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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.

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)
$CO_2 p_n$: 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.

4. Empirical studies

In order to provide a basis for the comparison of CO_2 emission scenarios, we first estimate the future GDP annual growth rate for Taiwan as follows: for the period 1996–2000, GDP growth will be 6.2%; for 2005–2010, 5.1%; for 2010–2015, 4.4%; and for 2015–2020, 3.5%. These figures are set as the upper bounds of the economic growth rate, or BAU (business as usual). Then, we set 2020 as the year when the amount of CO_2 emissions should be reduced to year 2000 levels, i.e., $249{,}509 \times 10^3$ t (9.97 t per head $\times 25{,}026 \times 10^3$). The population figures are derived from the mid-range estimates of the Council for Economic Planning and Development (*CEPD) in 1997. As for measuring energy conservation based on the government's initiative, the following industries achieved an energy conservation rate of 10% from 1990–1998: food, paper and printing, plastic products, non-metallic mineral products, iron and steel, road construction, internal navigation, and aviation. By simulating 10% energy conservation for the above-mentioned industries up to 2020, we can recalculate GDP and CO_2 emissions figures, which are then compared to the BAU case. This is termed the energy conservation case. In addition to this case, we further simulate an energy conservation as well as an electricity efficiency improvement case; this means that, apart from energy conservation, the efficiency of power generation will be improved such that CO_2 emissions per kwh of electricity will be reduced by 10%.

5. Results and policy implications

By utilizing the multi-objective programming model previously developed, we can infer the following results from the above four scenarios.

Case I (BAU case): In 2020, the industrial sectors will dominate the GDP structure in Taiwan (see Table 1). Basic manufacturing will occupy 13.88% of GDP; the technology industry's share of GDP will have increased from 8.67% in 1994 to 10.88% and that of the energy industry from 3.65 to 9.53%. Meanwhile, traditional industries' share of GDP will have decreased from 9.40% in 1994 to 6.22%, and that of the service sector from 57.65 to 47.95%. Under the simulated planning for economic development, the above is the most likely scenario for Taiwan's industrial structure for the year 2020 without CO_2 emission controls.

Case II (CO_2 emission control case): With the control of CO_2 emissions to be set at year 2000 levels, the GDP average annual growth rate in 2020 will decrease to 3.29%, and the inter-industry structure will undergo a significant change. In particular, the GDP output value of industry as a whole will decrease tremendously, while that of the service sector will increase to 65.07%. This indicates that under the mitigation of CO_2 emissions, the

Table 1
Alternative scenarios for GDP estimation Unit: 10^6US$

			1994 GDP		Case I		Case II		Case III		Case IV	
Sectors			Actual	%	2020 GDP	%	2020 GDP	%	2020 GDP	%	2020 GDP	%
Agriculture			7537	3.92	11 760	1.79	12 444	2.79	12 444	2.70	12 444	2.61
Industry	Manufacturing	Basic	24 945	12.97	91 137	13.88	34 434	7.72	35 390	7.68	35 676	7.48
		Technology	16 668	8.67	71 447	10.88	48 952	10.98	53 646	11.64	55 548	11.65
		Traditional	18 068	9.40	40 828	6.22	28 272	6.34	28 665	6.22	952 595	6.05
	Energy		7017	3.65	62 599	9.53	19 829	4.45	19 890	4.32	20 648	4.33
Transportation			7196	3.74	64 006	9.75	11 829	2.65	12 082	2.62	16 758	3.52
Service			110 850	57.65	314 884	47.95	290 159	65.07	298 700	64.82	306 813	64.35
Total			192 284		656 662		445 923		460 819		476 756	
Average growth rate (1994–2020)						4.84		3.29		3.42		3.55

Table 2
CO_2 reduction cost estimation unit: US$/ton

	Case II	Case III	Case IV
Based on the difference between the Base Case and Alternative Case	404	376	345

Table 3
CO_2 reduction cost estimation for each industry *unit: US$/ton

Sector			Case II US$/ton	Case III US$/ton	%	Case IV US$/ton	%
Agriculture			2256	3852	70.72	3852	70.72
Industry	Manufacturing	Basic	287	288	0.29	282	− 1.70
		Technology	5447	4231	− 22.33	3995	− 26.65
		Traditional	254	244	− 4.04	229	− 9.96
	Energy		716	700	− 2.20	709	− 1.05
Transportation			256	257	0.24	235	− 8.26
Service			3488	1538	− 55.90	963	− 72.39
Total			404	376	− 7.07	345	− 14.63

industrial sectors will be severely confined, and thus their GDP output value will greatly decline. In the industrial sector, the impact will be greatest on basic manufacturing, the output share of which will drop from 13.88% in 1994 to 7.72% by 2020, followed by the energy sector, the output share of which will drop from 9.53% in 1994 to 4.45%. This means that the steel, petro-chemical, coal and petroleum refinery, and electricity industries will be severely restricted, and their GDP output reduced. On the other hand, the GDP output share of the service sector will rise from 47.95% to 65.07%.

Case III (energy conservation case): In this case, the GDP output level will reach US$460,819 million by 2020. The technology industry will benefit most from Case III, with its GDP output share increasing from 10.98% in 1994 to 11.64% in 2020. Then again, the GDP output share of the service industry will decrease from 65.07 to 64.82% in this case.

Case IV (energy conservation plus electricity efficiency improvement case): In this case, the output share of the transportation industry will grow from 2.65% as in Case II to 3.52% in 2020, and that of the technology industry from 10.98% to 11.65%. On the other hand, the GDP output share of basic manufacturing will drop from 7.72 to 7.48%, and that of traditional industries from 6.34 to 6.05%.

Based on Case I, we can calculate the CO_2 reduction costs for each policy alternative, as shown in Table 2. It should be noted that CO_2 reduction costs in the controlled case are larger than those of the conservation and efficiency cases; CO_2 reduction costs in case II are US$404 (USD : NTD = 1 : 33) per t. In Case III, reduction costs are US$376, which is 7.07% less than in case II. Alternatively, in Case IV, CO_2 reduction costs are US$345, which is 14.63% less than in Case II. Table 3 provides information concerning CO_2 reduction costs for each industry. Obviously, the reduction costs for high value-added industries, such as the technology or service industries, are notably greater than average reduction costs across industries. This shows that through energy conservation, the reduction costs of the technology industry can be curtailed by 22.33%, while those of the service industry can be curtailed by 55.90%. In case IV, the reduction costs of the service industry can be curtailed by 72.39%. The reduction costs of the transportation industry do not vary much due to energy conservation; however, they still drop to 8.26% in Case IV. In contrast, reduction costs for the agricultural industry increase to 70.72%. In short, through energy conservation and electricity efficiency improvement, the impact of reducing CO_2 emissions on industry as a whole will be abated. Therefore, we can conclude that energy conservation and electricity efficiency improvement are effective measures for mitigating the impact of reduced CO_2 emissions.

6. Conclusion

The purpose of this paper is to utilize mutli-objective programming and input–output approaches to evaluate CO_2 emission reduction costs in Taiwan, and to assess the impact of CO_2 mitigation on industrial adjustment. Through mutli-objective programming, we explore policy alternatives for better resource allocation under the conflicting interests of economic growth and environmental protection. The results of our simulation suggest that in the year 2020, with CO_2 emissions constraints in place, the economic growth rate in Taiwan will fall from 4.84 to 3.29%, and the focus of the inter-industrial structure will shift from the industrial sector to the service sector. In other words, the GDP output share of the energy-intensive industries in the industrial sector will be greatly diminished. However, through energy conservation, specific industries, such as the technology and service industries are projected to show a 3.42% increase in their growth rates. Moreover, by improving the efficiency of power generation by 10%, the average annual growth rate can further increase to 3.55%.

As for CO_2 reduction costs, in the CO_2 emissions control case (Case II), the reduction costs will be US$404 per t of CO_2. With the energy conservation of specific industries mentioned above, the reduction costs will be US$376 per t of CO_2, which is approximately 7.07% less than in Case I. What is more, with 10% efficiency improvements in power generation, i.e. case IV, CO_2 reduction costs will be further reduced to US$345, which is approximately 14.63% less than case I. Hence, the government should take appropriate steps, such as tax exemption, in order to encourage industrialists to install energy-saving equipment and to utilize energy more effectively. Such measures would prove useful in softening the impact of CO_2 emission controls on Taiwan industry as a whole.

It should be acknowledged that the empirical results derived in this paper are subject to several restrictions. The model employed in this paper is a linear programming model, and it cannot avoid every potential weakness embedded in linear programming models. For instance, programming models are more suitable to the planned economy system than to the free market system. Also, programming models cannot trace the changing paths of planned systems when policy instrument change or system parameters alter. They can only trace the optimal path under a predetermined system. In addition, the "penny switching problem" also remains unsolved in programming models. That is, if the cost of technique M is slightly cheaper than the cost of technique N (say, one penny), the solution of the programming model will totally substitute technique M for technique N. This may not be the case in reality. Whatever kind of policy or strategy is finally implemented, in reality will probably implicate a trade-off between economic efficiency and its social-political acceptability. Furthermore, the linear programming model does not perfectly describe the nonlinear environments found in the real world, including the fixed coefficient of carbon emissions. Finally, the input data adopted in the model can never be perfect, and the model itself is simplified in several respects. For example, the technical coefficient of energy sectors in the input–output table is based on the monetary unit in our model, which may change the derived results when the wholesale price index or the exchange rate in an economy varies significantly.

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