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Development of an interactive enviro-economic equilibrium model for Guangdong Province, China

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ABSTRACT

China is facing tremendous multiple pressures of reducing carbon emissions, developing economy and improving people's lives. The implementation of economic/environmental policies is considered as a powerful tool for the nation's macroeconomic regulation and optimal allocation of resources. The objective of this paper is to develop an interactive enviro-economic equilibrium (IEEE) model to analyze the compound effects of provincial policy on other provinces within both regional and national contexts, and investigate the interactions among different taxes on relevant social-economic and environmental systems. In detail, a CGE-based multi-dimensional policy modelling is initiated for the analysis of inter-provincial interdependences under the interference of Guangdong's policy. A factorial Guangdong CGE is initiated for statistically quantifying the interactive effects of carbon, production and income taxes on Guangdong's GDP, social welfare and total carbon emissions. It is found that imposing carbon tax on one province will also reduce the carbon emissions of other provinces, while lowering production tax and income tax will promote the carbon emissions of other provinces. Production tax is always more significant than other taxes on relevant SEE issues. The significant contribution to GDP and carbon emissions is production tax, and the significant contribution to social welfare is production tax. Meanwhile, in terms of GDP and carbon emissions, there exist an interaction between production tax and carbon tax; and in terms of social welfare, there exist an interaction between income tax and production tax.

Keywords: Computable general equilibrium, factorial analysis, interactive effects, environmental policy, carbon mitigation, income/production taxes

NONMENCLATURE

Abbreviations	
IEEE	interactive enviro-economic equilibrium
CGE	Computable general equilibrium
FA	Factorial analysis

1. INTRODUCTION

Global climate change has become one of the most challenging environmental issues and has attracted widespread attention all over the world. China's commitment at the Pairs Climate Conference on economy-wide carbon emission intensity mitigation has put tremendous pressures on the nation's socio-economic and environmental (SEE) systems [1]. Such pressure has been amplified owing to the imperative requirements for both developing economy and improving people's lives. Implementing policies is considered a powerful tool for national macroeconomic regulation and optimal allocation of resources [2].

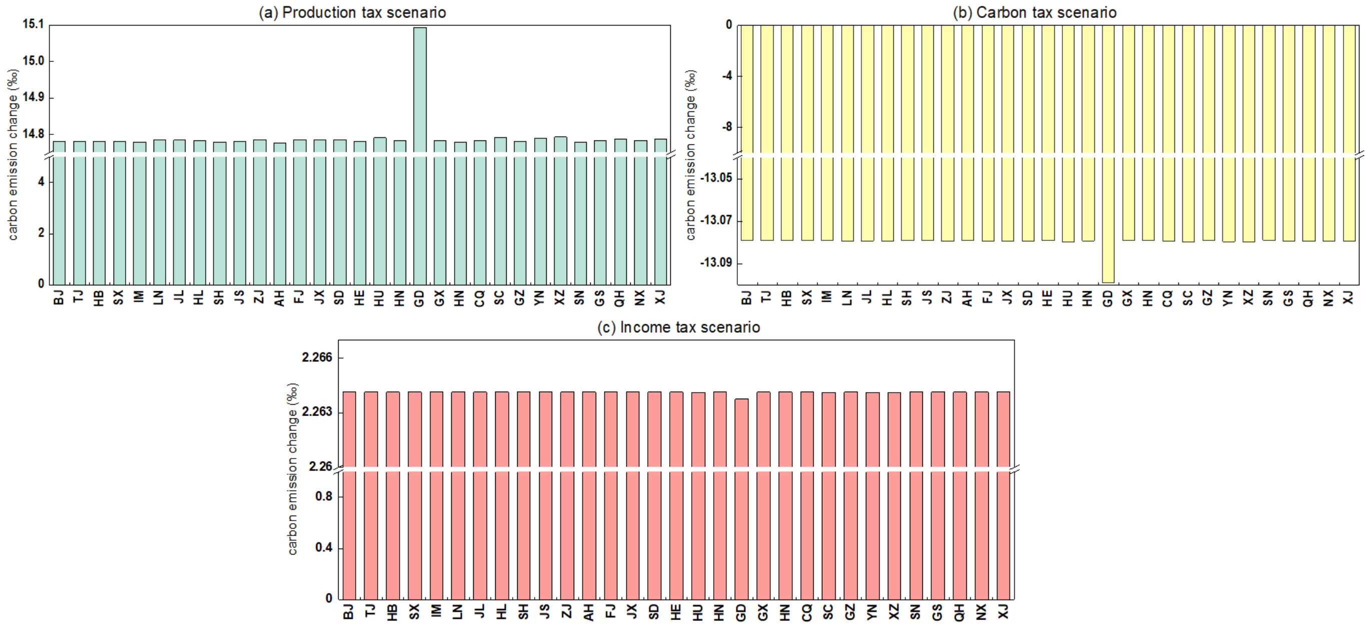

Fig 1 Changes in consumption-driven emissions across provinces under the interference of Guangdong provincial (a) production tax, (b) carbon tax and (c) income tax policies.

However, formulating and adjusting such policies would be challenging for decision makers due to the relevant immediate and long-term SEE effects. Therefore, it is desired to systematically study the effects of such policies on the systems.

Previously, great efforts were made in the field of economic and environmental policies impacts. Some scholars focused on evaluating the impacts of economic policy. Ojong et al., evaluated the relationships between petroleum profit tax and Nigeria's economy and explored the impact of corporate income tax on Nigeria's economy, and the effectiveness of non-oil revenue on economy [3]. Jeon et al., analyzed the impact of economic policy uncertainty in four Asian countries, including South Korea, Japan, Hong Kong and China, on the return of the Korean housing market [4]. Dwivedi et al. examined the impacts of production tax credits and investment tax credits on reducing wind and solar technology costs, as well as t the impacts on electricity market prices for renewable generators that provide reactive power support for the grid [5]. Some delved into the influences of environmental policy. Fu et al., developed a risk-aversion interval two-stage stochastic programming (RITSP) model to explore the optimal energy development strategy for electric-dependent regions within the carbon-price mechanism [6]. Shobande et al., disclosed the impact of energy policy on carbon emission of the nation's economy, including the United States, China and Nigeria [7]. Benavente et al., developed a static computable general equilibrium model for Chile to investigate the economic changes after the implementation of a carbon tax [8]. Floros et al., studied the energy demand of Greece's double-digit manufacturing industry and assessed the impact of carbon taxes on energy-related carbon dioxide emissions [9].

However, there exist complex interactions among various economic and environmental policies; such interactions may engender complexities in relevant SEE issues. Particularly, the compound effects among carbon policies and income/production taxes have not been quantitatively characterized or inferred through effective systems-analysis approaches. Also, no study has been reported in analyzing the multidimensional effects of policy interferences in a region (or multiple regions) on other region(s) as linked through various supply chains.

Therefore, as an extension of previous efforts, an interactive enviro-economic equilibrium (IEEE) model will be developed to analyze the compound effects of various provincial policies (of Guangdong) on multiple SEE systems within not only Guangdong itself but also other Chinese provinces. Two sub-models (i.e., CGE-based multi-dimensional policy model, and factorial Guangdong CGE one) will be developed for analyzing various effects (and their interactions) from multiple social-economic sectors. In detail, this objective entails: (i) characterizing the interdependences among sectoral

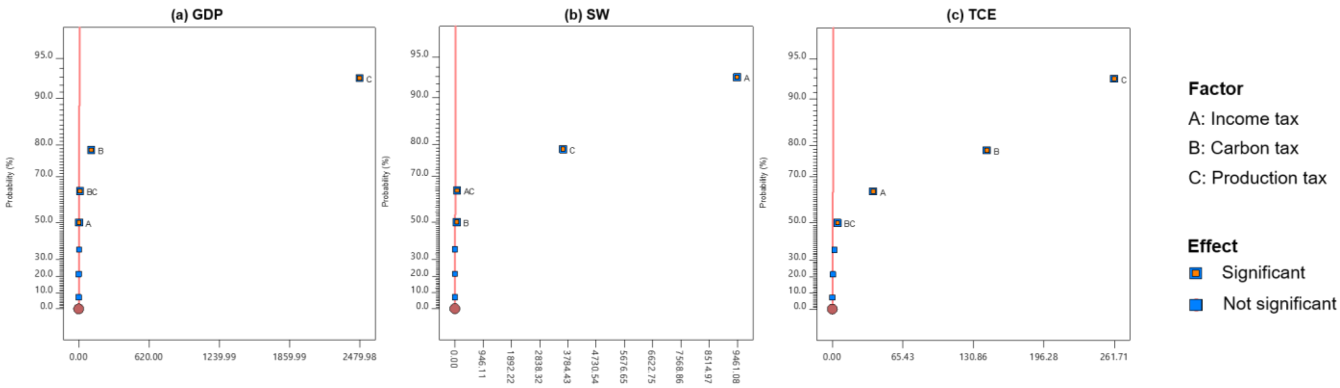

Fig 2 The half-normal plot of the standardized effects of the factors (i.e., income tax, carbon tax and production tax). Note: GDP is the gross national product, SW is the social welfare an TCE is the total carbon emissions.

activities of multiple provinces due to policy initiatives of carbon mitigation and income/production taxes in one or multiple provinces; and (ii) quantifying the interactive effects of such initiatives on detailed SEE issues including GDP, social welfare, and carbon emission. It is expected that the results will help support robust decisions for managing a variety of emerging SEE issues in Guangdong and other related provinces.

2. MATERIAL AND METHODS

2.1 Development of interactive enviro-economic equilibrium model

An interactive enviro-economic equilibrium model is developed to 1) examine the system's response to the carbon/economic policy stimulus implemented in specific province; 2) characterize the interactions of carbon/economic policy on related social, economic and environmental (SEE) issues. There are two modellings in the IEEE. In detail, the technical framework and model construction procedures of IEEE are as follows: firstly, a CGE-based multi-dimensional policy modelling is developed through the integration of CGE model and input output analysis. The output of CGE model is used as the input of multi-regional input-output analysis; secondly, a factorial CGE model is developed through the integration of CGE model and factorial analysis.

2.2 Computable general equilibrium model

CGE model is a traditional economic model to describe the new equilibrium state of the system after the impact of exogenous shocks (e.g., carbon/economic tax interference) [10–12]. Based on the Walras' general equilibrium theory, the model consists of six blocks: production, trade, income and expenditure, equilibrium and closure, carbon emissions and calibration. In detail, the production module describes how to use capital, labor, energy, and intermediate inputs to produce outputs. A seven-layer nested linear constant elasticity of substitution (CES) production function is developed in this module. The trade module refers to the Armington assumption that treat all imported and exported goods in actual trade as differentiated goods. The income and expenditure module present the changes in the income and expenditure of different economic entities. The carbon emissions module mainly describes carbon emission and carbon tax. The equilibrium and closure module achieve a simultaneous balance between the factor market and the commodity market. The calibration module is to improve the robustness of the simulation results. There are a total of 1520 variables and equilibrium equations in the developed model.

2.3 Multiregional input output analysis

MRIO analysis is an acknowledged method for uncovering implied flows embodied in the exchange of goods and materials [13–17]. According to the network theory, it treats the sectors/provinces and material flows as the nodes and paths in a network model. Based on the Leontief inverse matrix $(I-A)^{-1}$, the emissions embodied in final consumption could be obtained by $em=\varepsilon^{d}(I-A)^{-1}f$, where ε^{d} is the direct emission intensity and f is the final demand vector. The carbon emissions embodied in the trade exchange cannot be ignored. Due to the diffusion effect of the network, the change of one node (i.e., the policy interference in a certain region/sector) will affect the changes of other nodes (i.e., corresponding changes in the rest regions/sectors of the system). To describe the system response to changes in certain nodes, RAS method (also known as bi-proportional matrix balancing technique) for network balancing is employed to rebalance the network. Specifically, the developed CGE model can obtain the changes in specific regional economic behaviors cause by policy implementation, which corresponds to changes in specific components of MRIO (e.g., final demand). Based on a well-balanced input-output table, the RAS method can help to obtain the updated inter-sector flows inter-sectoral/provincial flows through continuous iteration.

2.4 Factorial analysis

Factorial analysis is employed to investigate the interactive effects for IEEE model. The quantitative impacts of implementing different policies on relevant social, economic and environmental issues remain unknown. FA is a powerful tool that can effectively facilitate exploring the main effects and the interactive effects through uncovering the specific changes of each parameter's effect under the impact of another parameters [18]. Compared with other statistical methods, FA could effectively quantify the sensitivity of the model output to the main factors and their combinations by processing the curve characteristics of the system response when the factors change at different levels. Taking a two-factor factorial design as an example, the sum of squares of each factor and the interaction between two factors could be expressed as follows:

$$y_{ijk} = \mu + \tau_i + \eta_j + (\tau\eta)_{ij} + \varepsilon_{ijk} \tag{1}$$

$$SS_\alpha = \frac{1}{\beta n}\sum_{i=1}^{\alpha} y_{i..}^2 - \frac{y^2}{\alpha\beta n} \tag{2}$$

$$SS_\beta = \frac{1}{\alpha n}\sum_{j=1}^{\beta} y_{.j.}^2 - \frac{y^2}{\alpha\beta n} \tag{3}$$

$$SS_{\alpha\beta} = \frac{1}{n}\sum_{i=1}^{\alpha}\sum_{j=1}^{\beta} y_{ij.}^2 - \frac{y^2}{\alpha\beta n} - SS_\alpha - SS_\beta \tag{4}$$

$$SS_T = \frac{1}{n}\sum_{i=1}^{\alpha}\sum_{j=1}^{\beta}\sum_{k=1}^{n} y_{ijk}^2 - \frac{y^2}{\alpha\beta n} \tag{5}$$

$$SS_E = SS_T - SS_{\alpha\beta} - SS_\alpha - SS_\beta \tag{6}$$

where y_{ijk} is the system observed response when factor α is at the ith level ($i = 1, 2, \ldots, a$) and factor β is at the jth level ($j = 1, 2, \ldots, b$) for the kth replicate ($k = 1, 2, \ldots, n$); μ is the overall mean effect; τ_i is the effect of α factor at the ith level of the; η_j is the effect of β factor at the jth level of the; $(\tau\eta)_{ij}$ is the interaction effect between τ_i and η_j; and ε_{ijk} is a random error component. SS_α, SS_β and $SS_{\alpha\beta}$ are the sums of squares for the α, β factors and their interactions, respectively; SS_T and SS_E are the total sum of squares and the error component, respectively. $y_{i..}$, $y_{.j.}$ and $y_{ij.}$ are the total of all observations under α factor at the ith level, factor β at the jth level, and the $ijth$ interaction between factors α and β, respectively; y is the grand total of all observations.

3. Calculation

The developed IEEE model is applied in Guangdong Province, China to analyze the effects of provincial policy on social-economic and environmental systems within both regional and national contexts, and to explore the interactive effects of carbon policy and economic policy on related SEE issues. Since 1989, Guangdong's GDP has remained the highest in China for consecutive years, with an average annual growth rate of 13.5%. However, the rapid urbanization process in Guangdong has caused great pressure on resources, environment and ecology. The problems of Guangdong's energy structure have become increasingly prominent, and the carbon emission reduction has been widely concerned in recent years. Moreover, as an important economic hub, Guangdong has frequent trade activities with domestic and foreign. Meanwhile, as a testing field for reform and opening up, the interaction among various policies on related SEE issues of Guangdong is unknown. Therefore, it is of great necessity to study the impact of Guangdong's implementation of carbon policies on other provinces across China, and the interactive effects of different policies on system.

Specifically, changes in carbon tax, income tax and production tax are selected as the exogenous shocks. We first examine the changes in carbon emissions of various provinces under varying degrees of changes in these three types of taxes in Guangdong. Then, we conduct a factorial design with 33 experiments, where three factors (i.e., three kinds of taxes) with each at three levels (i.e. low level, medium level and high level) are considered. We select GDP, social welfare and carbon emissions as the system responses at the economic, social and environmental aspects. Instead of using a commercial software, this research is to program a Guangdong carbon tax CGE model through investigating the detailed Guangdong SAM table, and it is solved by the General Algebra System (GAMS) software with the PATH solver. MRIO analysis is solved using the Matlab software. Factorial analysis is solved using the Design expert software.

4. Results

Figure 1 presents the changes in the carbon emissions of other provinces under the interference of three scenarios in Guangdong. In the production tax scenario, the production tax in Guangdong Province is reduced by 10%; in the carbon tax scenario, the carbon tax is levied at 6 ton/yuan; and in the income tax scenario, the income tax is reduced by 40% in Guangdong Province. It could be seen that lowering production tax and income taxes will increase carbon emissions in Guangdong and all other provinces, while imposing a carbon tax will reduce emissions. This is because lowering production taxes will reduce the corresponding production costs, and the consequences of expanding production include increased carbon emissions. Meanwhile, the complex supply chain relationships have promoted the increase in trade volume between Guangdong and other provinces, thereby increasing the emissions of other provinces. The reduction of income tax stimulates the work enthusiasm of the labor account, and also brings about the subsequent expansion of production. The levy of carbon tax will increase production costs and affect Guangdong's production to a certain extent. The reduction of production in one province will affect the production and related emissions of other provinces through the supply-demand relationship of the supply chains. Among them, the change in carbon emissions of each province caused by the disturbance of production tax ranges from 14.5‰ to 15.5‰, the change caused by carbon tax is around -13‰, and the change caused by income tax is around 2.26‰. In general, policy changes in one province will affect the carbon emissions of other provinces, but the differences between provinces are not obvious.

In order to better understand the impact of the uncertain adjustment of various carbon and economic policies on the SEE system for Guangdong Province, it is of great necessity to examine these uncertain parameters and their interactions on related SEE issues. By estimating the cumulative normal probability, Figure 7 presents the half-normal plots of the effects from economic (i.e., Figure 7 (a)), social (i.e., Figure 7 (b)) and environmental (i.e., Figure 7 (c)) perspectives, visually distinguishing whether the effect is significant or not. Among them, factors far away from the red line denote that the effects are obvious, and factors close to the red line indicates that the effect is weak and can be ignored. In detail, the most significant factor affecting GDP is production tax, followed by carbon tax. The interaction between carbon tax and production tax is also regarded as a significant factor because their P value is less than 0.01. But the contribution rate of the interaction is much weaker, accounting for 0.001%, while the most significant factor affecting GDP (i.e., production tax) accounting for 99.8%. For SW, the most significant factor is income tax accounting for 87.21%, followed by production tax, which contributes 12.82%. Besides, the contribution rate of the interaction between income tax and production tax is significant. For TCE, the most significant factor affecting TCE is production tax, accounting for 75.65%, followed by carbon tax and income tax, which contribute 22.75% and 1.61% respectively. The contribution rate of the interaction between carbon tax and production tax is much weaker, accounting for 0.02%. The result of carbon emissions deviate from our general knowledge that carbon tax has the greatest impact on total emissions. This may be attributed to the low setting of the low-carbon tax rate (the benchmark tax rate is 10 yuan/ton), which also shows that the low-carbon tax rate has less impact on GDP and emissions than the production tax. This may be attributed to the low-carbon tax rate setting (the benchmark tax rate is 10 yuan/ton), which also suggests that the low-carbon tax rate has less impact on emissions than production tax.

5. Conclusions

In this study, an IEEE model has been first developed to analyze the compound effects of provincial policy on other provinces as linked through supply chains, and explore the interactive effects of carbon/production/income policies on related SEE issues. Approaches of computable general equilibrium, factorial analysis and multiregional input-output analysis are integrated to make up for the limitations of a single method (e.g., the supply chain mechanisms cannot systematically be tracked in CGE model, as well as the interactive effects of various socio-economic sectors cannot be statistically characterized in CGE model and IOA analysis). IEEE model is capable of: (i) uncovering the inter-provincial interdependences through changes in the policy of a single province; (ii) quantifying the interactive effects of carbon-mitigation policy and income/production tax. It is discovered that imposing carbon tax on one province will also reduce the carbon emissions of other provinces, while lowering production tax and income tax will promote the carbon emissions of other provinces. Policy disturbances in one province will affect the carbon emissions of others, but the differences among provinces are not obvious. In addition, there exist interactions among different policies, which should be taken seriously of the policy regulation process. In general, production tax is always more significant than other taxes on relevant SEE issues. The significant contribution to GDP and carbon emissions is production tax, and the significant contribution to social welfare is production tax. Meanwhile, in terms of GDP and carbon emissions, there exist an interaction between production tax and carbon tax; and in terms of social welfare, there exist an interaction between income tax and production tax.

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