



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*



CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH

THE IMPACT OF
MITIGATING CO₂ EMISSIONS ON
TAIWAN'S ECONOMY

GEORGE J. Y. HSU
TSER-YIETH CHEN

DISCUSSION PAPER SERIES No. 9703

August 1997



財團
法人 中華經濟研究院

CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH
75 Chang-Hsing St., Taipei, Taiwan, 106
Republic of China
TEL: 886-2-735-6006
FAX: 886-2-735-6035

ISBN 957-9676-32-1

Discussion papers are intended to provide prompt distribution of CIER's preliminary research work to interested scholars and to invite their discussions and critical comments.

The opinions expressed in these papers are those of the authors and do not necessarily reflect the views of the CIER.

Any comment or communication, please write to: Publications Department, Chung-Hua Institution for Economic Research, 75 Chang-Hsing Street, Taipei, Taiwan 106, ROC.



CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH

THE IMPACT OF
MITIGATING CO₂ EMISSIONS ON
TAIWAN'S ECONOMY

GEORGE J. Y. HSU
TSER-YIETH CHEN

DISCUSSION PAPER SERIES No. 9703

August 1997



財團
法人 中華經濟研究院

CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH
75 Chang-Hsing St., Taipei, Taiwan, 106
Republic of China
TEL : 886-2-735-6006
FAX : 886-2-735-6035

ISBN 957-9676-32-1

Discussion papers are intended to provide prompt distribution of CIER's preliminary research work to interested scholars and to invite their discussions and critical comments.

The opinions expressed in these papers are those of the authors and do not necessarily reflect the views of the CIER.

Any comment or communication, please write to: Publications Department, Chung-Hua Institution for Economic Research, 75 Chang-Hsing Street, Taipei, Taiwan 106, ROC.

Discussion Paper Series No. 9703

**The Impact of Mitigating CO₂ Emissions
on Taiwan's Economy**

by

George J. Y. Hsu

*Director, Center for Energy and Environmental Studies
Chung-Hua Institution for Economic Research*

Tser-yieth Chen

*Associate Research Fellow
Chung-Hua Institution for Economic Research*

August 1997

Chung-Hua Institution for Economic Research

75 Chang-Hsing St., Taipei, Taiwan 106

Republic of China

1000

1000

1000

1000

1000

1000

1000

1000

1000

1000

George J. Y. Hsu and Tser-yieth Chen *

The Impact of Mitigating CO₂ Emissions on Taiwan's Economy

Abstract

A computationally multi-objective programming approach and a Leontief interindustry model is used to investigate trade-off between national GDP and CO₂ emissions in Taiwan. Based on the empirical findings of the model, the impact of mitigating CO₂ emissions on Taiwan's economy is evaluated. The results show that Taiwan's GDP will drop 34% of the targeted GDP in 2000 and Taiwan's economy will be much weakened if the government stabilizes annual CO₂ emissions at the 1990 level. When we relax CO₂ emissions up to 128% of the 1990 level, Taiwan's economy will be able to maintain a 5.37% average annual growth rate up to year 2000; a 157% CO₂ emission level for a 5.92% annual GDP growth rate; and a 213% CO₂ emission level for a 6.85% annual GDP growth rate. Finally, policy implications are discussed in order to aid policy makers in economic planning.

Keywords: greenhouse effect, economic development, multi-objective programming, interindustry analysis

*Director and Associate Research Fellow, Center for Energy and Environmental Studies, Chung-Hua Institution for Economic Research, 75 Chang-Hsing Street, Taipei, Taiwan 106, ROC. Tel: 886-2-7356006, Fax:886-2-7390533.

I. Introduction

There is growing concern that increasing accumulation of carbon dioxide is leading to undesirable changes in the global climate, such as the greenhouse effect. This has resulted in proposals to get physical targets for reducing emissions of CO₂. In June 1992, the Framework Convention on Climate Change (FCCC) was signed in Rio de Janeiro by more than 150 countries to promote international cooperation for achieving such reductions. They officially addressed an international target to stabilize CO₂ emissions at the 1990 level by the year 2000 among the 36 Annex I Countries. The second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) approved December 1995 recognized global CO₂ emissions should be less than 50% of current levels to stabilize CO₂ atmospheric concentrations, and Annex I Countries should make an effort to limit and reduce their emissions within a given time frame.

International trade plays a critical role in Taiwan's economy. Therefore, Taiwan must pay close attention to the issue of global environmental change. By the end of 1996, total CO₂ emissions in Taiwan were 171 10⁶ tons. Projected CO₂ emissions in 2000 will reach 236 10⁶ tons, which is 203% of the 1990 level (116 10⁶ tons). From 1990 to 2000, the average growth rate of CO₂ emissions will be 7.1%. This shows that the possibility of stabilizing Taiwan's CO₂ emissions at the 1990 level by the year 2000 is not optimistic. The Taiwan government may initiate relevant policy actions in the foreseeable future to fulfill its global responsibility in reducing production of CO₂ which contributes to the greenhouse effect. With this in mind, it is important to understand the current progress of advanced countries in implementing such policy actions and to simulate the impact of domestic measures to reduce greenhouse CO₂ emissions on Taiwan's economy.

The purpose of this study is to simulate the impact of mitigating CO₂ emissions on Taiwan's industrial development and to formulate appropriate strategies for the government. In order to achieve this objective, relevant literature is first reviewed. Next, a multi-objective programming coupled with an input-output model is constructed to evaluate the economic impact of reducing CO₂ emissions on the Taiwan economy as a whole. Empirical data is

collected and various strategies for mitigating industrial CO₂ emissions are simulated. Based on the simulation, policy implications are also recommended.

II. Literature Review

There is a lot of literature utilizing mathematical programming methods for planning resource and environmental issues. Some of these are reviewed below. Loucks (1975) addressed multi-objective programming in essence within resource utilization and economic development decisions, with each objective being a trade-off itself. 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 the social welfare changes accurately. Nijkamp (1986) conducted multi-objective techniques to discuss the policy impact of resource allocation. Nordhaus (1991) and Morrison and Brink (1993) presented two surveys to reveal the economic costs of mitigating climate change.

As to the programming model on the mitigation of CO₂ emissions, four papers are reviewed here. First, Manne and Richels (1991) provided a Global 2100 model, which is a programming analysis, to estimate the costs and benefits of controlling or decreasing CO₂ emissions for the USA. Fells and Woolhouse (1994) established an optimization model to simulate the impact of mitigating CO₂ emissions on economic growth in the UK. Rose and Stevens (1993) used a non-linear programming model to estimate net welfare changes of alternative strategies for the mitigation of CO₂ emissions for eight countries. Finally, Rose (1995) employed a linear-programming model to simulate reduction in GDP from five proposals for mitigating CO₂ emissions in Mainland China.

III. The Model

In this study, multi-objective programming coupled with an input-output model is presented to determine the trade-off between GDP growth and CO₂

emissions in Taiwan. There are three reasons for setting up such an approach. First, multi-objective programming focuses on resource allocation, i.e., to decide what the economy should be. Multi-objective analysis can seek to derive trade-offs between economic and environmental objectives subject to constraints. Second, the multi-objective approach is superior to the conventional single-objective method. It emphasizes the range of choices associated with a decision. The decision makers themselves can judge the relative values of objectives and find the "best" possible values under the given conditions (Zeleny, 1982). Third, the merit of the multi-objective method is that it avoids the issues of econometric modeling, like heteroscedasticity, autocorrelation, multicollinearity, etc. The model for the problem to be solved is stated as:

$$\begin{aligned}
 \text{Max} \quad & Z=(\text{GDP, CO}_2 \text{ emissions}) \\
 & =(G(X), -C(X)) \\
 & =(VX, -CX) \\
 \text{s.t.} \quad & F_{1994}^d \leq (I-A+M)X= F_{2000}^d \\
 & X \leq X_u \\
 & X \geq X_L \\
 & WX \leq W_{\max} \\
 & LX \leq L_{\max}
 \end{aligned}$$

where GDP is gross domestic product. V represents $1 \times n$ vector of direct income coefficients, i.e., ratio of sectoral value-added to total sales for each sector, and n represents 33 industrial sectors. C is $1 \times n$ vector of CO_2 emission coefficients, i.e., the ratio of total CO_2 emissions of energy used for each sector. X means $n \times 1$ vector of sector output, i.e., the dependent variables of this model. I is $n \times n$ unit matrix, A is $n \times n$ matrix of technical coefficients and M is $n \times n$ diagonal matrix of import coefficients. F_{2000}^d and F_{1994}^d represents $n \times 1$ vector of the 2000 and 1994 levels of final demand. In addition, X_u and X_L are $n \times 1$ vector of projected upper and lower limits of production level of each sector in the year 2000. W is $1 \times n$ vector of water utilization coefficients, ratio of water utilization to total water supply for each

sector and W_{\max} is the maximum resource limit of the water supply. L means $2 \times n$ matrix of labor input coefficients, i.e., ratio of labor employed to total sales for each sector (two types of labors were measured, i.e., technical and non-technical labor) and L_{\max} is 2×1 vector of the two-type labor employed.

In this model, $G(x)$ is the objective of maximizing GDP and $C(X)$ is the objective of minimizing CO₂ pollution. $C(X)$ is multiplied by -1 because CO₂ emissions are to be minimized. The first constraint set is derived from the relationship $X-AX+M=F$, or $X+MX=AX+F$, which indicates that the sum of domestic output and importation in each industry sector (which is total supply) must be equal to the intermediate requirement by other sectors and the final demand sector (which is total demand). And the level of each final demand sector in year 2000 can not be less than that in year 1994. This is a general equilibrium restriction. The second and the third constraint sets limit each sector to a specified upper bound of capacity expansion and a lower bound of depressed scale. The last two constraints are the water supply and labor supply constraint conditions, respectively.

IV. Empirical Results

Empirical data in the model includes the 1994 input/output table, the 1996 energy balance table, and other related information such as GDP, CO₂ emissions, population, and import/export figures, etc. These data are run by the above model and year 2000 is the planning year. The empirical results are summarized as follows.

First, we proceed with an internal simulation to verify the performance of the model and find that this model has a good explanation ability and forecast performance. The empirical results show that the simulated domestic total output of 1994 is NT\$ 13,621 billion, which is very close to the actual domestic total output, 13,633 billion (the gap of estimation difference is only 0.05%). For the 1994 production level, the model shows that the simulation GDP in 1994 is also very close to the actual GDP in 1994 (i.e., NT\$ 6,345 billion vs. NT\$ 6,376 billion). We then judge that the model is accurate. Furthermore, the simulated GDP in 1996 is NT\$ 7,462 billion, and the actual GDP is NT\$ 7,492. Note that we estimate the CO₂ emissions (no restrictions)

in the year 2000 will be $249 \cdot 10^6$ tons, representing 213% of the emissions in 1990.

Next, the objectives of the model as stated in the previous section are to maximize GDP and minimize CO_2 emissions. Each objective space for a dimension (axis) and together form an objective space, as shown in Figure 1. Our solutions are then obtained by optimizing each objective individually. The maximum GDP for the year 2000 is NT\$ 9,918 billion (point D in Figure 1) and the corresponding GDP annual growth rate is 6.85%. This result is very similar to the forecast results from the Council for Economic Planning and Development; CEPD (6.7%) and the estimated GDP (NT\$ 9,670 billion). Of course, at this production level, the corresponding CO_2 emissions are $249 \cdot 10^6$ tons as mentioned above. This is the first non-inferior solution we obtained.

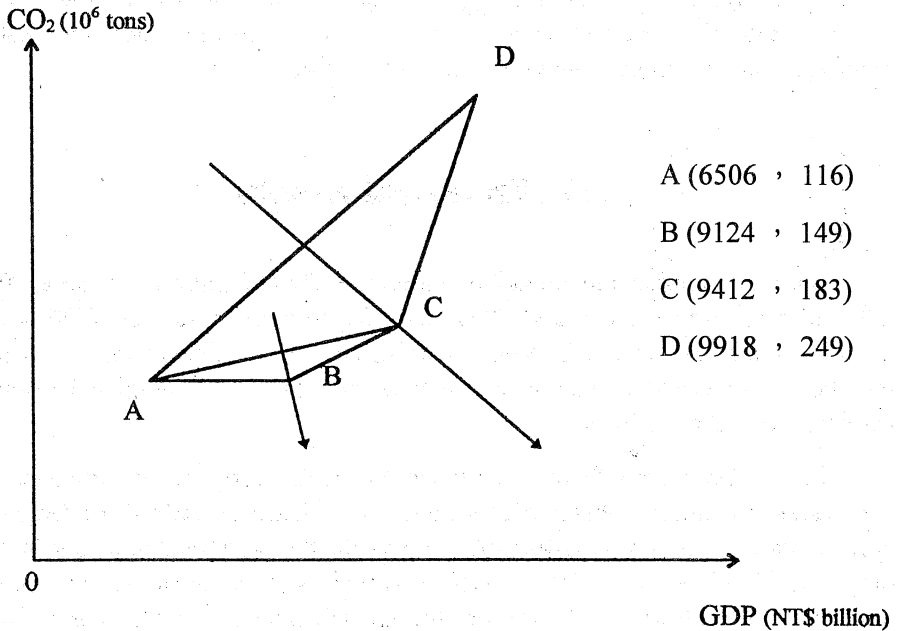


Figure 1 Non-inferior Solutions of the Center-point Method in the Objective Space

On the other hand, minimizing CO₂ emissions is the second objective (NT\$ 6,506 billion GDP in 2000 with a corresponding 116 10⁶ tons of CO₂ emissions in 1990). This represents another non-inferior solution (point A in Figure 1). Based on the solution of minimum CO₂ emissions, we can determine that Taiwan's GDP in 2000 will drop to NT\$ 6,506 billion (65.6% of NT\$ 9,918 billion) and total domestic output will be NT\$ 12,765 billion. Taiwan's economy will be seriously weakened if the government pursues a policy of minimizing CO₂ emissions. The annual growth rate would be -0.40% which is significantly lower than that of the government's target of greater than 6%. Here we note that zero GDP growth is not realistic, not to mention negative growth. In addition, the ideal point is no CO₂ emissions and a maximum level of GDP. This, of course, can never be realized. Note that there is a constant percentage relationship between relaxing CO₂ emissions and the impact on GDP. If we relax CO₂ emissions up to 120% and 140%, the GDP level in 2000 will decrease to NT\$ 8,933 and NT\$ 9,848 billion, respectively. It represents 90.0% and 99.3% of NT\$ 9,918 billion and the economic growth rate would be 5.01% and 6.72%, respectively. This shows that the higher the regulation of CO₂ emissions, the stronger the impact on the economy. Furthermore, Taiwan's economy will show no deterioration when we relax CO₂ emissions up to 170% (197 10⁶ tons).

The solving algorithm we employed in this paper is the "center-point" method which was first developed by Hsu and Tzeng (1992). We derive that there are four non-inferior solutions (Table 1) which match the derived points A(6516, 116), B(9124, 149), C(9412, 183), D(9918, 249) as shown in Figure 1. These solutions represent the production levels of all the economic sectors in Taiwan and from the non-inferior solutions A, B, C, and D. We can find that NT\$ 2,618 billion of GDP will trade off 33 10⁶ tons CO₂ emissions (between point A and B); NT\$ 288 billion of GDP will trade off 34 10⁶ tons CO₂ emissions (between point B and C); NT\$ 506 billion of GDP will trade off 66 10⁶ tons CO₂ emission (between point C and D). Please note that solution D is an aggressive policy, solution A is a conservative policy, and solution B and C are moderate policies. In solution A, one can attain the target of maintaining Taiwan's CO₂ emissions at the 1990 level by the year 2000, while the economy has an average -0.40% annual GDP growth. This would be unacceptable to the government. On the other hand, in solution D, with NT\$ 9,918 billion GDP represents a rapidly growing economy, showing an average of 6.85% GDP growth. If the government

chooses an economic policy like solution D, abundant CO₂ emissions (249 10⁶ tons) would be produced and this would be unacceptable to the IPCC. In addition, solution C is similar to solution D. They can reach 5.92% of annual GDP growth and represent a relatively prosperous economy which only has an impact on the economy of 5% or less. However, the corresponding CO₂ emissions are still high, i.e., 183 10⁶ tons (157% of the emissions in 1990). This implies that if Taiwan's government chooses this solution, rather difficult intra-country negotiations are needed. Finally, solution B is a good compromise strategy that Taiwan's government could adopt. The reason is Taiwan's estimated GDP in 2000, in this case, would only decrease to NT\$ 9,124 billion (91.9% of NT\$ 9,918 billion) and have 149 10⁶ tons of CO₂ emissions in 2000 (128% of the emissions in 1990). Taiwan's government can make an effort to reach the above target by offering enough financial incentives to encourage investment activities related to CO₂ mitigation and energy-saving matters. As elaborated here, value judgments on the alternative choices in multi-objective generating techniques should not be made by the analyst, but by the decision maker after generating the model and analyzing its policy implications. Therefore, we do not make conclusions or recommendations about which policy alternative should be adopted. Policy makers should do this based on their implicit or explicit preferences. In the process of economic and industrial planning, the managerial role of the government should be taken into account. The economy could perform better if government were appropriately involved. However, one point should be kept in mind, i.e., solutions and conclusions of this type of model imply an "optimum" which is generally "better" than the real situation. In reality, the economy may always perform less than the optimum due to poor management or unmanageable factors. The conclusions arising from these empirical findings imply the direction of government efforts towards a better situation.

In this study, we find CO₂ emissions have a significant mitigating impact on Taiwan's economy. One of the reasons is that there is a high income elasticity of energy in Taiwan. Taiwan's average income elasticity of energy is projected to be 0.94 (1990-2006), which is very close to unity and higher than that of countries of similar economic development like Israel and New Zealand. This implies GDP growth in Taiwan was almost equivalent to energy use. Under the given figure of the coefficient of CO₂ emissions, if

Table 1 Estimated Results of Four Non-inferior Solutions for the Taiwan Economy
unit: NTS billion ; %

Sector	1994 GDP		Solution A		Solution B		Solution C		Solution D	
	GDP	Growth	GDP	Growth	GDP	Growth	GDP	Growth	GDP	Growth
1. Agriculture	176.4	219.4	3.70	179.5	0.29	186.6	0.94	199.0	2.03	
2. Fisheries	55.3	36.9	-6.51	36.9	-6.51	66.5	3.13	58.2	0.87	
3. Other Minerals	29.0	19.3	-6.51	22.9	-3.83	22.5	-4.12	43.9	7.15	
4. Food Products	159.9	106.8	-6.51	216.2	5.15	216.2	5.15	181.9	2.17	
5. Fabrics & Apparel	178.2	119.0	-6.51	132.2	-4.86	317.4	10.10	264.3	6.78	
6. Products of Wood & Bamboo	30.5	20.3	-6.51	41.2	5.15	41.2	5.15	40.2	4.71	
7. Paper Industry	94.2	71.7	-4.43	103.9	1.66	108.4	2.38	128.8	5.35	
8. Chemical Raw Materials	54.1	38.7	-5.40	44.9	-3.03	65.9	3.36	81.2	7.01	
9. Artificial/ Chemical Fabrics	32.8	21.9	-6.51	22.9	-5.79	58.5	10.09	48.6	6.77	
10. Plastic	33.2	25.5	-4.32	26.9	-3.43	42.4	4.15	50.6	7.28	
11. Plastic Products	96.0	90.6	-0.95	90.6	-0.95	171.0	10.10	146.7	7.32	
12. Other Industrial Chemicals	69.2	47.8	-5.96	67.3	-4.45	73.0	0.92	99.0	6.17	
13. Cement	93.8	62.6	-6.51	73.0	-4.08	72.0	-4.30	143.7	7.38	
14. Steel & Iron	104.5	70.3	-6.38	94.2	-1.70	79.5	-4.45	163.8	7.79	
15. Other Metals	23.5	16.5	-5.62	19.7	-2.80	18.3	-4.00	39.6	9.13	
16. Metallic Products	113.2	75.8	-6.45	90.3	-3.70	86.1	-4.44	178.2	7.86	
17. Machinery	111.5	74.4	-6.51	78.3	-5.72	78.6	-5.64	176.6	7.97	
18. Electronic/ Electrical Products	303.8	231.5	-4.42	243.4	-3.62	241.0	-3.78	567.9	10.99	
19. Transport Equipment	161.3	107.7	-6.51	287.3	10.10	110.8	-6.06	240.1	6.85	
20. Other Manufactures	68.2	45.5	-6.51	47.8	-5.73	48.8	-5.40	100.9	6.76	
21. Construction	318.3	212.5	-6.51	238.7	-4.68	240.0	-4.60	486.3	7.32	
22. City Water	17.9	13.7	-4.32	17.1	-0.76	17.1	-0.79	39.3	13.95	
23. Land Transportation	152.2	110.2	-5.24	131.1	-2.45	195.4	4.25	235.1	7.51	
24. Water Transportation	47.5	31.7	-6.51	90.4	11.33	90.4	11.33	75.2	7.97	
25. Air Transportation	49.2	33.4	-6.23	35.5	-5.27	35.7	-5.18	117.0	15.55	
26. Communications	203.2	386.9	11.33	231.3	2.18	236.6	2.57	312.2	7.42	
27. Wholesale & Retail Trade	873.6	1538.2	9.89	1538.2	9.89	1538.2	9.89	1295.4	6.79	
28. Finance & Insurance	477.4	893.9	11.02	893.9	11.02	893.9	11.02	732.9	7.41	
29. Misc. Services	2294.1	1598.1	-5.85	3795.8	8.76	3795.8	8.76	3232.5	5.88	
30. Coal Products	4.5	3.4	-4.47	4.4	-0.30	4.7	0.57	7.2	8.06	
31. Petroleum Refining Products	95.4	70.6	-4.89	87.4	-1.45	100.1	0.80	212.4	14.27	
32. Natural Gas	3.7	2.4	-6.51	3.3	-1.84	3.3	-1.78	5.4	6.48	
33. Electricity	139.0	106.7	-4.31	135.6	-0.41	154.5	1.78	212.4	7.32	
Total GDP and Average Growth Rate	6665.1	6505.6	-0.40	9123.8	5.37	9412.0	5.92	9917.9	6.85	
CO ₂ Emission Percentage to Year 1990	116 10 ⁶ ton	100.00%	128.31%	91.99%	156.70%	94.90%	100.00%	213.45%		
GDP Ratio to Target Year 2000	9917.9	65.59%								

we want to limit energy consumption to reduce CO₂ emissions, it will weaken GDP growth proportionately in Taiwan. This also can be illustrated by the fact that energy-intensive industries have a massive weight in Taiwan's industrial structure. The cement, steel, paper and chemical industries make up more than one-third of industrial GDP and these energy-intensive industries have played a critical role in the economic development of Taiwan. On the other hand, total CO₂ emissions in 1990 were 171 10⁶ tons; of which, 54% came from the manufacturing sector, 17% from the transportation sector, and 10% from the residential sector. In the manufacturing sector, chemical (16.2%), steel (12.9%), and cement (6.7%) were the top three industries "contributing" to CO₂ emissions. There are three reasons. One, the steel industry uses coal in its manufacturing processes. Two, the chemical industry is a high petroleum-intensity industry and utilizes a lot of energy. Three, the cement industry is also an energy-intensive industry. If we adopt CO₂ emission regulations, it will significantly influence coal- and oil-related industries. Furthermore, we can set up several policy alternatives to simulate the above findings. There are three kinds of policies: energy conservation, increasing the power supply ratio of cogeneration, and using more natural gas instead of petroleum and coal. It is worth conducting a further study to illustrate this issue in the near future.

Note that if we adopt the indicator of per capita CO₂ emissions, we find that the impact of CO₂ emissions will be lessened. The main reason is Taiwan has a relatively high population (22 million) among those countries which have similar CO₂ emissions. Empirical results show that Taiwan's GDP in 2000 will decrease to NT\$ 7,708 billion (77.7% of solution D's NT\$ 9,918 billion). The figure (77.7%) is slightly larger than that of the CO₂ emissions case mentioned above (65.6%). We also estimate that there will be 10.62 tons/person of CO₂ emissions in 2000. It represents 185% of the emissions in 1990 (5.74 tons/person). Similarly, we can also estimate a compromise solution like B. Taiwan's estimated GDP in 2000, in this case, will only decrease to NT\$ 9,293 billion (93.7% of NT\$ 9,918 billion) and there will be 158 10⁶ tons of CO₂ emissions in 2000 (124% of the emissions in 1990). This provides another strategy that Taiwan's government can adopt as an alternative.

V. Concluding Remarks

This paper employs a multi-objective programming model to evaluate the economic impact of mitigating CO₂ emissions in Taiwan. We have shown that the costs incurred by CO₂ emission controls are rather enormous. The empirical results show that Taiwan's GDP in 2000 will drop 34% of the maximized GDP objective and Taiwan's economy will weaken if the government stabilizes annual CO₂ emissions at the 1990 level. Estimated results also show that Taiwan's government could adopt four non-inferior solutions. In one of the solutions Taiwan's estimated GDP in 2000 would only decrease to NT\$ 912 billion (91.9% of NT\$ 992 billion) and there would be 149 10⁶ tons of CO₂ emissions in 2000 (128% of the emissions in 1990). This solution would not significantly hurt Taiwan's economy and might be conditionally accepted by the IPCC. Taiwan's government can also reach the target by offering financial incentives to encourage investment activities related to CO₂ mitigation and energy-saving matters. One remark should be made here, the impact can be viewed as a kind of mitigating cost associated with CO₂ emission reduction targets. Given the current state of technology, energy efficiency improvements and CO₂ emission abatements, Taiwan will have enormous CO₂ mitigating costs. If CO₂ emission controls are required, the incurred costs should be justified. However, there also remain a number of uncertainties in the speed of technological development and our understanding of the greenhouse effect in the near future. Taiwan then has a greater potential to reduce its actual expenditures. Therefore, we should recognize that the empirical results derived in this paper are subject to several restrictions. For example, the model is simplified in several aspects, some of them are planned to highlight the main points we are concerned with. In addition, the input data adopted in the model can never be perfect. The "penny switching problem" also remains unsolved in the programming model. That is if the cost of technique M is slightly cheaper than that of technique N (say one penny), the solution of the programming model will totally substitute technique M for technique N. This may not be true in reality.

In order to limit CO₂ emissions, Taiwan's government should adopt

appropriate strategies. Some top priorities for these strategies are listed as follows: (a) efficient use of energy, (b) introduction of non-fossil fuels, (c) international cooperation to proceed with joint implementation, and (d) innovative technologies. In Taiwan, the government and its people have attempted to promote energy conservation since the first oil crisis. Energy intensity in the 1990s is 11.38 LOE/NT\$1000, which is better than that in the 1960s (13.19) and represents continuous improvement. Achieving the goal of mitigating CO₂ in Taiwan will require a strong effort both from the government and the people in energy conservation. In fact, the energy supply structure, manufacturing processes, and transportation system should be re-examined in order to develop or form new lifestyles with less energy use and low CO₂ emissions. Moreover, for Taiwan to reduce CO₂ emissions and energy imports, it needs to carry out economic restructuring by shifting its industrial structure from labor- and energy-intensive to less energy-intensive, high-technology, and light-engineering manufacturing industries such as household electrical appliances and electrical apparatus. Energy-intensive industries should not be encouraged and only be developed in those cases where there is good evidence the products will be competitive at world prices. For energy restructuring, natural gas should have priority in economic development and should replace petroleum and coal. Electricity generation should utilize more natural gas as well. As to international cooperation, technology transfer to developing countries should be promoted so as to arrest CO₂ emissions. However, our findings and policy recommendations are all based on a theoretical perspective. What kind of policy or strategy should be implemented in reality may contain a trade-off between economic efficiency and social-political acceptability.

References

- Akihiro, A. (1996), *Global Warming, Carbon Limitation and Economic Development*, Internal Report of the National Institute for Environmental Studies, Tokyo.
- Fells, L. and L. Woolhouse (1994), "A Response to the UK National Program for CO₂ Emissions," *Energy Policy*, 22(8), pp.666-684.
- Hafkamp, W. A. (1991), "Three Decades of Environmental-Economic Modeling Economic Models of Pollutant Emissions," in Dietz, F. T. et al., (eds.), *Environmental Policy and the Economy*, North-Holland, Amsterdam.
- Hafkamp, W. A. and P. Nijkamp (1982), "An Integrated Interregional Model for Pollution Control," in Lakshmanan, T. R., and P. Nijkamp (eds.), *Economic Environmental Interactions Modeling and Policy Analysis*, Martinus Nijhoff, Boston.
- Hope, C., J. Anderson and P. Wenman, (1993), "Policy Analysis of the Greenhouse Effect: An Application of the PAGE Model," *Energy Policy*, 21 (3), pp.327-338.
- Hsu, G. J. Y., P. S. Leung and C. T. K. Ching (1988), "Energy Planning in Taiwan: An Alternative Approach Using a Multiobjective Programming and Input-Output Model," *The Energy Journal*, 9 (1), pp.53-72.
- Hsu, G. J. Y. and L. Y. R. Tzeng (1992), "A New Algorithm of Multi-objective Programming: the Center-point Method (in Chinese)," *Journal of Management Science*, 9 (1), pp.39-50.
- Loucks, D. P. (1975), "Planning for Multiple Goals," in Blitzer, C. R., P. Clark, and L. Taylor (ed.), *Economy-Wide Models and Development Planning*, Oxford University Press, London.
- Miller, R. E. and P. D. Blair (1985), *Input-Output Analysis: Foundations and Extensions*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Manne, A. S. and R. G. Richels (1991), "Global CO₂ Emissions Reduction: the Impact of Rising Energy Costs," *The Energy Journal*, 12 (1), pp.87-

107.

- Morrison, M. B. and P. Brink (1993), "The Cost of Reducing CO₂ Emissions," *Energy Policy*, 21 (3), pp.284-295.
- Nordhous, W. D. (1992), "The Cost of Slowing Climate Change: A Survey," *The Energy Journal*, 12 (1), pp.37-65.
- Nijkamp, P. (1986), "Equity and Efficiency in Environmental Policy Analysis: Separability versus Inseparability," in Schnaiberg, A., N. Watts, and K. Zimmermann (eds.), *Distribution Conflicts in Environmental-Resource Policy*, Gower, London.
- Rose, A. (1995), *Global Warming Policy, Energy, And The Chinese Economy*, Pennsylvania University Press, Pennsylvania State.
- Rose, A. and B. Steven (1993), "The Efficiency and Equity of Marketable Permits for CO₂ Emissions," *Resource and Energy Economics*, 15, pp.117-146.
- Zeleny, M. (1982), *Multiple Criteria Decision Making*, New York: McGraw Hill Press.

Discussion Paper Series

1. Kang Chao and Ellen S. S. Chien. "The Relative Real GDP and Price Structure of Mainland China," 1981. (No. 8101)
2. Kang Chao. "Economic Readjustment in Mainland China," 1981. (No. 8102)
3. Mingshu Hua. "The Inflationary Effect on the Structure of Trade," 1981. (No. 8103)
4. Kang Chao and P. C. Chang. "A Study of Regional Factor Productivities in Chinese Agriculture," 1982. (No. 8201)
5. Chun-yuan Wang. "The Spillover Monetary Effect of Devaluation: A Disequilibrium Interpretation of the Cooper Paradox and the 'Reversed'," 1982. (No. 8202)
6. Chihwa Kao. "Second-Order Efficiency in the Estimation of Heteroscedastic Regression Models," 1984. (No. 8401)
7. Chihwa Kao. "An Em Algorithm for the Heteroscedastic Regression Models with Censored Data," 1984. (No. 8402)
8. Hak Choi. "Methods of Generating Demand Functions - A Tabular Review," 1984. (No. 8403)
9. Chihwa Kao. "Robust Regression with Censored Data," 1984. (No. 8404)
10. Chihwa Kao. "The Bootstrap and the Censored Regression," 1984. (No. 8405)
11. San, Gee. "The Early Labor Force Experience of College Students and Their Post-College Success," 1984. (No. 8406)
12. Chihwa Kao. "Small Sample Studies of Estimating, the Regression Models with Multiplicative Heteroscedasticity: The Results of Some Monte Carlo Experiments," 1984. (No. 8407)
13. San, Gee. "Student Financial Aid, In-School Employment, and Educational and Labor Market Outcomes," 1984. (No. 8408)
14. An-loh Lin and Scott A. Monroe. "The Structure of Gasoline Demand Across the United States," 1985. (No. 8501)
15. Hak Choi. "Why the EEC-ROC Trade Remains Unimportant," 1985. (No. 8502)
16. Hak Choi, J. Chou and D. E. Nyhus. "A Disaggregated Exports Forecasting Model for Taiwan," 1985. (No. 8503)

17. Diagee Shaw. "On-site Samples' Regression: Problems of Nonnegative Integers, Truncation, and Endogenous Stratification," 1987. (No.8701)
18. Li-min Hsueh and Su-wan Wang. "The Implicit Value of Life in the Labor Market in Taiwan," 1988. (No.8801)
19. Chien-hsun Chen. "Modernization in Mainland China: Self-Reliance and Dependence," December, 1990. (No.9001)
20. Tain-jy Chen and Wen-thuen Wang. "The Effects of Production Quotas on Economic Efficiency: The Case of Taiwan's Canned Food Industry," December 1990. (No.9002)
21. Ya-hwei Yang. "The Influence of Preferential Policies on Strategic Industries: An Empirical Study of Taiwan," December 1990. (No.9003)
22. Solomon W. Polachek and Charng Kao. "Lifetime Work Expectations and Estimates of Sex Discrimination," January 1991. (No.9101)
23. Ke-jeng Lan. "Inflation Effects on the Labor Market: A Transition Rate Model," April, 1991. (No.9102)
24. Hui-lin Wu, Quen-leng Miao, and Ke-jeng Lan. "Wage Differentials: Among College-and-Above Graduates in Taiwan," April 1991. (No.9103)
25. George J. Y. Hsu and Tser-yieth Chen. "Uncertainty and Asymmetric Information in the Modelling of Electric-Utility Tariff Regulation," May 1991. (No.9104)
26. Ya-hwei Yang. "An Analysis on the Structure of Interest Rate in the Banking Sector, the Money Market and the Curb Market," June 1991. (No.9105)
27. Jiann-chyuan Wang. "Quota Restriction Policies and Their Impact on Firms' Quantity Setting Decision Under 'Learning-By-Doing'," June 1991. (No.9106)
28. Jiann-chyuan Wang. "Cooperative Research in Taiwanese Manufacturing," October 1991. (No.9107)
29. Mo-huan Hsing. "The Empirical Relevance of the Orthodox Demand Theory," October 1991. (No.9108)
30. Hui-lin Wu and Ke-jeng Lan. "Labor Shortage and Foreign Workers in Taiwan," October 1991. (No.9109)
31. Ji Chou and De-min Wu. "The Cost of Capital and the Effective Tax Rate in Taiwan: 1961 - 1985," October 1991. (No.9110)
32. George J. Y. Hsu, Pao-long Chang, and Tser-yieth Chen. "Industrial Outage Costs in Taiwan: Estimation from a Proposed Curtailed Rate Program in Taiwan," January 1992. (No.9201)
33. Charng Kao, Solomon W. Polachek, and Phanindra V. Wunnava. "Male-

- Female Wage Differentials in Taiwan: A Human Capital Approach," Feb. 1992. (No.9202)
34. Lee-in Chen Chiu. "The Economic Reunion of Taiwan and the Mainland China: The Impact on Industrial Development," May 1992. (No.9203)
 35. Yi Chou, Pao-long and Chyau Tuan. "TQC Chinese Style and Its Management Implication -- Taiwan V.S. Mainland China," June 1992. (No.9204)
 36. Chung-hua Shen and Lee-rong Wang. "Testing Efficiency of the Coffee Futures Market -- A Markov Switching Model," June 1992. (No.9205)
 37. Tain-jy Chen and Hsien-yang Su. "On-the-Job Training as a Cause of Brain Drain" July 1992. (No.9206)
 38. George J. Y. Hsu, Pao-long Chang and Tser-yieth Chen. "A Priority Service Program and Power Outage Costs: The Case of Taiwan's Cement Industry," October 1992. (No.9207)
 39. George J. Y. Hsu and Ai-chi Hsu. "Energy Intensity in Taiwan's Industrial Sectors: Divisia Index vs. Laspeyres Index," October 1992. (No.9208)
 40. Lee-in Chen Chiu. "Regional Differential of Enterprise Efficiency and Labor Productivity in Coastal China," December 1992. (No.9209)
 41. Chi-ming Hou and Chien-nan Wang. "Globalization and Regionalization -- Taiwan's Perspective," March 1993. (No.9301)
 42. Yi Chou. "The Practice Beyond Property Right Boundaries -- Quality Management in Chinese State-owned Enterprises and Rural Enterprises," March 1993. (No.9302)
 43. Tzong-shian Yu. "Economic Development in Transition -- The Case of Taiwan," June 1993. (No.9303)
 44. Tzong-shian Yu. "An Analysis of the Effects of Economic Policies on Taiwan's Economic Growth and Stability," June 1993. (No.9304)
 45. Ke-jeng Lan. "An Evaluation of the Effectiveness of Government Automation Promotion Schemes in the Electrical Component Industry," June 1993. (No.9305)
 46. Yi Chou. "Measurement of Technical Efficiency and Its Management Implications -- The Example of Taiwan Sugar Corporation," June 1993. (No.9306)
 47. Chien-nan Wang. "On the Choice of Exchange Rate Regimes," June 1993. (No.9307)
 48. Yi Chou and Chyau Tuan. "Quality Management of Chinese Township Enterprises in Inland and in Coastal Areas," November 1993. (No.9308)
 49. Lee-in Chen, Chiu and Jr-tsung Huang. "Improvement of Capital Productivity

- and Technical Efficiency via DFI: Evidence from the Industrial Interaction between Taiwan and Mainland China," December 1993. (No.9309)
50. An-loh Lin. "Trade Effects of Direct Foreign Investment: The Bilateral Case," February 1994. (No.9401)
 51. Jiann-chyuan Wang and Homin Chen. "The Impact of North American Economic Integration on Taiwan," March 1994. (No.9402)
 52. Joseph S. Lee. "Is There a Bona Fide Labor Movement in Taiwan?" April 1994. (No.9403)
 53. Jiann-chyuan Wang and Kuen-hung Tsai. "An Evaluation of the Effect of Government Research and Development Promotion Schemes in the Electrical Component Industry," June 1994. (No.9404)
 54. Anthony H. Tu. "The Dynamic Self-Hedged Behavior During the Period of 1987 Crash: Evidence from the U.S. Stock Market," August 1994. (No.9405)
 55. Ji Chou, Yun-peng Chu and Shiu-tung Wang. "Effects of Trade Liberalization on Taiwan -- A Computable General Equilibrium Analysis," October 1994. (No.9406)
 56. Ya-hwei Yang. "Economic Crime and Business Cycles in Taiwan," January 1995. (No.9501)
 57. Jiann-chyuan Wang and Homin Chen. "An Evaluation of the Effectiveness of Government R&D Tax Credits," March 1995. (No.9502)
 58. Tzong-shian Yu. "Policies for Industrial Development and Evaluation of their Achievements in the Republic of China on Taiwan," April 1995. (No.9503)
 59. King-min Wang. "Grazing Management and Rehabilitation of Degraded Rangeland in Western Australia," August 1995. (No.9504)
 60. Hui-lin Wu, Chia-hui Lin, and Ke-jeng Lan. "An Empirical Study of Youth Mobility in Taiwan," November 1995. (No.9505)
 61. Mo-huan Hsing. "A Demand System with Homothetic Utility Function: Measurability and Empirical Relevance," November 1995. (No.9506)
 62. An-loh Lin. "Dummy Functions in the Koyck Distributed-lag Model," December 1995. (No.9507)
 63. An-loh Lin. "Estimation of the AR(1) Model Containing a Dummy Variable," January 1996. (No.9601)
 64. Ya-hwei Yang, Yenpao Chen, and Tzung-ta Yen, Ying-yi Tu. "The Financial Aspects of Taiwanese Investment in South China," March 1996. (No.9602)
 65. Jiann-chyuan Wang, and Kuen-hung Tsai. "Success Factors in Cooperative Research in Taiwan," May 1996. (No.9603)
 66. Lee-in Chen Chiu. "Toward an Interregional Integration of Habitat,

Production and Ecosystem — Developing Taiwan into a Regional Operations Center,” September 1996. (No.9604)

67. Sze-yueh Wang and Lee-in Chen Chiu. “The Impact of Mainland China’s Open Door Policy on Regional Industrial Development,” November 1996. (No.9605)
68. Momoko Kawakami. “Development of the Small- and Medium-Sized Manufacturers in Taiwan’s PC Industry,” November 1996 (No.9606)
69. Tser-yieth Chen and Oliver S. Yu. “A Performance Evaluation of the Commercial Lighting Programs of the United States,” November 1996. (No.9607)
70. Yunchang Jeffrey Bor, Wen-jung Lien and Su-wan Wang. “The Impacts of Traiff Liberalization on Taiwan and APEC Economies: A Multiregional General Equilibrium Analysis,” December 1996. (No.9608)
71. Chin Chung. “Doulbe-edged Trade Effect of Foreign Direct Investment and Firm-Specific Assets: Evidence from the Chinese Trio,” December 1996. (No.9609)
72. Chin Chung. “Industry Characteristics and FDI Strategy: A Three-Way Typology of Taiwanese Investment in Mainland China,” December 1996. (No.9610)
73. Chin Chung. “The Emerging Pattern of Division of Labor across the Taiwan Strait: Macro Overview and Sectoral Analysis of the Electronics Industry,” December 1996. (No.9611)
74. Tser-yieth Chen. “A Measurement of the Resource Utilization Efficiency of University Libraries in Taipei,” January 1997. (No.9701)
75. Tser-yieth Chen and Tsai-lien Yeh. “Bank Efficiency and Ownership in Taiwan: An Evaluation with Data Envelopment Analysis,” April 1997. (No.9702)
76. George J. Y. Hsu and Tser-yieth Chen. “The Impact of Mitigating CO₂ Emissions on Taiwan’s Economy,” August 1997. (No.9703)