652	0.00203	0.03908	0.00373	0.00201	0.00281	0.03026	0.00026			
D	0.01695	0.17989	0.01623	0.02481	0.01114	0.02409	0.12561	0.05341	0.04196	0.03403	0.02003	0.02279	0.01475	0.02882	0.01917	0.07476			
W	0.48550	0.17658	0.05907	0.15922	0.10893	0.14660	0.16617	0.04271	0.15250	0.09122	0.14841	0.13586	0.13841	0.20240	0.15958	0.25305			
V	0.08353	0.35965	0.26291	0.07508	0.14212	0.17650	0.12893	0.30058	0.14041	0.27010	0.11694	0.10104	0.14109	0.09312	0.12217	0.13995			
COD Generated	0	0.00112	0.00309	0.00201	0.00017	0.04919	0.00179	0.00036	0.00420	0.00136	0.00030	0.00187	0.00020	0.00057	0.04559	0.00019			
SO_2 Generated	0	0.00027	0.00043	0.00091	0.00008	0.00148	0.01893	0.00009	0.00380	0.00015	0.00126	0.00040	0.00014	0.00036	0.00329	0.00008			
TSP Generated	0	0.00305	0.00367	0.00796	0.00095	0.04508	0.04840	0.00040	0.02780	0.00254	0.04981	0.00649	0.00227	0.00354	0.03771	0.00049			

Table 3: Economic-Environmental Input-Output Table

(Original Unit: Economic Sectors: 10^8 RMB, Environmental Sectors: 10^5 TON)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0.10828	0.00034	0.39938	0.15228	0.08551	0.00275	0.01074	0.00007	0.00036	0.01774	0.00468	0.00047	0.00041	0.00036	0.43490	0.00512	0	0	0
2	0.00337	0.02376	0.00792	0.01730	0.00454	0.09383	0.19844	0.50944	0.31375	0.09939	0.13412	0.14947	0.01475	0.01797	0.03782	0.03468	0.150	0.160	0.083
3	0.08609	0.00034	0.11987	0.00248	0.02195	0.00103	0.00031	0.00164	0.00066	0.01641	0.00069	0.00052	0.00159	0.00180	0.0035	0.01942	0	0	0
4	0.00203	0.00168	0.00384	0.16342	0.25334	0.01197	0.00330	0.00036	0.00224	0.01338	0.00882	0.00162	0.00233	0.00198	0.00803	0.00619	0	0	0
5	0.00443	0.00330	0.00054	0.00295	0.11797	0.00163	0.00251	0.00068	0.00394	0.00185	0.00168	0.00202	0.00295	0.00216	0.00122	0.00448	0	0	0
6	0.00069	0.00305	0.01507	0.00641	0.00762	0.19970	0.00194	0.00057	0.00129	0.01029	0.01792	0.00173	0.01102	0.00788	0.00369	0.02364	0	0	0
7	0.00478	0.03582	0.00689	0.01815	0.00557	0.02537	0.00024	0.00693	0.02520	0.01741	0.05656	0.04342	0.01803	0.01863	0.00203	0.01302	0.097	0.098	0.062
8	0.02797	0.03200	0.00948	0.01420	0.00578	0.01429	0.06161	0.02905	0.02461	0.01237	0.04663	0.03639	0.01814	0.02036	0.00931	0.05425	0	0.082	0
9	0	0	0.00015	0.00001	0	0.00015	0.00005	0.00001	0.00201	0.00066	0.00059	0.02795	0.00936	0.00118	0.00122	0.00011	0	0.024	0
10	0.08048	0.02847	0.01604	0.15184	0.07293	0.09254	0.03524	0.01789	0.03621	0.24634	0.09051	0.01718	0.03974	0.05484	0.04227	0.04244	0.135	0.157	0.024
11	0.00585	0.01582	0.00450	0.00135	0.00075	0.00456	0.00941	0.00192	0.00802	0.01462	0.03956	0.03078	0.01302	0.01354	0.00526	0.05326	0	0	0
12	0.00078	0.01143	0.00164	0.00135	0.00049	0.01731	0.00612	0.00177	0.01022	0.00617	0.02335	0.18800	0.29392	0.15515	0.02429	0.02796	0	0	0
13	0.00723	0.01342	0.00223	0.00366	0.01284	0.01010	0.00720	0.00187	0.01107	0.01334	0.01014	0.00748	0.05392	0.02682	0.00946	0.01384	0	0	0
14	0.01323	0.05263	0.00648	0.02026	0.00464	0.01218	0.07029	0.01520	0.05069	0.02480	0.06839	0.03513	0.02167	0.17003	0.01652	0.04285	0.049	0.055	0.021
15	0.00244	0.00487	0.00032	0.00016	0.00589	0.00020	0.00041	0.00003	0.00393	0.00049	0.02480	0.04491	0.00554	0.00198	0.00259	0.00068	0.039	0.029	0.010
16	0.06639	0.05565	0.06521	0.18205	0.13766	0.13092	0.15423	0.01563	0.16348	0.10810	0.17268	0.15116	0.19859	0.17978	0.06680	0.19016	0.210	0.260	0.140
17	0	0.00072	0.00198	0.00129	0.00010	0.03148	0.00115	0.00023	0.00269	0.00087	0.00019	0.00120	0.00013	0.00037	0.02918	0.00011			
18	0	0	0.00002	0.00002	0	0.00004	0.00118	0.00001	0	0	0.00010	0	0	0	0.00005	0			
19	0	0.00235	0.00260	0.00628	0.00075	0.03780	0.04549	0.00020	0.01652	0.00203	0.03908	0.00373	0.00201	0.00281	0.03026	0.00026			
D	0.01695	0.17971	0.01617	0.02465	0.01113	0.02275	0.12278	0.05339	0.04144	0.03397	0.01950	0.02269	0.01473	0.02876	0.01809	0.07474	0.086	0.084	0.040
W	0.48550	0.17640	0.05885	0.15817	0.10885	0.13844	0.16243	0.04270	0.15061	0.09106	0.14451	0.13525	0.13820	0.20197	0.15057	0.25298	0.110	0.107	0.061
V	0.08353	0.35928	0.26193	0.07459	0.14202	0.16668	0.12603	0.30049	0.13867	0.26962	0.11387	0.10059	0.14088	0.09292	0.11527	0.13991	0.190	0.150	0.088
COD Generated	0	0.00112	0.00309	0.00201	0.00017	0.04919	0.00179	0.00036	0.00420	0.00136	0.00030	0.00187	0.00020	0.00057	0.04559	0.00019			
SO_2 Generated	0	0.00027	0.00043	0.00091	0.00008	0.00148	0.01893	0.00009	0.00380	0.00015	0.00126	0.00040	0.00014	0.00036	0.00329	0.00008			
TSP Generated	0	0.00305	0.00367	0.00796	0.00095	0.04508	0.04840	0.00040	0.02780	0.00254	0.04981	0.00649	0.00227	0.00354	0.03771	0.00049			

Here, both economic growth and environmental protection will be taken into account. When the economy grows from $Y1_{1995}$ = (425.08, 375.24, 227.75, 19.81, 2.30, -10.85, 14.97, 23.20, 1.65, -9.29, -0.81, -56.05, -6.36, 133.55, -1.20, 875.53) to $Y1_{2000}$ = (596.20, 526.29, 319.43, 27.78, 3.23, -15.22, 21.00, 32.54, 2.31, -13.03, -1.14, -78.61, -8.92, 187.31, -1.68, 1227.98), increasing by an average of 7% each year, the following related analysis would be performed.

A) How to set the pollution discharge tax rate so that the average pollution elimination ratio remains at the 1995 level. Correspondingly, how much pollution will be generated, eliminated and discharged and what impact does this have on the economic system?
B) How to set the pollution discharge tax rate so that the total amount of pollution discharged remains at the 1995 level. Correspondingly, how much pollution will be generated, eliminated and discharged and what impact does this have on the economic system?
C) If the pollution discharge tax rate is set at the level (1069.50 RMB/Ton for COD, 1209.80 RMB/Ton for SO_2 and 530.20 RMB/Ton for TSP) suggested by the research found in *Design and Implementation of a Pollution Emission Charge System in China* (Yang Jintian and Wang Jinnan, et al, 1998), how much pollution will be generated, eliminated and discharged? What impact does this have on the economic system?

The calculated results are shown in Table 4, Table 5 and Table 6. According to Table 4 and 5, we can conclude the following:

If the average pollution elimination ratio is kept at the 1995 level, the pollution discharge tax rate should be set at 1062.25 RMB/Ton for COD, 1202.69 RMB/Ton for SO_2 and 527.40 RMB/Ton for TSP. Pollution discharged, however, will increase from 2.17×10^5 ton of COD, 2.45×10^5 ton of SO_2 and 3.17×10^5 ton of TSP to 3.04×10^5 ton, 3.43×10^5 ton and 5.20×10^5 ton, increasing by 40.09%, 40.00%, and 64.04%, respectively. And the total pollution abatement cost will increase from 12.25×10^8 RMB to 17.13×10^8 RMB, increasing by 39.84%.

If the pollution discharged is kept at the 1995 level, the pollution discharge tax rate should be set at 1064.52 RMB/Ton for COD, 1205.30 RMB/Ton for SO_2 and 528.52 RMB/Ton for TSP. Pollution eliminated, however, will increase from 3.83×10^5 ton of COD, 0.12×10^5 ton of SO_2 and 15.15×10^5 ton of TSP to 6.26×10^5 ton, 1.17×10^5 ton and 22.78×10^5 ton, increasing by 63.45%, 8.75 time, and 50.36%, respectively, while simultaneously the total pollution abatement cost will also increase by 64.16%, from 12.25×10^8 RMB to 20.11×10^8 RMB.

If the pollution discharge tax rate is set at 1069.50 RMB/Ton for COD, 1209.80 RMB/Ton for SO_2 and 530.20 RMB/Ton for TSP suggested by the research in "Design and Implementation of a Pollution Emission Charge System in China" (Yang Jintian and Wang Jinnan, et al, 1998), the average pollution elimination ratio of COD will be 58.90%, SO_2 will be 69.70%, and TSP will be 79.91%. The pollution discharge of COD, SO_2 and TSP will be 3.46×10^5 ton, 1.09×10^5 ton and 5.32×10^5 ton, which when compared with the figures from 1995, increased by 59.45%, -55.51% and

Table 4: Optimal Pollution Elimination Ratio with Reference of 1995

(Unit: %)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Situation of 1995	COD	---	64.00	64.00	64.00	63.79	64.00	63.99	63.99	64.02	64.00	64.01	64.00	63.96	64.00	64.00	60.00
	SO_2	---	0.00	3.65	1.90	0.00	2.98	6.22	8.65	0.00	1.13	8.24	0.00	0.16	1.17	1.50	0.03
	TSP	---	76.98	70.88	78.92	78.87	83.84	94.00	49.73	59.42	79.70	78.47	57.42	88.44	79.47	80.26	53.53
Case A	COD	---	76.19	80.00	80.00	80.00	80.00	0.00	80.00	0.00	0.00	80.00	0.00	80.00	80.00	0.00	80.00
	SO_2	---	0.00	79.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TSP	---	95.00	95.00	95.00	95.00	95.00	38.78	95.00	95.00	95.00	95.00	95.00	95.00	95.00	0.00	95.00
Case B	COD	---	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	17.07	80.00
	SO_2	---	80.00	80.00	80.00	80.00	80.00	6.50	80.00	80.00	80.00	80.00	80.00	80.00	80.00	0.00	80.00
	TSP	---	95.00	95.00	95.00	95.00	95.00	64.53	95.00	95.00	95.00	95.00	95.00	95.00	95.00	0.00	95.00
Case C	COD	---	80.00	0.00	0.00	0.00	80.00	80.00	0.00	80.00	80.00	0.00	80.00	80.00	80.00	80.00	0.00
	SO_2	---	80.00	0.00	0.00	0.00	80.00	80.00	0.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	0.00
	TSP	---	95.00	0.00	0.00	0.00	95.00	95.00	0.00	95.00	95.00	86.17	95.00	95.00	95.00	95.00	0.00

Table 5: Pollution Situations, Pollution Discharge Tax Rate and Related Items

	1995			Case A			Case B			Case C		
	COD	SO_2	TSP	COD	SO_2	TSP	COD	SO_2	TSP	COD	SO_2	TSP
Pollution Generated (10^5 Ton)	6.00	2.57	18.86	8.42	3.61	26.46	8.43	3.62	26.49	8.43	3.61	26.49
Pollution eliminated (10^5 Ton)	3.83	0.12	15.15	5.37	0.17	21.26	6.26	1.17	22.78	4.96	2.52	21.17
Pollution Discharged (10^5 Ton)	2.17	2.45	3.71	3.04	3.43	5.20	2.17	2.45	3.71	3.46	1.09	5.32
Average Elimination Ratio (%)	63.83	4.83	80.34	63.83	4.83	80.34	74.26	32.27	86.00	58.90	69.70	79.91
Pollution Discharge Tax Rate (RMB/Ton)	---	---	---	1062.3	1202.7	527.4	1064.5	1205.3	528.5	1069.5	1209.9	530.8
Total Pollution Abatement Cost (10^8 RMB)		12.25			17.13			20.11			19.59	

Table 6: Total Products and Their Price Change of Economic Sector

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total Products	1995	670.04	612.39	361.88	51.23	18.10	47.98	85.90	171.07	5.00	237.29	105.62	73.98	44.73	319.49	11.94	1404.82
	Case A	939.77	858.90	507.56	71.85	25.38	67.29	120.48	239.94	7.01	332.81	148.14	103.76	62.74	448.10	16.75	1970.34
(10^8 RMB)	Case B	939.87	859.70	507.61	71.88	25.40	67.35	120.84	240.17	7.04	333.42	148.25	103.91	62.80	448.45	16.85	1971.54
	Case C	939.85	859.60	507.60	71.88	25.39	67.34	120.74	240.26	7.08	333.39	148.23	103.89	62.79	448.39	16.82	1971.31
Product Price Change Based on 1995	Case A	-0.017	-0.049	0.152	0.062	-0.011	1.266	-1.701	-0.026	0.148	-0.126	0.208	-0.353	-0.144	-0.066	-4.751	0.014
	Case B	0.043	0.071	0.216	0.291	0.134	1.583	-0.656	0.067	0.998	0.14	0.532	0.107	0.101	0.155	-3.844	0.133
(%)	Case C	0.033	0.215	-0.315	-0.414	-0.094	1.737	1.874	0.104	1.159	0.219	0.616	0.59	0.347	0.337	1.484	0.152

67.82%, respectively. At the same time, the total pollution abatement cost will increase by 59.92%, from 12.25×10^8 RMB to 19.59×10^8 RMB.

In addition, calculation results show that the total product and price of each industry also change with the pollution discharge tax rate, as shown in Table 6, under the condition where the same final demand is met. This indicates that a pollution discharge tax also has an impact on the economic system, and that there are complicated interactions between the economic and the environmental sectors, and it is important to design an environmental policy whose pollution discharge tax rates reflect this complexity.

6. Concluding Remark

We have presented a new framework for analyzing and designing a pollution discharge tax based on an economic-environmental input-output model which allows us more clearly to discuss the interactions between environmental policy and the environmental protection behavior of economic industries.

The case study shows that the interaction between economic and environmental systems can be regulated with a pollution discharge tax. However, in order to make the system work efficiently and to realize certain special requirements for economic or environmental quality, it is necessary to make adjustments in pollution discharge tax rates. For example, in case A and B of the case study, if there are no additional regulations appending to the pollution discharge tax, under the pollution discharge tax rate programmed, the given environment condition cannot be reached. This fact can be well understood from a study of cases A, B and C. The solution of case C is not the most efficient in terms of pollution elimination, but is an optimal one in terms of economy from the point of view of industries.

The case study also shows that the E-E I/O-Model system provides an acceptable method for dealing with the interactions between environmental policy and the environmental protection behavior of economic industries. If necessary initial investment is made in environmental protection, and TDP market and environmental policy mechanism are introduced into the present environmental protection system, the activities of environmental protection will work as an industry without fail, and calculation results can be realized.

However, there are many remaining research issues requiring analysis with our framework E-E I/O-Model, such as the interactions among policy parameters and technological innovations; policy parameters and the capacity of fixed assets; and policy parameters and environmental protection investment.

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