A CGE Modeling Based on the Multi-Layer Input-Output Structure for Waste Management Policy Evaluation

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論文内容の要旨

Introduction

In recent years, despite the growing consciousness in favor of waste reduction, reuse and recycling, there is still no consensus as to what extent we should achieve these goals, who should implement the plan, and how they should be done. In this respect, we could therefore say that the waste management policy, designed to achieve the goal of materials-cycle sustainable society, still remains in a state of trial and error.

Even though there is an evident chain consisting of production, consumption, waste generation, and waste disposal (or recycling), the decision making at each link along the path is performed in isolation from the other. This mechanism impedes the conscientious recycling of potential resources contained in wastes. For this reason, it is indispensable to establish cooperation in forms of social systems that regulate the flow of goods and bads from an environmental viewpoint through the processes of manufacturing, consumption, waste generation, and final waste disposal or recycling. Economic instruments for restraining final waste disposal and promoting recycling are some of the tools to attain such formation of social systems.

In Japan, the industrial waste disposal tax is the first environment tax enforced under the anticipation that it helps, to some extent, control the environmental burden released from industrial wastes (Ishiwata, 2002). However, whether this tax alone is effective and, if so, how much the tax rate should be are among the controversial questions need to be solved.

In this study, we theoretically develop a computable general equilibrium model so that it can elucidate the transaction between the entire production activities of goods and waste disposal services on the one side and the corresponding household consumption behavior on the other. The mathematical model and database developed in this research make it possible to examine the proposed environmental scenarios in order to accomplish a material-cycle sustainable society.

The first objective of this dissertation is to develop the computable general equilibrium model aiming at bridging the gap between two academic areas, i.e. the Input-Output model for waste disposal policy analysis and the theoretical environmental taxation model. The second objective is to study the effect of proposed tax policies, such as the waste disposal tax and deposit-refund system, with respect to their economic and environmental effects such as the final waste disposal curtailing effect and the material recycling impacts.

Structure of the Economy

In what follows, we describe the large-scale CGE model emphasizing linkages among sectors and consumer of the national economy. Figure 1 shows an overview of the economy. Based on the commodity technology assumption that there exists an industry mainly producing the concerned commodity by means of a well-defined production technology, all production technologies are separated into m goods and services technologies, n energy-related producing technologies and p waste treatment technologies*. This model also introduces a product-mix structure within the activity framework where industries use the available production technologies and jointly generate commodity outputs and wastes. All industries are categorized into $m+n$ goods and service including energy-related industries (G-industries) and p waste treatment service industries (W-industries). Furthermore, this procedure implicitly presumes that any waste treatment service industry mainly uses one of the available waste treatment technologies.

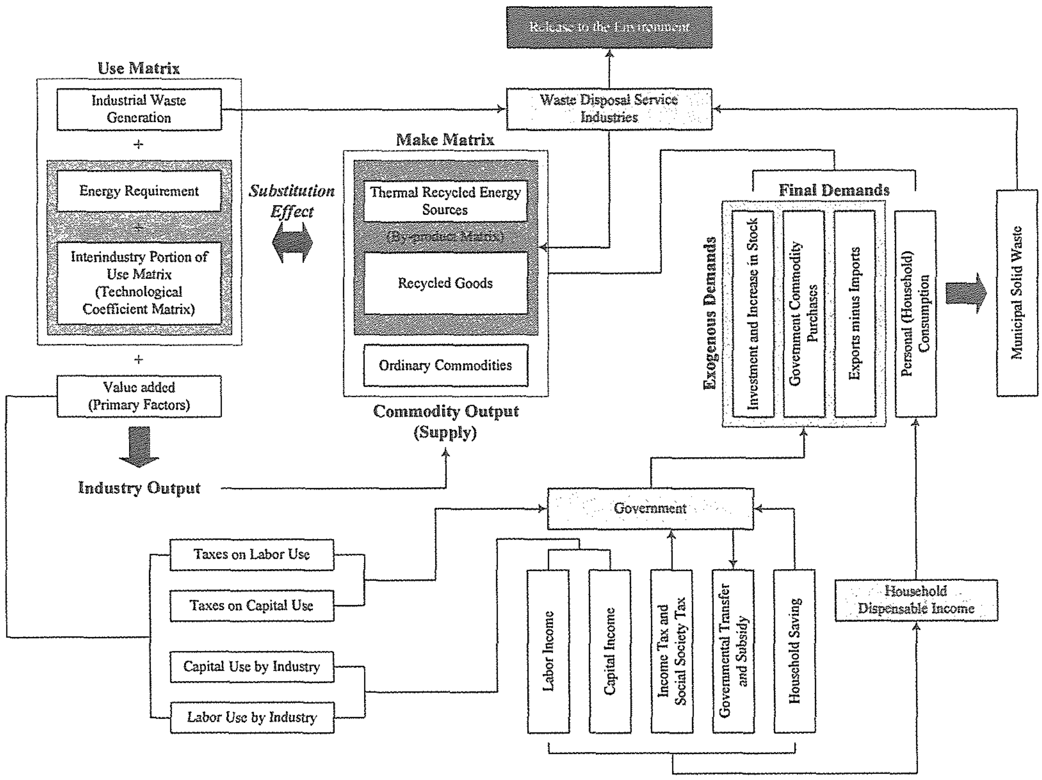

Figure 1: The structure of economy

* We assume that, in this model, there are q types of industrial and household municipal solid wastes need to be disposed of by p waste treatment technologies. The share of industrial waste k disposed of by the waste treatment technology i, s_{ik}, is represented by the industrial allocation matrix $S_1 = (s_{ik})_{i=1,\dots,p;k=1,\dots,q}$. The household allocation matrix $S_2 = (s_{ik})_{i=1,\dots,p;k=1,\dots,q}$ shows the share of household waste k that is treated by treatment method i. See also Nakamura, S. and Kondo, Y. (2002) for the further detail about this concept.

The CGE Model

Industry technology production function is represented by a multi-level production process as shown in Figure 2. The top level process consists of a Leontief production function in which intermediate input is combined in fixed proportions with other intermediate inputs and extended value-added. At the inter- mediate level, industries substitute among a primary factor value-added input – capital and labor, a total energy requirement input and a total waste disposal service input.

One of the main purposes in performing this analysis is to determine the substitution effect between the virgin and the recycled materials or by-products, such as virgin steel and steel scrap, in the intermediate input requirement for any industry. At the bottom level, we therefore allow for the substitution between the virgin and the recycled materials or by-products within the intermediate input components and between the original energy sources and the recycled ones.

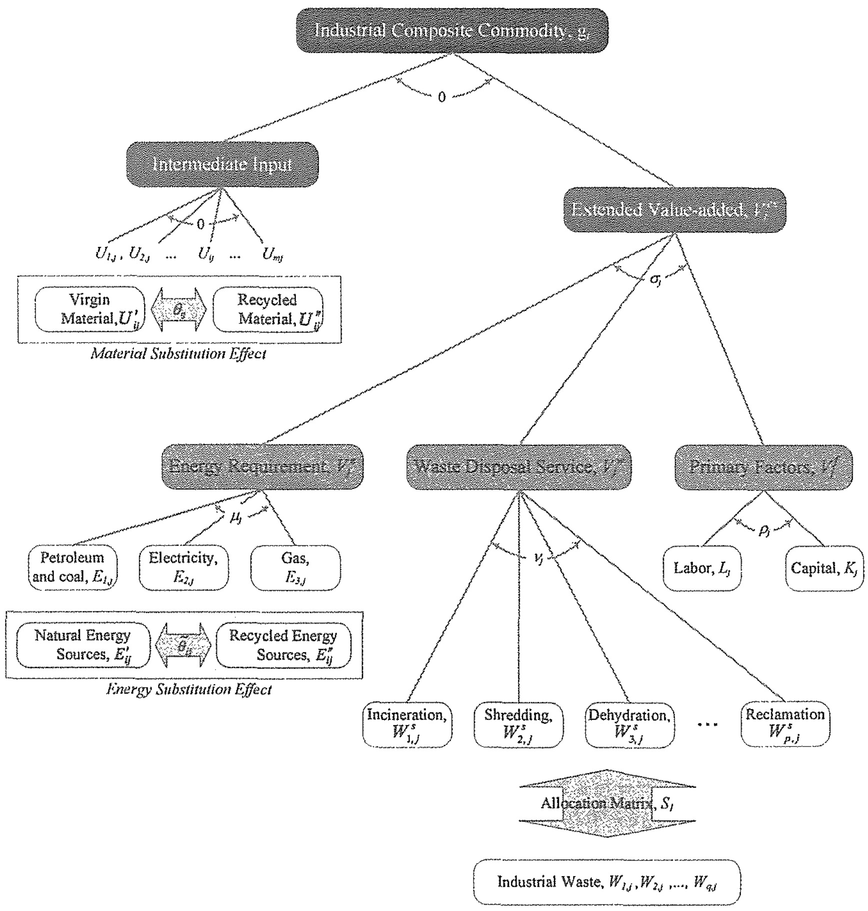

Figure 2: Production function and substitution elasticity

At the demand side of the model, we use the concept of *damage function* to take into account the environmental externalities in the society. The environmental damage function is associated with total amount of landfill consumption for household municipal solid wastes and industrial wastes (in Ton), and total carbon dioxide emission level (in Ton-carbon).

The marginal damage functions with respect to each variable are assumed to be positive and increasing — i.e.

the first and second partial derivatives are positive.

Encountering policy alternatives, the social planner maximizes *net social surplus* — household consumption utility less the above social environmental damage function. This model is used to evaluate the proposed tax policy by checking the trade-off between decreasing in the utility level and the environment quality improvement.

Household's utility is represented by a multi-level consumption process as shown in Figure 3.

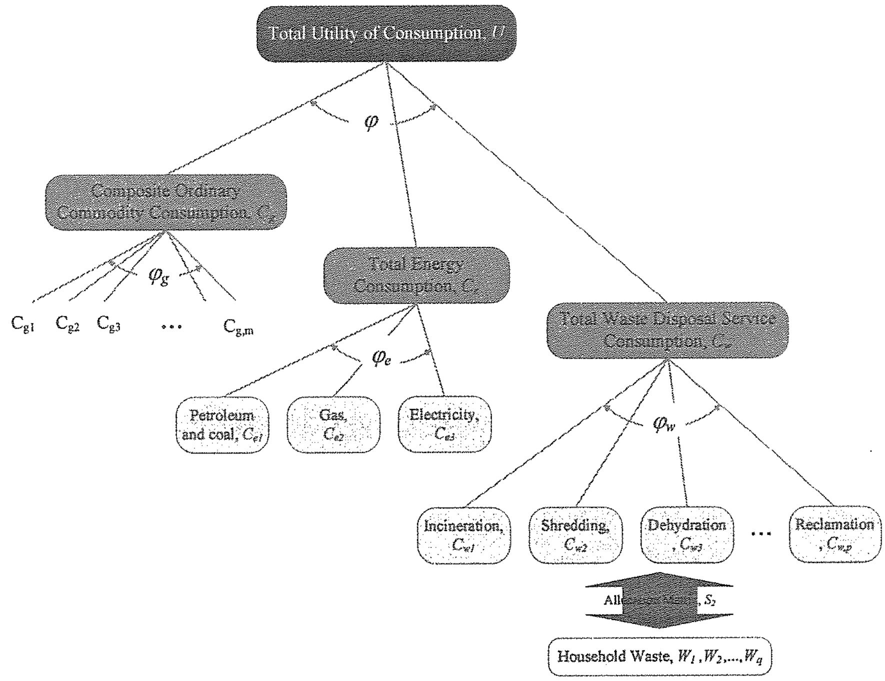

Figure 3: Household demand function and substitution elasticity

The government's consumption behavior is explained through the so-called exogenous demands. In order to reflect the influence of commodity prices, this model presumes a CES-typed utility function for an exogenous demand. We also make the assumption that there is no need for any waste disposal service demand in the exogenous consumption bundle. As a result, the government uses the collected taxes and saving revenue deducted by the direct transfer to a household and the investment in the aggregated commodities to consume ordinary commodities, energies.

The allocation of import-export demands are determined by the functional form that shows the response from domestic prices and the exchange rate toward the import and export demands. Moreover, the import demand is also affected by *the income effect*, which is in proportion to the corresponding commodity's total domestic output value.

A global general equilibrium is characterized by a set of activity levels for all industries and a set of prices for all commodities and factors of production such that four sets of conditions are satisfied: (1) Commodity balance, (2) Zero-profit conditions for industries, (3) Trade balance for foreign sector and (4) Government budget balance.

We firstly present private market equilibria – ignoring the effect of each sector's activity on the environmental externalities – and then show that the Walras's law could be established from this model.

Empirical Model and Data

Three objectives were considered in the selection of data accounts. First, the accounts must explicitly identify flows of products, factors, and income; second, the accounts must correspond to basic variables of the general equilibrium model; third, the number of accounts should be as small as possible without relinquishing the first two objectives.

The following six 1995 Japanese input-output tables representing economy-wide transaction were chosen: (1) Input-output technological table (X), (2) Input-output product mixed table (V), (3) Waste Input-output (WIO) table, (4) Physical unit input-output table, (5) By-products and scraps input-output table, and (6) Environmental emission coefficient table. These six tables are adjusted and rearranged with regard to the industrial types and their behaviors of waste generation and waste recycling. The industrial classification with 42 sectors is separated into 2 groups as 39 ordinary commodity sectors and 3 energy related sectors (G-industries). Waste treatment service industries (W-industry) are classified into 6 sectors. Each sector has 4 major intermediate inputs for its waste disposal activities, i.e. electricity, petroleum products, chemical products and transportation service, which represents the different waste treatment technology. There are 20 types of industrial and household wastes in this model. The share of waste disposed of by the waste treatment technology is represented by the non-negative rectangular allocation matrix $S_1 = (s_{ik})_{i=1,...,6;k=1,...,20}$ and $S_2 = (s_{ik})_{i=1,...,6;k=1,...,20}$ for industrial and household wastes, respectively.

Simulation Scenario and Results

Three experiments are conducted to assess the economic and environmental effects of changes in waste disposal tax policy. The scenario for the first experiment is described by levying a 1000 yen per ton of tax to the disposal service of both industrial wastes and the household solid wastes by the reclamation (land-filling) method and keeping all other taxes to be constant. To test for the possibility of alleviating the welfare lost as the result of imposing a waste disposal tax, the government revenue neutralization scheme is introduced in the second scenario by keeping the total revenue from all taxes and saving of government constant. The tax revenue from the waste disposal taxes can be used to decrease either the income tax rate or the capital tax rate. The third experiment accounts for the *deposit-refund system* (Fullerton and Kinnaman, 1995; Palmer and Walls, 1997) by setting all household waste disposal prices to be zero and taxing commodity consumption with the appropriate sale tax rate. The purpose of this scenario is to verify the effectiveness of implementing a deposit-refund system in the real economy with disaggregate consumption goods, pre-existing distortionary taxes, and substitution behaviors between recycled and virgin materials or energy inputs.

Some of the results are specified here. By imposing 1000 yen per ton of landfill tax to the whole economy, the industrial and household wastes are estimated to be reduced by about 20%. Accompanied by the carbon emission suppression about 547.2 thousand tons-Carbon, the proposed tax policy could manifestly bring about the total environmental burdens restrain effect under the relatively slight declination in the welfare level.

Implications and Conclusions

This dissertation contributes to developing the CGE-based model designed for the environmental policy appraisal program. Framework focuses on the entire life-cycle of each product and waste generated from virtually any source in the economy. The proposed model demonstrates how industrial, household, and waste disposal service (or recycling) sectors are connected each other. In addition, it shows how wastes are generated from these sectors and how they are disposed of. Calibrated with the 1995 Japanese input-output data set, the proposed model is applied to evaluate the environmental and economic consequences of the waste disposal tax by running the simulation in which the benchmark equilibrium of the CGE model is perturbed by the imposed tax policy.

This model has some points to be noted. First, the model could be easily applied to cope with the potential for illegal waste disposal by setting an appropriate scheme, for example by levying the output taxes on the dirty goods and followed by subsidizing for clean technology used in production, or for recycling the final good. The point is also to avoid the enforceability or measurement problems of a tax on pollution by applying the tax to observable market transactions such as the purchase of an output by consumer and simultaneously to subsidize other market transactions such as the purchase of clean inputs by the polluting firm.

In general equilibrium, only the relative prices of waste disposal services matter, and the waste disposal tax can therefore be set equal to zero as long as taxes on all other relevant activities are adjusted so as to induce desired relative prices. To avoid the possibility of illegal dumping, the free collection of garbage is quite sensible with the subsidy on legal disposal close to the direct cost of garbage collection However, taxes on relevant private consumption are required to restore the proper relative prices in general equilibrium. This consumption tax rate should reflect the externality such as aesthetic and health costs on those who live near the landfill area and the possible externality from illicit dumping or burning. This is called a deposit-refund system or a two-part instrument.

Second, in many recycling markets, the government orders the producers to recycle their products. Thus, recycling is not voluntary. The government often specifies the recycling rate of a weight base. Unfortunately, under the strong assumption that the technology of each firm remains constant in this static model make us unable to handle with this aspect. Some adaptation should be implemented to make this model become more realistic under the economic systems with goods and bads.

Third, considering the recycling promotion aspect, the thermal recycling is much more feasible to implement than the recycled raw materials because of the inefficiency of material recycling method. Promoting thermal recycling also contribute to the reduction in carbon-dioxide emission resulting from fossil fuel refinery processes.

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論文審査結果の要旨

三重県、鳥取県、岡山県、広島県をはじめとして、様々な地域で廃棄物（ゴミ）を減少させるために、様々な税制が導入され、または導入が検討されている。課税により廃棄物は減少するが、その課税方法、税収の使途が適切であるか、また課税の税率が適切であるかは経済成長と環境問題を考える上で非常に重要である。本研究の主題は廃棄物に対する税制の効果の推定と各種税制の妥当性の検討のためのモデルの開発にある。論文は全編７章よりなる。

第１章は序論である。ここでは日本の廃棄物発生の現状と廃棄物処理の問題点について述べている。

第２章は先行研究を紹介し、その問題点を述べている。特に本研究の分析手法の中心を成す、一般均衡分析と産業連関分析による研究をレビューし、それらの研究と廃棄物の発生メカニズムとの関係を明らかにしている。

第３章は本研究の骨格をなす通常産業と廃棄物処理産業の連関構造のモデル化、副産物(secondary product)の発生、廃棄物(by-product: waste disposal）の発生および処理を表現する行列の提案、さらには両者を多層構造を用いて統一的に表現するモデルの提案をしている。これは最近の学会で注目されている環境分析の構造モデルであり、その斬新性は高く評価される。

第４章が本研究の中心である。ここでは廃棄物削減税制、廃棄物管理政策を分析体系に包含するためのツリー状の生産・効用関数を持つ一般均衡モデル（CGE)、それに先の多層構造の産業連関モデルを整合的に組み込んだモデルが展開される。従来のCGE研究との相違は環境（廃棄物）部門の内生化にある。このモデルにより、様々な廃棄物マネージメント政策の評価が可能となる。

これは環境分析の従来の研究を遙かに凌ぐ画期的なモデル体系であり、その独創的成果は今後の研究の発展に大きく寄与すると評価される。

第５章では、上記モデルの妥当性を検討するために現実のデータを用いて検証を行っている。現実データをモデルに適用するためには様々な問題がある。また大規模かつ複雑なモデルの検証のためには、計算上の様々な技術的問題も生じる。本章ではこれらについて緻密に検証を行い、現実社会の現象の再現性から、モデルの実用性を証明している。これは研究の実用面での貴重な成果である。

第６章では上記モデルに基づいて、現実に行われている政策や検討されている政策を取り入れて様々なシミュレーションを行っている。その第一は廃棄物対策税制のマクロ経済に対する影響の分析である。第二は政策シミュレーションによる最終廃棄物の削減効果、対策税制がマテリアル・リサイクルに与える影響の分析である。本モデルの特定化の下では、全産業の廃棄物に対して埋め立て税、1,000円/トンはわずかな社会厚生の減少(0.06%)を生じるが、産業廃棄物および一般廃棄物が20%減少し、55万トンの炭酸ガス排出削減をもたらすことがわかった。このような各産業別のライフサイクル分析に基づく詳細なシミュレーションはわが国では例が無く、実用的な意味においても重要な成果であると評価される。

第７章は研究の結論と今後の展望を述べている。

以上要するに、本論文は廃棄物管理政策の評価のための多層的投入産出構造に基づくCGEモデルを提案し、検証したものであり、産業連関分析、一般均衡分析、土木計画学を含む情報科学の学際分野の発展に寄与するところが少なくない。

よって、本論文は博士（学術）の学位論文として合格と認める。