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Integrated planning for mitigating CO_2 emissions in Taiwan: a multi-objective programming approach

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Abstract

In this paper, a multi-objective programming approach integrated with a Leontief inter-industry model is used to evaluate the impact of energy conservation policy on the cost of reducing CO_2 emissions and undertaking industrial adjustment in Taiwan. An inter-temporal CO_2 reduction model, consisting of two objective equations and 1340 constraint equations, is constructed to simulate alternative scenarios consisting of Case I (no constraint on CO_2 emissions), Case II (per capita CO_2 emissions at Taiwan year 2000 levels, i.e. 9.97 t), Case III (Case II emission levels with energy conservation), and Case IV (Case II emission levels with energy conservation plus improved electricity efficiency). The empirical results show that the cost of reducing CO_2 emissions in Cases II, III, and IV is US$404, US$376 and US$345 per t, respectively. Some policy implications are also elaborated upon in order to assist decision makers with relevant planning. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

The issue of global warming has been a foremost concern of the international community since the enactment of the COP III Kyoto Protocol in December 1997. Although Taiwan is not a member of the Annex I signatory countries, according to the experience of the Montreal Protocol of 1988, the enforcement of such international regulations will affect Taiwan's economic development. In other words, Taiwan has to be prudent in evaluating the potential impact of mitigating CO_2 emissions on its economic growth and industrial structure.

The purpose of this study is to simulate the cost of reducing CO_2 emissions in Taiwan and to formulate appropriate strategies for the government. In order to achieve this objective, multi-objective programming coupled with an input–output model covering inter-temporal periods is constructed to evaluate the cost of reducing CO_2 emissions for the Taiwan economy as a whole. Empirical data is collected and various scenarios for mitigating industrial CO_2 emissions are simulated. Based on the simulations, the cost of reducing CO_2 emissions is estimated. Finally, some policy suggestions are put forward.

2. Literature review

A review of the literature relating to the current model developed in this paper is first undertaken as follows: Hafkamp and Nijkamp (1982) developed a multi-objective programming approach and applied it to the issue of integrated resource planning. They also argued that a single-objective approach cannot evaluate social welfare changes accurately. Nijkamp (1986) conducted multi-objective techniques to discuss the policy impact of resource allocation, whilst in the programming model on the mitigation of CO_2 emissions, Manne and Richels (1991) provided a Global 2100 model to estimate the costs and benefits of controlling or decreasing CO_2 emissions for the USA. Fells and Woolhouse (1994) established an optimization model to simulate the impact of mitigating CO_2 emissions on economic growth in the UK. Rose and Steven (1993) used a non-linear programming model to estimate the net welfare changes of alternative strategies for the mitigation of CO_2 emissions in eight countries.

In the studies applying to the case of Taiwan, Hsu *et al.* (1987) utilized the NISE (Non-Inferior Set Estimation)

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method, which is a bi-criterion model for evaluating the trade-off between energy use and economic growth in Taiwan. Hsu and Chen (1997) adopted the center-point method, which is one of the multi-objective programming models to evaluate the relationship between economic growth and CO_2 emissions. The cost of CO_2 emissions were also estimated. Chang and Juang (1998) constructed a fuzzy multi-objective programming approach for estimating the compromised solution among energy use, economic development and the emission of CO_2. Hsu and Xu (1998) conducted a similar fuzzy multi-objective programming method with three objectives, i.e., per capita GDP, per capita CO_2 emissions, and national employment. In contrast to these studies, this paper employs the constraint method elaborated in Hsu (1994), as shown in the following model.

3. The model

The model for the problem to be solved has 33 economic sectors with two objective equations and 1340 constraint equations stated as

3.1. Objective functions

$$Max\ Z_1 = \sum_t (1+\rho)^{-t} \sum_n (V_{t,n} * X_{t,n}),$$

$$Min\ Z_2 = \sum_n co2p_n * X_{2020,n}.$$

3.2. Constraint functions

1. inter-temporal inter-industry constraints

$$(I - A + M) * X_{t+1} \geqslant (I - A + M) * X_t \geqslant \underline{F}.$$

2. water resource constraints

$$\sum_n w_n^j * X_{t,n}^j \leqslant W^j; \quad j = 1,2.$$

3. total labor constraints

$$\sum_n (l_n^i * X_{t,n}) \leqslant \sum_n (l_n^i * X_{1994,n}) * (1+\gamma_n^i)^t * \bar{B} \quad i = 1,2.$$

4. labor constraints for each industry

$$LQ94_n^i * (1+\gamma_n^i)^t * \underline{b} \leqslant l_n^i * X_{t,n} \leqslant LQ94_n^i * (1+\gamma_n^i)^t * \bar{b},$$

$$i = 1,2.$$

5. industrial expansion constraints

$$X_{t-1,n} * ep_L \leqslant X_{t,n} \leqslant X_{t+1,n} * ep_U.$$

6. non-negative constraints

$$X_{t,n} \geqslant 0.$$

$V_{t,n}$: coefficients of value-added of each industry in t period

$X_{t,n}$: output value of each industry in t period
ρ: discount rate (preset at 0.05)
CO_2p_n: coefficients of CO_2 emission of each industry
t: periods ($t = 1, \ldots, 5$)
n: each industry ($n = 1, \ldots, 33$)
I: identity matrix
A: input coefficient matrix
M: import coefficient matrix
$F_{1994,n}$: final demand vector of each industry in 1994
$X_{1994,n}$: output value of each industry in 1994
w_n^j: water coefficients of each industry (index j for agriculture and non-agriculture; $j = 1, 2$)
W^j: water supply upper bound (index j for agriculture and non-agriculture; $j = 1, 2$)
l_n^i: labor coefficients of each industry (index i for skilled and non-skilled labor; $i = 1, 2$)
γ_n^i: growth rates of employment in each industry
$LQ94_n^i$: actual employment in each industry in 1994
$ep_{L(U)}$: industry expansion lower (upper) bound
$\bar{B}$: total labor expansion upper bound
b: labor employment expansion bound
$\underline{F}$: industry expansion lower bound

The method of estimating the amount of CO_2 emitted in the production process of each industry is measured in terms of energy usage, given that the consumption of energy times the coefficient of each energy type is equivalent to the amount of CO_2 emitted. From the heat unit of energy balance of 1994 table, we can obtain the consumption quantity of each type of energy, including coal, petroleum, natural gas and electricity. By applying the carbon-stored coefficient provided by IPCC, we can derive the amount of CO_2 emissions of each industry. By utilizing the ratio of the output value of each industry, we can further derive the CO_2 coefficient. It is important to note that the environmental costs of CO_2 emissions should not be wholly born by the electricity industry, but, for the sake of fairness, should be shared by each industry in proportion to its consumption of electricity. Otherwise, electricity-intensive industries would be effectively exempted from shouldering the environmental costs of CO_2 emissions. Furthermore, the amount of CO_2 emissions per kwh is calculated in accordance with the amount of CO_2 emissions resulting from the actual consumption of fuels in power generation. Therefore, the alternatives to reducing CO_2 emissions include the promotion of energy conservation and improvements in the efficiency of power generation. These alternatives will later be explored in detail for empirical scenario analysis.

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