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Effects of carbon taxes on different industries by fuzzy goal programming: A case study of the petrochemical-related industries, Taiwan

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Abstract

Implementation of a carbon tax is one of the major ways to mitigate CO_2 emission. However, blanket taxes applied to all industries in a country might not always be fair or successful in CO_2 reduction. This study aims to evaluate the effects of carbon taxes on different industries, and meanwhile to find an optimal carbon tax scenario for Taiwan's petrochemical industry. A fuzzy goal programming approach, integrated with gray prediction and input–output theory, is used to construct a model for simulating the CO_2 reduction capacities and economic impacts of three different tax scenarios. Results indicate that the up-stream industries show improved CO_2 reduction while the down-stream industries fail to achieve their reduction targets. Moreover, under the same reduction target (i.e. return the CO_2 emission amount to year 2000 level by 2020), scenario SWE induces less impact than FIN and EU on industrial GDP. This work provides a valuable approach for researches on model construction and CO_2 reduction, since it applies the gray envelop prediction to determine the boundary values of the fuzzy goal programming model, and furthermore it can take the economic interaction among industries into consideration.

Keywords: Carbon taxes; Fuzzy goal programming; Industries

1. Introduction

The Kyoto Protocol, which aims to slow down the effects of global warming, went into effect on February 16, 2005. Both developed and developing countries around the world have recognized the urgent need to take action to reduce carbon dioxide (CO_2) in order to address the climate change challenge. Because man-made CO_2 is emitted primarily from use of fossil fuels by the industry sector, it is necessary to draft an optimal strategy and scenario for CO_2 reduction with lower economic impact. Recently, use of price mechanisms has become an important strategy for carbon emission reduction, while carbon taxes have been frequently advocated as a cost-effective instrument. Some countries in Europe, such as Netherlands, Sweden, Finland, and Norway, have implemented carbon taxes for years. A relevant research shows that carbon taxes may be an interesting policy option and that their main negative impacts may be compensated through the design of the tax and the use of the generated fiscal revenues (Baranzini et al., 2000).

The literature on carbon taxes for limiting CO_2 emissions is abundant. For example, impacts of carbon taxes on energy systems in Japan were studied with a partial equilibrium model (Nakata and Lamont, 2001). Their results suggest that carbon taxes decrease CO_2 emission according to a proposed target, but also cause a shift in fuel use from coal to gas. In New Zealand, a computable

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general equilibrium (CGE) model is used to assess the relative effectiveness of carbon taxes on the economy, and results show that carbon taxation would adversely affect GDP (Scrimgeour et al., 2005). Norway's high carbon tax since 1991 contributed to only 2% reduction in CO_2 emissions because of widespread tax exemptions and inelastic demand of various sectors affected by this tax (Bruvoll and Larsen, 2004). As in the case of Norway's relatively high carbon tax since 1991 and its resulting low CO_2 reduction, Gerlagh and Lise (2005) developed an economic partial equilibrium model to demonstrate that carbon taxes have a modest effect on emissions. Kahn and Franceschi (2006) recommended an international tax system, based on per unit carbon taxes, to be placed on specific greenhouse gases and non-renewable carbon emissions to encourage fuel switching. A study by Voorspools and D'haeseleer (2005) indicated that the effect of a CO_2 tax on electricity trade and power generation among eight interconnected European zones had the net effects of redistributing cross border trade plus encouraging fuel shifts, with an accompanying overall CO_2 reduction of about 6%. Johansson (2006) theoretically evaluated the possibility of different policy instruments to contribute to reductions in industrial CO_2 emissions while preserving the competitiveness of industry.

In recent decades, Taiwan has made very significant progress in economic development. Based on its high gross domestic product (GDP), Taiwan is now classified as a newly industrialized economy, and therefore needs to address the problem of reducing its CO_2 emissions. As early as 1998, the National Energy Council of Taiwan set its CO_2 mitigation goal as "returning its total emission amount to the year 2000 level 2020". Impacts of carbon taxation on Taiwan's four major energy-consuming industries: iron and steel, chemical, cement, and paper, were examined by using a two-stage translog price model (Hua and Wu, 2000). This study aims to evaluate the effects of carbon taxes on different industries, and meanwhile to find an optimal carbon tax scenario for Taiwan's petrochemical industry. A fuzzy goal programming approach (Yang et al., 1991) integrated with gray prediction (Deng, 1989) and input–output theory (Leontief and Ford, 1972) is used to construct a model for simulating CO_2 reduction capacities and economic impacts of various carbon tax scenarios. Moreover, some policy suggestions regarding imposing carbon tax on industries are given based on the simulation results.

2. Method

2.1. Model construction

According to input–output theory, every industry needs to buy various materials or services from other industries and sectors for production, and would provide its products or services to other industries and sectors. Based on this concept, all activities of an industry affect not only itself, but also the other industries. This means that there exists an interactive relationship among all industries in an economic system. In this paper, we combine fuzzy goal programming and input–output theory to construct an industrial CO_2 reduction model. Thus, economic interaction among inter-industries can be taken into account during the process of CO_2 reduction simulation.

In this study, we divide Taiwan's manufacturing sector into 34 sub-sectors in which including five petrochemical-related industries: petrochemical materials (PM), plastic materials (PL), artificial fibers (AF), plastic products (PP), and rubber products (RP). The original model which contains 2 objectives and 78 constraints is stated as follows.

(I) Objective functions—(a) *Industrial GDP objective*: This objective seeks the maximum industrial GDP value of the petrochemical industry:

$$\text{Max} \sum_{i=1}^{5} V_i X_i, \tag{1}$$

where i is the petrochemical-related inter-industry (including AM, PL, AF, PP and RP), V_i is value-added rate for inter-industry i, X_i (decision variables for this model) is total output of inter-industry i.

(b) *CO_2 objective*: The CO_2 objective seeks the minimum CO_2 emission from the petrochemical industry:

$$\text{Min} \sum_{i=1}^{5} \left(\sum_{j=1}^{4} c_{ij} e_{ij} X_i \right), \tag{2}$$

where j is the energy type (oil, coal, electricity, and gas), c_{ij} is CO_2 emission coefficient (ton $CO_2/10^{10}$ kcal), e_{ij} is energy input coefficient (10^{10} kcal/million USD).

(II) Constraint functions—(a) *Final demand*: The total output from each inter-industry must satisfy the lower limit of its final demand:

$$(I - D)_i X \geqslant Y_i \; (i = 1, 2, \ldots 34), \tag{3}$$

where I is an identity matrix (34 × 34), D is the industrial input coefficient matrix (34 × 34), X is the total output vector (34 × 1),which comprises all 34 sub-sectors (decision variables for this model), Y_i is the lower limit of final demand for industry i.

(b) *Domestic production*: To avoid an excessive high value in the result of model simulation, we set the upper limit for each inter-industry:

$$X_i \leqslant \overline{X}_i \quad (i = 1, 2, \ldots, 34) \tag{4}$$

where $\bar{X}_i$ is the upper limit of total output for sub-sector i.

(c) *Energy supply*:

$$e_i X_i \leqslant \overline{E}_i \quad (i = 1, 2, \ldots, 5) \tag{5}$$

$$e_i X_i \geqslant \underline{E}_i \quad (i = 1, 2, \ldots, 5) \tag{6}$$

where e_i is total energy input coefficient, $\bar{E}_i$ and $\underline{E}_i$ is the upper limit and the lower limit for inter-industry i, respectively.