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THERESIA: Toward Holistic Economy, Resource and Energy Structure for the Integrated Assessment of Global Warming Mitigation Options

by

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Abstract

In this paper, the authors describe an energy-economy model formulated as a dynamic optimization model which deals with multi-regions, multi-sectors and energy technologies. This model, named THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment - deals with 15 world regions, 12 non-energy industry sectors and 7 energy sectors to assess the middle-to-long term global warming policies including the calculation of sectoral economic impacts and energy technology strategies. THERESIA also incorporates two labour categories, i.e., the high-educated labour and the general labour forces, to evaluate how the substitutability between professional labour and capital influences the relationship between economic activities and environmental policies, reflecting the expansion of such knowledge-based industries as information and business services. The simulation results show us that (1) the high labour-capital substitutability case gives higher economic growth than low substitutability case, (2) world Gross Domestic Products loss in 2037 is 1.37% (CO2-550ppmv stabilization scenario) and 3.10% (CO2-450ppmv stabilization scenario) in low labour-capital substitution while 2.96% (CO2-550ppmv stabilization scenario) and 5.25% (CO2-450ppmv stabilization scenario) in high labour-capital substitution case, and (3) the economic loss in the construction sector is large as well as machinery sectors while damages in the service sectors are relatively small.

Keywords: Multi-region, Multi-sector, Inter-temporal optimization, Energy technologies

1 Introduction

Since 2005 when the Kyoto Protocol was taken into effect, the evaluation of global warming mitigation measures becomes one of the central international policy issues. The Nobel Peace Prize 2007 for the Intergovernmental Panel on Climate Change (IPCC) activities seemed to recall the public concern on global environmental issues. However, the situation towards the implementation of mitigation institutions is still far from the agreement since there remains a serious uncertainty in the long-term costs and

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benefits of global warming mitigation. With respect to the economic damages under the greenhouse gas control policies, the existing integrated assessment models collected in the IPCC-AR4-WG3 provide 0.2%–2.5% world Gross Domestic Products (GDP) losses comparing with Business As Usual (BAU) in 2030 under the 535–590 ppmv CO2 equivalent concentration stabilization policy.

Although IPCC-AR4 as well as Stern Review in 2006 concludes the mitigation costs are small, it should be noted that the existing models do not always incorporate the dynamic changes in sectoral production or the industry reallocation which will change the world industry structure in the next decades especially in the Asia region. In 2008, Japanese government proposed a new mitigation measure which focuses on the potential carbon emission mitigation by sector – i.e., "sectoral approach" as Post-Kyoto. Although it is not clear whether this approach is acceptable or not, the assessment of such new proposal requires detailed formulation of economic activities as well as the dynamics and the variety of energy technologies.

Global Trade Analysis Project (GTAP) (Hertel, 1997; GTAP, 2008) has often been employed to evaluate the trade and industry structure under the global warming mitigation policies. (National Institute for Environmental Studies (NIES), 2008; Paltsev *et al.*, 2005) Iterative dynamic calculation procedure is basically employed to generate the dynamic economic activities. However, the dynamic interrelationships among energy technology options, industry structure and the warming measures are not evaluated since the existing multi-sectoral models are basically formulated as static models.

In this paper, the author describes an alternative model which is also formulated as a dynamic optimization model incorporating multi-regions, multi-sectors and energy technologies, named THERESIA - Toward Holistic Economy, Resource and Energy Structure for Integrated Assessment - for the middle-to-long term assessment of climate policies. THERESIA deals with 15 world regions, 12 non-energy industry sectors and 7 energy sectors. THERESIA also incorporates two labour categories, i.e., professional labour and general labour forces. The author employs the CES production function between capital and professional labour with low substitutability. Capital and professional labour CES function is connected with non-professional labour, secondary energy sources and other inputs in the Cobb=Douglas production function form. The results are compared with the case where the high substitutability between capital and professional labour is assumed.

2 Overview of Integrated Assessment Models

When the policy maker wants to build up policy measures taking into account the interactions among environmental impacts, economic cost and technological availability, quantitative evaluations of those factors are mostly needed and then he will explore the most preferable option mix based on the comprehensive information. Integrated assessment models (IAMs) have contributed to evaluate the policy measures under the complex interrelationships among environment, energy, economy, technology, resource and societal issues, especially in the global warming issues. Intergovernmental Panel on Climate Change (IPCC) eagerly employed IAM's to provide the future socio-economic scenarios and evaluation of policy measures, e.g. carbon control cost under various warming mitigation policies and the role of carbon sequestration technologies (IPCC-SRES, 2000; IPCC-TAR, 2001; IPCC-AR4, 2007).

A pioneering work of IAM is DICE model developed by Nordhaus (1994) where global warming system, economic activities and warming damage functions are integrated in a compact non-linear optimization model. Although DICE did not include the energy technology flows, it has been expanded and used for the assessments of climate policies. MERGE developed by A. Manne and Richels (Manne, 1993) is an expansion of energy-economics model ETA-MACRO developed in 1970s (Manne, 1977). MERGE involves the above four modules which are linked by data exchanges. IMAGE (Alcamo, 1993) and IMAGE 2.0 (Alcamo, 1994) assessed the warming impacts on agriculture and biosphere using detailed land use data. In Japan, National Institute of Environmental Studies (NIES) has been developing the AIM project including plural detailed model modules (NIES, 2008). MARIA (Mori, 2000) expanded the DICE model to include detailed energy flow module, land use change module and food demand and production module dividing the world into eight regions. These models are still being expanded to assess the global warming policies reflecting new scientific findings and political situations.

Most of the IAMs developed in 1990's mainly focused on the long-term assessments of global warming mitigation and energy technologies under 100 year time horizon as well as fossil fuel resource exhaustion issues through 21st century. Economic activities are mostly aggregated into one macro-sector. Thus, they fail to assess the dynamic structural changes in the international reallocation of industry sectors. Schafer *et. al*. (2003) extensively mentions the need for the multi sector model for the IAM.

On the other hand, there are some Computable General Equilibrium (CGE) models including multi-sector economic activities for multi regions. GTAP (Hertel, 1997) and G-CUBED (McKibbin, 2000), which are originally developed to analyze the international trade issues, have been extensively applied to the global warming issues. For instance, recent version of AIM (NIES, 2008) and MIT-EPPA (Schafer *et al*., 2003; Paltsev *et al*., 2005) extensively combine GTAP and energy technology model to generate the dynamic sectoral impacts of global warming mitigation measures. However, the original CGE model is basically formulated as static and they do not include detailed energy technology flows like MERGE (Manne, 1993) or DNE-21 (Akimoto *et al*., 2004). Most of current studies involving CGE module require an iterative calculation procedure to generate dynamic scenarios exchanging intermediate data among model modules. However, when one is interested in the capital formation behaviour in the manufacturing and the energy sectors under carbon control policies, an inter-temporal optimization model is needed.

A pioneering work to develop an inter-temporal optimization model with multi-sectors, multi-regions and energy technologies is provided by Homma *et al*. (2007), named DEARS (Dynamic Energy-economic model with multi-Regions and multi-Sectors) as a part of an integrated assessment project on global warming by Research Institute of Innovative Technology for the Earth (RITE) (Mori *et al*., 2006). DEARS incorporates the detailed energy-related technologies such as the advanced power generation options and carbon sequestration options. THERESIA described in this paper is developed to evaluate the middle-to-long term economic impacts of climate policies by extending the production structure of DEARS.

It should be also noted that existing IAMs are mainly utilized to assess the certain carbon control policy on the economic activities and energy technology strategies rather than to establish the cost and benefit analysis of global warming due to the lack of "economic damages caused by the expected global warming phenomena". Thus, the potential problems of cost benefit analysis in the global warming issues are not clarified yet. Nonetheless, IAM is still the only tool to assess the policies quantitatively keeping the internal consistency of the assessments.

3 Model Formulation

3.1 Overview and the formulation of the model

Figure 1 shows the conceptual structure of THERESIA model which is similar to the conventional input-output model except for the energy sectors. Both the primary and the secondary energy inputs are formulated in physical terms including multiple energy conversion technology options exhibited in Figure 2 unlike the existing CGE models.

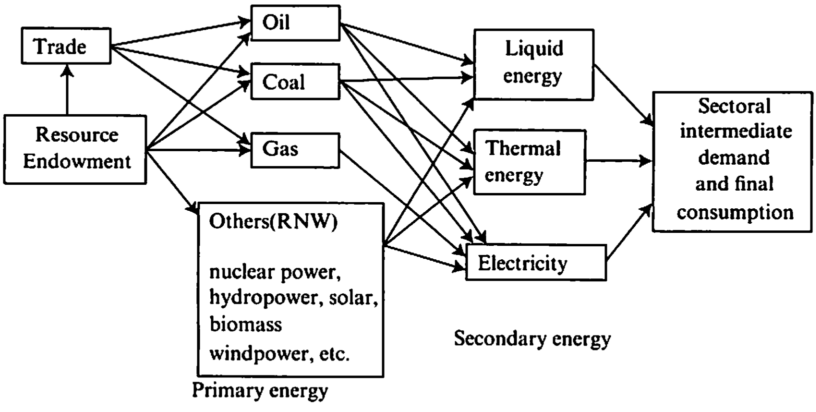
THERESIA has two special features to evaluate the sectoral activities in details: first, THERESIA can contain both the sectoral production functions and the aggregated one to deal with the trade-off between detailed outcome and numerical calculation difficulty while DEARS has one macro production function for each region. For instance, current THERESIA in this paper incorporates the sectoral production functions for the iron and steel industry sector, the chemical products, paper, cement and glass industry

Figure 1: Conceptual framework of THERESIA (simplified)[*)]

			Intermediate Inputs				Final demand			
			Non-energy sectors		Energy sectors		trade	Invest-ments	Con-sumption	Output
			1	2	Primary	Secondary	m	I	C	Q
Int. Inputs	Non-energy Sectors	1	$X_{11}= Q_1 \cdot a_{11}$	$X_{12}= Q_2 \cdot a_{12}$	O	O	m_1	I_1	C_1	Q_1
		2	$X_{21}= Q_1 \cdot a_{21}$	$X_{22}= Q_2 \cdot a_{22}$	O	O	m_2	I_2	C_2	Q_2
	Energy Sectors	Primary	O	O	O	Xpe	mp	O	O	EC_pre= PpS
		Secondary	$Xe_1=$ PeE_1	$Xe_2=$ PeE_2	O	O	O	O	Ce= PeEc	EC= PeE
Value Added		Capital K	$Pk \cdot K_1$	$Pk \cdot K_2$	VA_pre	VA_E				Y
		LabourL	$PL \cdot L_1$	$PL \cdot L_2$						
Output		Q	Q_1	Q_2	EC_pre= PpS	EC= PeE				Q

*) For the sake of simplicity, intermediate inputs and labour costs for energy sectors are omitted in Figure 2. Needless to say, these numbers are not always 0 according to the statistics.

Figure 2: Concept of Energy Flows (simplified)



sector and the transportation machinery industry sector[1]. Second, labour sector is classified into two categories, i.e. professional labour and other non-professional group according to the GTAP data base. In THERESIA, two types of production function are formulated and compared: Cobb-Douglas type function of professional labour, other non-professional labour, capital and secondary energy inputs implying unity substitution elasticity among input factors and CES function with low substitutability between professional labour and capital implying that the role of education could be strongly embodied in the capital. There are some reasons to assume different substitutability between professional and non-professional labour; the first one is the rapid growth of information technology (IT) industries. The knowledge based engineers, the software developers and other experts like lawyers and executive managers may hardly be substituted by the information equipment while the general clerical workers could be replaced by the sophisticated technologies. It is also the case that there are workers in the firms who could be replaced by the industrial robots and also the professional engineers who are not.

3.1.1 Formulation of energy flows

Energy flows from fossil fuels to electricity are further disaggregated into such power generation options as conventional fired plant, advanced combined cycle plant and fuel cell with different efficiencies and capital costs. They are aggregated into VA_E in Figure 1. Extraction and production cost of primary energy source is assumed to be a function of cumulative production following Rogner (1997). Total extraction and production cost during the period is represented by VA_pre in Figure 1. These are formulated as follows for the period t and region h.

$$S^h_{k,t} = \sum_j XE^h_{k,j,t} \tag{1}$$

$$S^h_{k,t} = SD^h_{k,t} + Sim^h_{k,t} \tag{2}$$

[1] THERESIA still requires around two days for one calculation with 15 regions, 12 industry sectors and 7 energy categories for 7 periods by GAMS-CONOPT3 on 3.2GHz i7Core PC.

k: primary energy source, k=coal, oil, gas and others
j: secondary energy, j=liquid fuel, thermal energy and electricity
$S^h_{k,t}$: primary energy supply
$SD^h_{k,t}$: primary energy domestic production
$Sim^h_{k,t}$: primary energy net import
$XE^h_{k,j,t}$: energy flow from primary energy k to secondary energy j

$$XE^h_{k,j,t} = \sum_m XG^h_{k,j,m,t} \tag{3}$$

m: conversion technologies
$XG^h_{k,j,m,t}$: energy demand for conversion technology m of primary energy k for secondary energy j

$$E^h_{j,t} = \sum_m Eff^h_{k,j,m,t}\, XG^h_{k,j,m,t} + Eim^h_{j,t} \tag{4}$$

$E^h_{j,t}$: secondary energy supply
$Eim^h_{j,t}$: secondary energy net import (only for liquid fuel)
$Eff^h_{k,j,m,t}$: conversion efficiency of technology m

$$Scum^h_{k,t} = Scum^h_{k,t-1} + \frac{1}{2}(SD^h_{k,t-1} + SD^h_{k,t})\times Yr \tag{5}$$

$$VA\_pre^h_{k,t} = SD^h_{k,t} \times f^h_k(Scum^h_{k,t}) \tag{6}$$

$Scum^h_{k,t}$: cumulative production of primary energy k
Yr: duration of one simulation period (10 years)
$f^h_k(x)$: extraction and production cost supply curve of fossil energy

$$VA\_E^h_{j,t} = \sum_k \sum_m XG^h_{k,j,m,t} \times FCe^h_{k,j,m,t} \tag{7}$$

$FCe^h_{k,j,m,t}$: capital cost of conversion technology m of primary energy k for secondary energy j

Wholesale prices of the primary and the secondary energy are defined by the total cost, i.e. capital costs + intermediate inputs + labour costs (if available), divided by total supply.

3.1.2 Formulation of labour supply

GTAP data-base provides two labour supply categories, i.e. professional labour and other non-professional labour. It could be generally understood that (1) the business service industry including the information and communication sector and the finance service sector are relatively lower capital intensive than existing manufacturing industries and that (2) the capital and equipments are embodied in the human resources as a basis of those knowledge-based businesses. The more the fraction of these industries in the world economy grows, the more the professional or high-educated labour would be needed as the key driving force. It would be an interesting topic how the world industry structure is influenced by the establishment of the education and professional training system. Furthermore, those structure changes would also affect the economic impacts of the global warming mitigation policies. On the other hand, unskilled labour would be more flexibly substituted by capital.

THERESIA model tries to assess how the international economy and energy structure are affected by the heterogeneity of the above labour categories. THERESIA incorporates two types of production function and compares how the difference of substitution elasticity affects:

(Cobb-Douglas type) $$YE^h_{i,t} = A^h_{i,t} \cdot K^h_{i,t}{}^{\alpha^h_i} \cdot LH^h_{i,t}{}^{\beta^h_i} \cdot LL^h_{i,t}{}^{\gamma^h_i} \times \left[\prod_j E^h_{i,j,t}{}^{\theta^h_{i,j}} \right]^{1-\beta_i} \quad (8)$$

(CES type)

$$YE^h_{i,t} = B^h_i \cdot \left[\left\{ \left(K^h_{i,t}{}^{-\mu^h_i} + C^h_i \cdot LH^h_{i,t}{}^{-\mu^h_i} \right)^{-\frac{1}{\mu^h_i}} \right\}^{\lambda^h_i} LL^h_{i,t}{}^{1-\lambda^h_i} \right]^{\beta^h_i} \times \left[\prod_j E^h_{i,t}{}^{\theta^h_{i,j}} \right]^{1-\beta^h_i} \quad (9)$$

where i, $YE^h_{i,t}$, $LH^h_{i,t}$, $LL^h_{i,t}$, $K^h_{i,t}$ and $E^h_{i,j,t}$ represent industry sector, value added plus energy expenditure, professional labour input, other non-professional labour input, capital stock and j-type secondary energy inputs, for i-th industry, the h-th region and at period t, respectively. A^h_i, B^h_i, V^h_i, α^h_i, β^h_i, γ^h_i, μ^h_i, λ^h_i *and* $\theta^h_{i,j}$ are the parameters.

Labour supply constraints are as follows:

$$\textstyle\sum_i LH^h_{i,t} \leq LHtotal^h_t \quad (10)$$

$$\textstyle\sum_i LH^h_{i,t} + LL^h_{i,t} \leq Ltotal^h_t \quad (11)$$

where $LHtotal^h$t and $Ltotal^h_t$ represent exogenous supply of the professional labour and total labour force, respectively. Equation (11) implies professional workers can also work as unskilled general workers. As can be seen, our model currently does not consider the international mobility of professional workers as well as the institutional issues in the real labor market. These will be further discussed in the next stage.

3.1.3 Other Equations

Other model equations consists of row-wise balance representing the distribution of output commodity, column-wise balance corresponding to the financial balance and international trade balance which are basically similar to the existing CGE model. Intermediate inputs of each industry are defined according to the input-output coefficients and YE_i assuming the Leontief model.

Final demand vector $\mathbf{FD}^h_t$ consists of private sector investments $\mathbf{IP}^h_t$, governmental sector investments $\mathbf{IG}^h_t$, export $\mathbf{Tx}^h_t$, import $\mathbf{Tm}^h_t$, private sector consumption $\mathbf{CP}^h_t$ and governmental sector consumption $\mathbf{CG}^h_t$. Provided investment coeffcient matrix $\mathbf{CPF}^h_t$ and investment for sector i, $I^h_{i,t}$

$$\mathbf{IP}^h_t = \mathbf{CPF}^h_t \left[I^h_{1,t}, I^h_{2,t}, I^h_{3,t}, \cdots I^h_{N,t} \right]^T \quad (12)$$

holds where N represents number of sectors.

Conventional capital formation relationship

$$K_{i,t} = (1-\delta)\, K_{i,t-1} + I_{i,t-1} \cdot Yr \quad (13)$$

where $I_{i,t}$ represents investment, is also included.

THERESIA employs the aggregated consumption function and maximizes their discount sum as follows:

$$\max.\ \Phi = \sum_t (1-r)^t \sum_h w_h \sum_t L^h_t \ln\left[\prod_i (CP^h_{i,t})^{\mu^h_i} \Big/ L^h_t\right] \quad (14)$$

where w_h and μ_i represent the weights. We tentatively give w_h and μ^h_i the total consumption and the consumption fraction of commodity i in region h, respectively. It is also assumed that the consumption and the investment vectors in the governmental sector grow proportionally to GDP. According to GTAP, Armington model on the tradable goods is also imposed.

3.2 Data definition

THERESIA deals with 15 regions, 12 industry sectors, 4 primary energy sources and 3 secondary energy categories shown in Table 1 while DEARS (Honma, 2006) contains 18 regions, 18 industry sectors, 7 primary energy sources and 4 energy categories. Based on GTAP Ver.5, we aggregated the sectors and regions according to the Table.1

Table 1: Definition of regions, industry sectors and energy

(a) Region

Code	Region
USA	USA, Canada
MCM	Central America
BRA	Brazil
SAM	South America
WEP	Western Europa
EEP	Eastern Europa
FSU	Former USSR
AFR	Africa
JPN	Japan
CHN	China
ASN	East–South Asia
IND	India
TME	Middle–East
ANZ	Oceania
XAP	Rest of the world

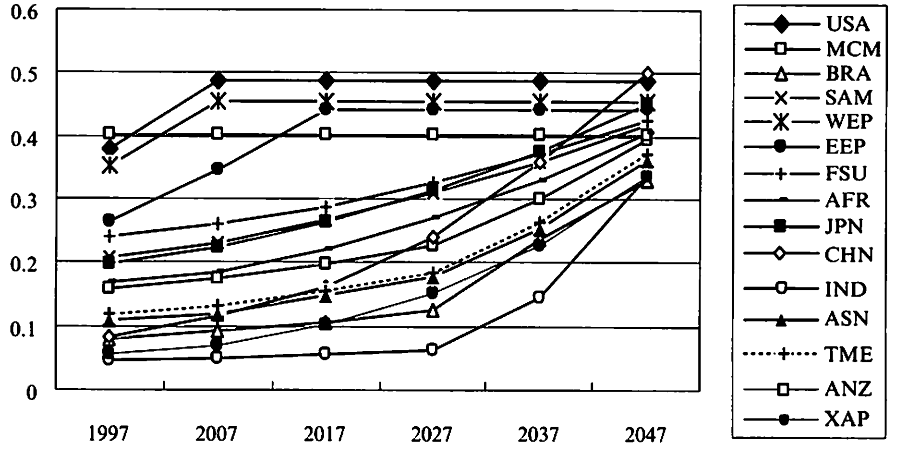
(b) Industry sectors

Code	Industry
INS	Iron and Steel
CPG	Chemical products, Paper Glass and Cement
TRN	Transportaion Machinery
OME	Other machinery
FPR	Food and Beverage
CNS	Construction
TWL	Textiles
OMF	Other manufacturing
AGR	Agriculture and Fishery
T_T	Transportation services
BSR	Business services
SSR	Social services

(c) Energy

	Code	Description
Primary	Coal	Coal
	Oil	oil
	Gas	Natural gas
	RNW	nuclear and renewables
Secondary	P_C	Oil products
	THM	Thermal energy
	ELC	Electricity

Figure 3: Assumption on future fraction of professional labour



*) Data for 1997–2047 is exhibited to show the convergence behaviour of professional labour fraction although the model results are available for 1997–2037.

(a) and (b). We extract the energy production, conversion and consumption data from IEA Energy Balance Tables (IEA, 2007). We aggregate such non-fossil primary energy sources as nuclear power, biomass, PV, wind and other renewables into one category "RNW" where the conversion efficiencies of nuclear power, PV and wind power are assumed to be 33%, 100% and 100% respectively.

While the wage expenditure by sector is provided in GTAP data, the sectoral labour force in number by category is not available. Since the definition of GTAP labour category follows ILO, according to the ILO Labour Statistics (ILO 2007), we picked up the total labour force (Ltotal) and professional labour force (LHtotal) by region. We distributed the Ltotal and LHtotal among sectors proportionally to the wage expenditure assuming that the effective wage is identical among sectors.

In THERESIA, total labour supply is given exogenously. We estimate the future labour supply in the following manner: first, future total labour supply of each region grows proportionally to the projected population given by UN (2006) by region. Second, we estimate the future trends of the share of professional labour extrapolating the historical trend assuming their upper limit to be 50%. Figure 3 exhibits the projection of the professional labour share.

The parameters on production functions are estimated based on GTAP ver 5 in 1997. We also assumed the 5% discount rate. For CES production function (Equation (9)), substitution elasticity between capital stock and professional labour is needed. It is preferable to estimate them based on the historical data. At the moment, due to the lack of the data, we tentatively assumed 0.2 uniformly[2]. Based on the cost share among capital, energy inputs, and two labour classes as well as the above elasticity of substitution, the parameters of the production functions in (8) and (9) can be determined by the calibration procedure (GTAP, 2008). Actual value would be between this low value and 1.0 (Cobb-Douglas case).

[2] The value 0.2 was selected as low as possible to give the stable calculation in this study.

4 Results

4.1 Simulation cases

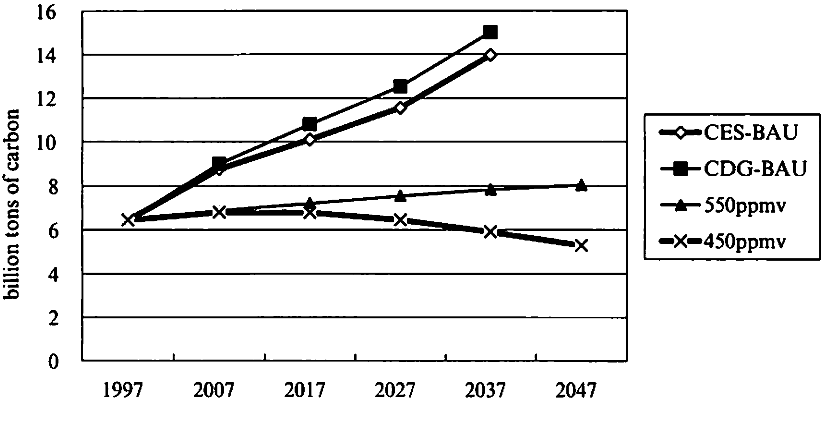
Various simulation cases are available based on THERESIA model. In this paper, we present the following 6 cases for 1997–2037:

CES-BAU: low substitution elasticity (=0.2) between professional labour and capital
CES-550: CES-BAU+ CO_2 550ppmv concentration carbon control policy
CES-450: CES-BAU+ CO_2 450ppmv concentration carbon control policy
CDG-BAU: high substitution elasticity (=1.0) between professional labour and capital
CDG-550: CDG-BAU+ CO2 550ppmv concentration carbon control policy
CDG-450: CDG-BAU+ CO_2 450ppmv concentration carbon control policy

In the carbon control policy cases, we employ the WRE-550 and WRE-450 carbon emission trajectories IPCC-TAR (2001) which provide atmospheric CO_2 concentration at 550ppmv and 450 ppmv in 2100, respectively. It should be noted that we deal with only carbon emission instead of the total assessment of all global warming gases such as CH_4, N_2O, CFC's, etc. since the measurement of emissions, the mitigation cost and the technological availability of these gases are far more uncertain than those of CO2. Furthermore, the above carbon emission control policy involving all countries imply the perfect global emission trading system unlike the emission target policies recently proposed by nations individually.

Figure 4 exhibits the carbon emission upper limit scenarios on WRE-550 and WRE-450. Carbon emission simulation results on CES-BAU and CDG-BAU are also exhibited in this figure, where carbon emission should have been already reduced from BAU path in 2007 to meet the future carbon concentration stabilization.

Figure 4: Carbon emission scenario on WRE-550 and WRE-450 and simulation results on CES-BAU and CDG-BAU

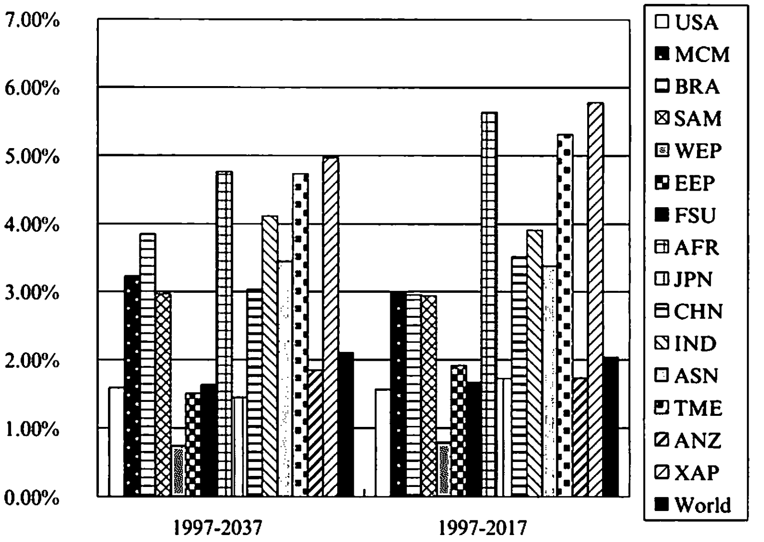


4.2 Results

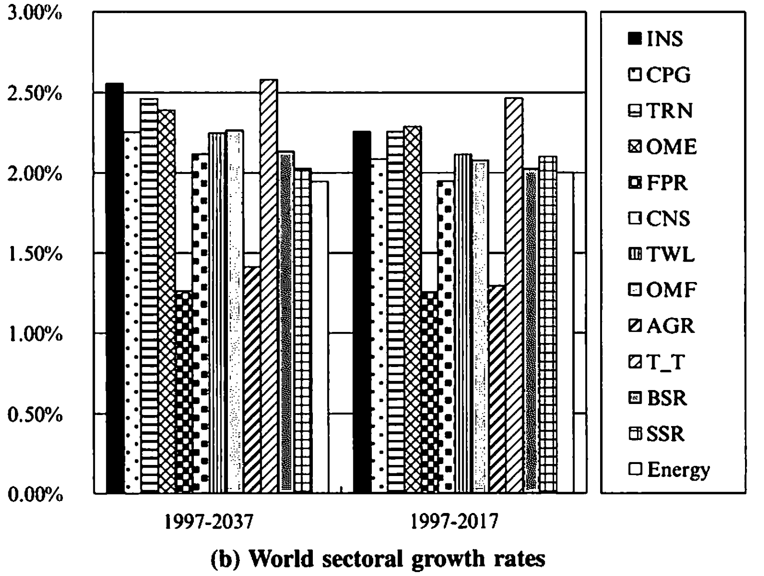
Simulation results on CES-BAU are firstly exhibited as reference of simulations. Figure 5 shows the simulation results on the growth rates of world regional GDP and world sectoral GDP between 1997–2037 and 1997–2017. In CES-BAU, world annual GDP growth rate is 2.15% where those of developed regions are slightly moderate.

Figure 6 exhibits the primary energy productionprofile for CES-BAU and CES 550. When carbon control policy is imposed, both economic activities and energy tech-

Figure 5: Annual growth rates of regional and sectoral GDP during 1997–2037 and 1997–2017 (CES-BAU)

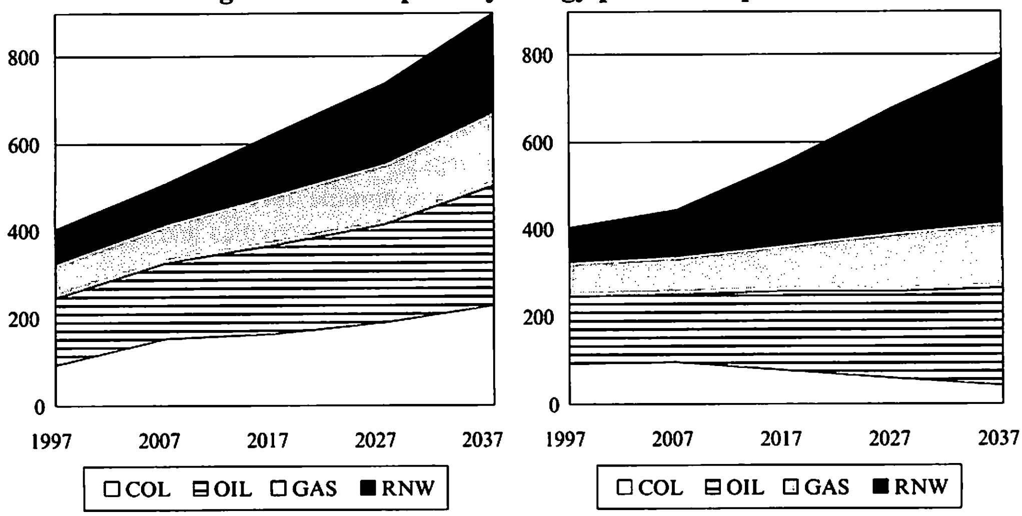


(a) Regional growth rates



(b) World sectoral growth rates

Figure 6: World primary energy production profiles



(a) CES-BAU **(b) CES-550**

nologies are influenced to meet the carbon emission limit. In this paper, we focus on the global cooperation scenario. Emission trades under the differentiated emission rights and other new measures like sectoral approaches are not touched upon in this paper. Figure 7 exhibits the regional and the sectoral loss of GDP of CES-550 from CES-BAU in 2017 and 2037.

One can observe that GDP loss appears relatively large in developed regions in Figure 7 except for AFR and TME. The loss in CHN is low while that in IND is large. The effects of carbon control policy could appear differently especially among developing regions.The losses of outputs in manufacturing industries and construction sector related to the capital formation are larger than service sectors. World GDP loss comes to 2.03% in 2017 and 1.37% in 2037, respectively. The above tendency holds in more stringent carbon control case.

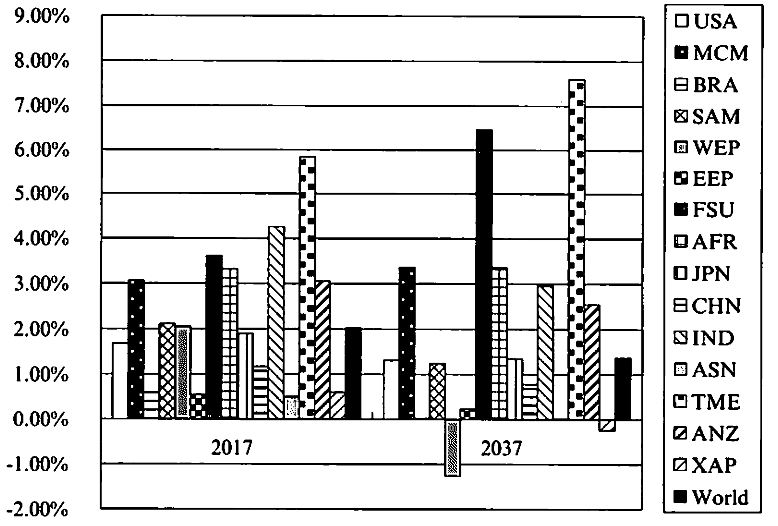
Figure 8 shows the regional and the sectoral loss of GDP of CES-450 from CES-BAU in 2017 and 2037, where world GDP loss comes to 2.67% in 2017 and 3.10% in 2037, respectively.

When the substitution elasticity between professional labour and capital stock is high, the economic activities vary even if other conditions are identical. Figure 9 shows the growth rate of outputs based on low elasticity case (CES-BAU) to see how the regional and the sectoral outputs are influenced.

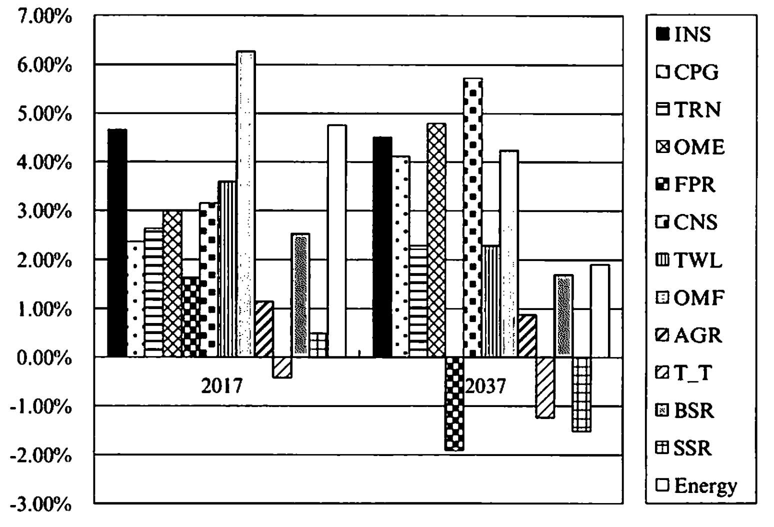
Figure 9(a) suggests that GDP in such newly developed regions as EEP, FSU, CHN,IND and ASN increases in CDG-BAU reflecting the flexibility of labour. One can observe that such capital related industries as material, machinery and construction sectors grow highly in high elasticity case especially in 2017 as shown in Figure 9(b) while the increased rates in 2037 are almost same. This suggests that CDG-BAU case stimulates the capital formation in the early stage. Thus, World GDP in CDG-BAU is larger than that of CES-BAU at 3.97% in 2017 and at 7.98% in 2037.

However, the loss of GDP in carbon control policy shows different picture. Figure 10 shows the regional and the sectoral loss of GDP of CDG-550 from CDG-BAU in

Figure 7: GDP losses in CES-550 case from CES-BAU in 2017 and 2037



(a) Regional losses

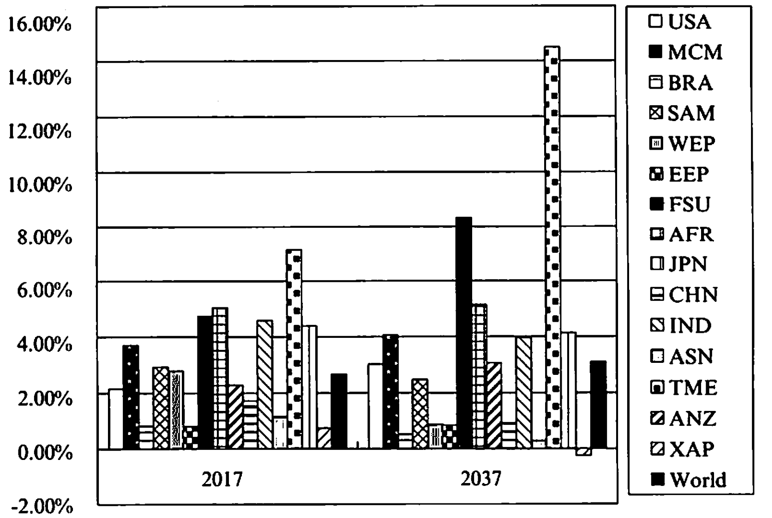


(b) World sectoral losses

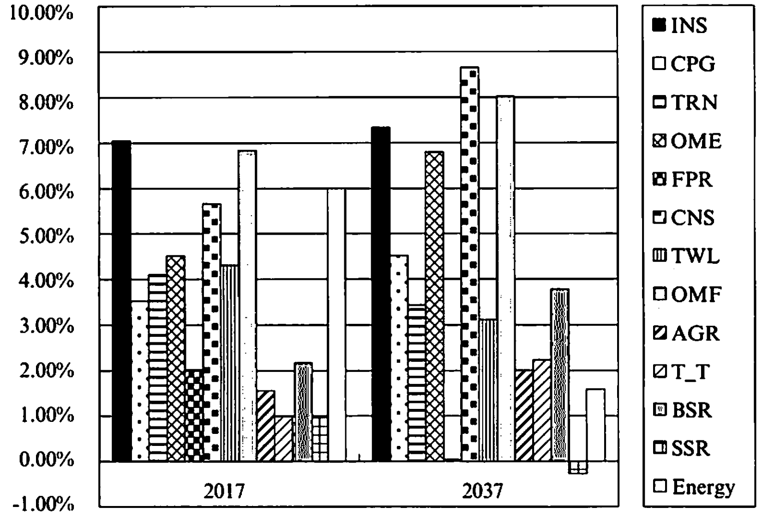
2017 and 2037, where world GDP loss comes to 3.57% in 2017 and 2.96% in 2037, respectively. It is shown that the GDP losses in TME, AFR, JPN and ANZ in Figure 10(a) are especially larger than those in Figure 8(a). Reflecting the decrease of investment, construction sector suffers from large loss as shown in Figure 10(b). The above observation holds in CDG-450 where world GDP loss comes to 4.17% in 2017 and 5.25% in 2037.

The sectoral and the regional GDP loss patterns in 2037 are summarized in Table 2. Comparing CES-450 values with those of CDG-450, one can observe how the assumption on professional labour substitutability affects the economic damage caused by thr carbon control policy.

Figure 8: GDP losses in CES-450 case from CES-BAU in 2017 and 2037



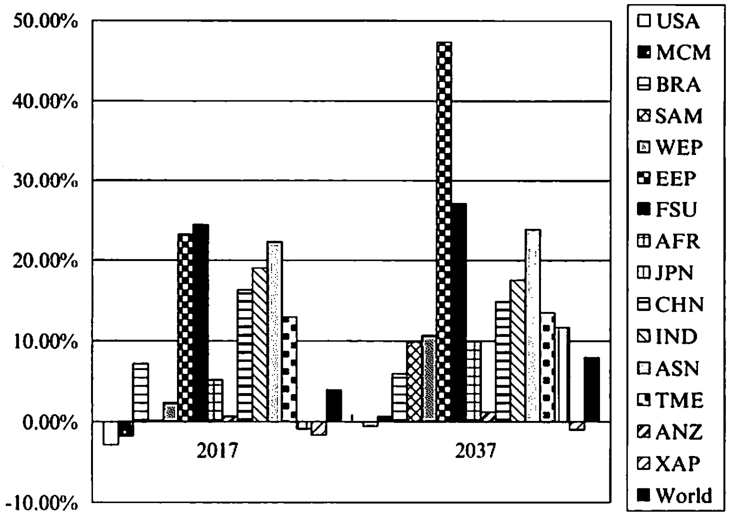
(a) Regional losses



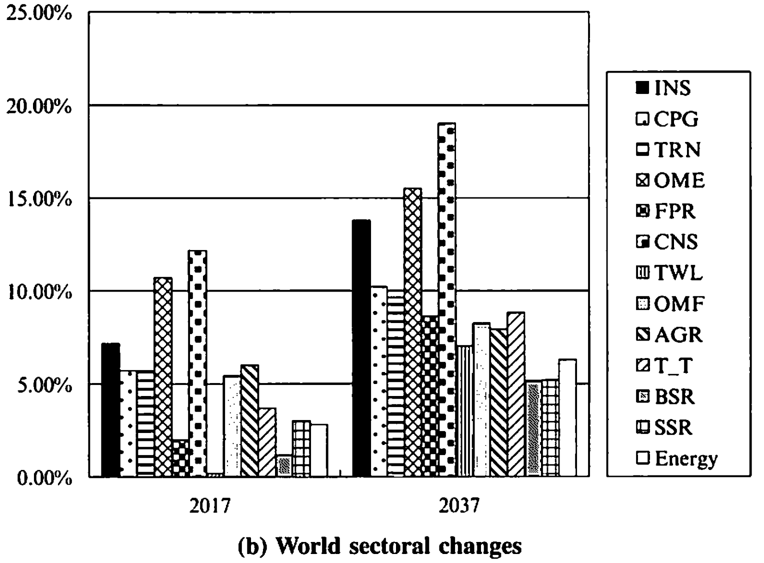
(b) World sectoral losses

First, GDP losses in CPG, FPR, T_T and SSR of CES cases are apparently lower than those of CDG cases while those in INS, TRN, OME and CNS related to the capital formation remain high. This point is remarkable. When professional labour force is strongly embodied in the capital stock, investment would be constrained by its supply capacity. In low substitution elasticity case, since the investment can not compensate for the labour supply constraints, the investment will decrease. This causes the lower demand for construction sector and other capital related sectors, i.e. iron and steel, machinery and etc. In other words, the lower elasticity between labour and capital would stimulate the shift from high capital intensive industry to lower ones, which also can be low energy intensive. This industry structure shift could have mitigated the eco-

Figure 9: GDP changes of CDG-BAU from CES-BAU in 2017 and 2037



(a) Regional changes

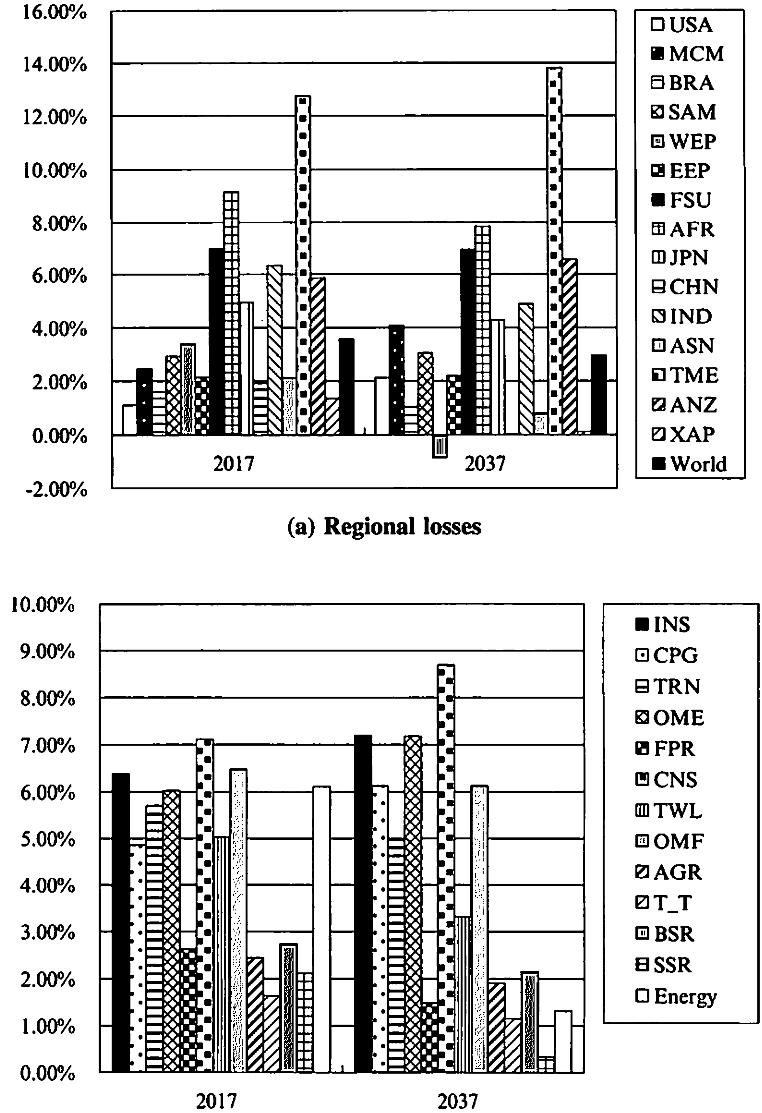


(b) World sectoral changes

nomic damage caused by the carbon control policies. One can also observe some large negative values inTable 2 which indicate rapid increase of production. Since both the global output loss of the sector and regional total loss are moderate, such extreme numbers could represent a part of indutry reallocation.

Figure 11 shows the trends of world capital stock and the ratio of the capital to the professional labour demand normalized at initial values to examine the above observation. Capital stock in low elasticity (K-CES) is lower than those in high elasticity case (K-CDG) while the difference of the ratio of capital stock to professional labour demand between these two cases (K/LH-CES and K/LH-CDG) is relatively small. Although the labour is fully employed in equation (11) in the equilibrium, some part of

Figure 10: GDP losses in CDG-550 case from CDG-BAU in 2017 and 2037



(a) Regional losses

(b) World sectoral loses

professional labour are employed as general worker, even if in most regions professional labour is also fully employed as shown in Figure 12. These figures suggest that capital tends to substitute the professional labour in the high substitution elasticity case.

Second, directions of carbon control influence are basically same except for some cells: in JPN output of iron and steel industry (INS) decreases in CES-450 while it increases in CDG-450. Chemical products (CPG) in USA and ANS and food products in TME are also the case.

Third, Table 2 also shows the differences in economic impacts of carbon control policy among regions. As can be seen in the column "total" of Table-2, the GDP losses

Table 2: Summary of regional and sectoral GDP losses in 2037

CES–550IN

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	−71.36%	−16.12%	5.28%	4.69%	4.58%	6.91%	5.63%	70.19%	1.53%	7.34%	2.03%	1.53%	2.18%
MCM	8.20%	16.83%	3.32%	4.54%	0.17%	9.85%	2.17%	6.29%	1.69%	3.63%	−4.54%	−0.04%	2.40%
BRA	43.43%	−13.58%	3.40%	4.62%	−27.87%	1.89%	94.97%	−12.55%	0.56%	−0.37%	−5.01%	0.56%	0.81%
SAM	19.71%	−48.03%	7.24%	5.25%	7.15%	6.98%	0.81%	−9.46%	1.91%	8.68%	9.10%	1.91%	2.71%
WEP	0.60%	−5.13%	5.16%	10.84%	2.43%	10.22%	5.21%	−24.90%	1.05%	−10.71%	−4.23%	1.05%	1.49%
EEP	8.11%	−14.25%	3.29%	4.53%	−2.60%	2.43%	5.66%	−24.98%	−0.02%	6.91%	−4.27%	2.87%	−0.02%
FSU	39.38%	−13.99%	5.83%	−180.82%	3.76%	9.24%	5.80%	47.66%	1.57%	17.92%	−9.84%	1.57%	2.23%
AFR	10.54%	−14.60%	4.24%	4.53%	0.20%	13.78%	5.71%	59.25%	2.71%	−0.15%	3.99%	−0.32%	3.85%
JPN	7.91%	−6.34%	4.21%	7.20%	2.12%	11.24%	3.65%	−25.00%	1.68%	−8.74%	6.66%	0.22%	2.39%
CHN	−4.99%	37.78%	1.02%	4.53%	−0.57%	2.21%	−3.56%	−31.09%	0.47%	−5.81%	−36.49%	2.11%	0.67%
IND	−14.76%	−14.40%	−7.29%	4.49%	0.21%	2.73%	−0.32%	−6.12%	0.40%	−4.15%	−0.39%	7.23%	0.57%
ASN	15.22%	7.00%	−0.48%	−51.63%	0.22%	2.41%	−86.87%	−77.43%	0.42%	−2.56%	8.78%	0.28%	0.59%
TME	40.24%	83.67%	2.99%	3.67%	−72.15%	23.97%	5.54%	39.04%	3.87%	11.35%	7.01%	−34.99%	5.48%
ANZ	7.90%	−14.74%	3.30%	−100.62%	0.19%	1.92%	5.69%	−5.89%	0.49%	12.09%	14.37%	−13.84%	0.70%
XAP	−13.13%	−8.39%	3.09%	4.61%	0.21%	−3.59%	25.30%	−6.60%	−0.51%	17.63%	−3.94%	1.29%	−0.73%
World	6.20%	2.85%	4.72%	5.83%	0.62%	7.58%	3.82%	7.80%	1.04%	−0.11%	1.65%	−0.91%	1.88%

CES–450

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	−121.34%	−35.02%	6.10%	7.34%	6.45%	10.56%	5.38%	74.18%	2.13%	5.32%	5.84%	2.13%	3.03%
MCM	22.41%	42.87%	3.67%	9.16%	0.81%	14.87%	3.83%	14.68%	3.19%	2.49%	−18.61%	3.58%	4.52%
BRA	42.11%	−7.64%	3.53%	9.21%	−32.67%	2.84%	94.96%	0.00%	0.90%	4.39%	−4.95%	0.90%	1.28%
SAM	22.86%	−46.78%	44.17%	23.15%	7.24%	9.70%	1.23%	−12.76%	2.75%	6.43%	1.24%	2.75%	3.91%
WEP	−1.95%	−2.04%	4.30%	11.22%	2.28%	6.76%	4.35%	−8.17%	2.00%	−7.42%	2.01%	2.00%	2.85%
EEP	22.44%	−8.24%	3.46%	9.15%	−3.45%	4.06%	5.43%	−8.23%	1.12%	27.08%	1.97%	−6.08%	1.60%
FSU	59.84%	−1.49%	7.09%	−649.52%	0.88%	15.99%	5.49%	54.65%	2.05%	18.40%	−6.73%	2.05%	2.92%
AFR	17.46%	−8.39%	4.70%	9.25%	0.84%	22.55%	5.48%	52.55%	5.02%	−30.38%	12.67%	1.23%	7.09%
JPN	22.83%	−8.26%	6.56%	11.03%	5.03%	15.19%	4.78%	−298.18%	3.22%	19.31%	10.82%	−9.25%	4.57%
CHN	−22.87%	44.93%	0.13%	9.11%	0.50%	5.99%	3.80%	−8.19%	0.35%	−14.96%	−110.85%	18.73%	0.50%
IND	−9.64%	−8.40%	−32.98%	9.12%	0.84%	6.83%	3.53%	0.00%	1.70%	−1.72%	1.77%	6.51%	2.42%
ASN	30.15%	12.20%	2.03%	−30.01%	0.85%	5.66%	−86.61%	−64.11%	2.22%	−34.44%	17.30%	−3.71%	3.16%
TME	74.74%	92.85%	3.11%	8.23%	−51.35%	28.45%	5.30%	47.16%	5.83%	21.02%	12.22%	−46.12%	8.22%
ANZ	22.08%	−8.41%	3.46%	−98.70%	0.82%	4.41%	5.46%	2.11%	2.29%	−65.57%	23.47%	−6.45%	3.26%
XAP	−6.04%	−3.42%	3.41%	9.24%	−0.47%	−2.79%	22.28%	−1.15%	−0.17%	1.97%	0.59%	−3.06%	−0.24%
World	8.62%	3.85%	5.91%	7.88%	2.12%	10.07%	3.76%	9.03%	2.06%	0.83%	4.32%	−0.88%	3.36%

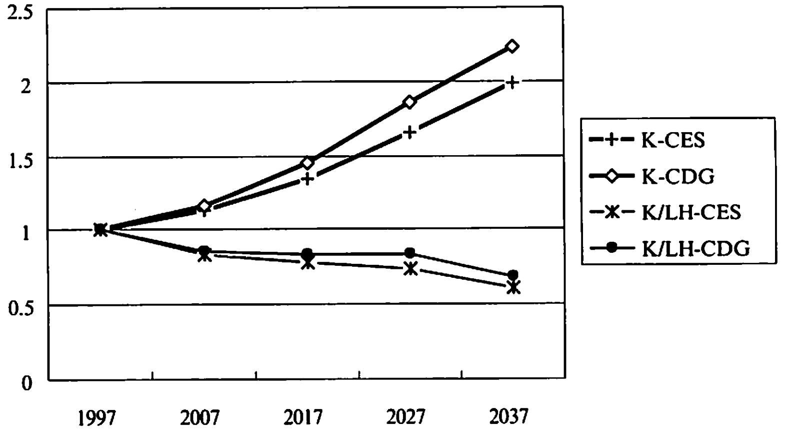
CDG–550

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	−15.62%	28.18%	6.00%	−21.86%	−12.55%	8.85%	16.27%	52.04%	1.57%	5.63%	0.04%	1.57%	2.23%
MCM	13.83%	12.19%	5.29%	22.53%	4.44%	12.74%	6.34%	4.47%	2.18%	−0.55%	−3.99%	0.80%	3.10%
BRA	20.27%	5.48%	5.18%	22.49%	−25.09%	6.62%	16.29%	12.92%	1.80%	3.95%	2.05%	1.49%	2.56%
SAM	−7.38%	6.99%	17.90%	7.91%	4.50%	9.09%	4.79%	−12.18%	2.98%	7.00%	2.86%	2.98%	4.23%
WEP	1.94%	−20.71%	5.82%	18.04%	4.46%	1.25%	15.20%	16.91%	1.95%	−11.80%	3.34%	1.95%	2.78%
EEP	5.49%	−31.91%	5.18%	22.54%	−1.14%	0.52%	9.30%	−225.69%	2.16%	7.95%	9.46%	0.99%	3.07%
FSU	56.11%	−18.87%	−2.95%	−473.33%	4.47%	15.87%	16.32%	48.36%	2.76%	20.10%	0.66%	2.76%	3.92%
AFR	14.69%	−35.44%	3.54%	22.68%	4.46%	21.07%	16.32%	32.39%	4.87%	4.15%	4.76%	9.82%	6.88%
JPN	−70.11%	−9.88%	7.42%	19.06%	5.69%	19.81%	7.34%	−3.25%	4.52%	−3.45%	7.58%	5.53%	6.40%
CHN	−11.63%	45.02%	−18.59%	22.48%	2.62%	1.92%	−6.93%	−33.89%	0.30%	−7.28%	−53.00%	3.31%	0.43%
IND	21.57%	−54.18%	−23.96%	22.55%	4.47%	3.08%	5.74%	8.27%	1.21%	9.41%	−20.89%	3.46%	1.73%
ASN	9.79%	−53.76%	3.86%	−12.79%	8.83%	3.39%	−76.27%	−108.47%	1.47%	−5.15%	9.78%	4.23%	2.10%
TME	25.92%	68.95%	33.59%	22.27%	1.19%	27.73%	16.29%	27.34%	7.99%	7.76%	13.01%	−17.06%	11.22%
ANZ	11.06%	−13.82%	5.23%	−246.78%	4.44%	16.89%	16.30%	8.92%	4.25%	4.19%	15.39%	1.94%	6.01%
XAP	14.70%	15.81%	4.84%	22.53%	2.06%	−0.61%	−4.47%	−17.20%	0.06%	21.72%	1.19%	−12.26%	0.08%
World	5.61%	5.52%	6.17%	5.79%	2.05%	9.01%	3.20%	10.01%	2.09%	0.85%	3.20%	1.62%	3.50%

	INS	CPG	TRN	OME	FPR	CNS	TWL	OMF	AGR	T_T	BSR	SSR	total
USA	−43.97%	20.44%	8.20%	−17.22%	−14.83%	11.38%	16.69%	74.92%	2.21%	3.58%	2.52%	2.21%	3.14%
MCM	30.46%	30.70%	7.38%	23.25%	6.79%	16.70%	7.91%	10.86%	3.46%	0.54%	−8.12%	0.25%	4.91%
BRA	39.00%	−4.15%	7.07%	23.22%	−27.03%	8.15%	16.72%	12.92%	2.63%	8.32%	3.25%	1.18%	3.74%
SAM	6.53%	−11.06%	21.63%	26.70%	6.85%	13.29%	5.05%	−9.50%	4.63%	9.45%	4.17%	4.63%	6.54%
WEP	10.51%	−15.96%	7.72%	21.76%	6.20%	6.83%	15.60%	18.31%	3.72%	−7.09%	4.62%	2.21%	5.27%
EEP	7.30%	−25.80%	7.06%	23.24%	−0.65%	4.15%	9.80%	−222.38%	3.47%	2.87%	23.59%	−12.34%	4.92%
FSU	69.39%	−30.18%	8.83%	−450.65%	6.83%	17.48%	16.74%	49.25%	4.95%	20.81%	3.69%	4.95%	6.99%
AFR	21.97%	−107.44%	5.56%	23.44%	6.82%	32.45%	16.75%	32.41%	8.45%	−32.81%	17.05%	9.66%	11.85%
JPN	−92.97%	−2.63%	9.60%	19.44%	8.16%	20.70%	8.12%	−19.47%	6.09%	44.98%	−9.57%	4.19%	8.59%
CHN	−14.58%	49.06%	−29.18%	23.19%	6.57%	5.33%	−2.57%	−57.50%	0.62%	−81.45%	−87.09%	20.13%	0.88%
IND	25.66%	−47.15%	−37.24%	23.30%	6.82%	8.00%	8.23%	11.36%	2.51%	10.45%	−11.71%	3.88%	3.57%
ASN	2.38%	−46.42%	4.04%	−25.51%	11.07%	8.50%	−75.30%	−102.13%	3.57%	−36.71%	18.36%	6.31%	5.05%
TME	70.21%	92.39%	−16.70%	22.78%	3.93%	35.42%	16.71%	28.43%	11.62%	19.54%	21.79%	−31.94%	16.17%
ANZ	30.63%	−27.98%	7.12%	−232.06%	6.79%	25.59%	16.73%	11.30%	6.64%	4.08%	20.25%	2.20%	9.34%
XAP	32.11%	11.48%	6.77%	23.25%	2.08%	1.27%	−12.47%	−14.12%	0.42%	5.54%	1.89%	−5.38%	0.61%
World	7.75%	7.76%	7.97%	8.98%	3.58%	12.97%	3.77%	14.31%	3.57%	3.62%	5.41%	2.93%	5.63%

*) The positive numbers represent GDP losses from BAU case.

Figure 11: Trends of world capital stock and their ratio to professional labour demand



K-CES and K-CDG represent trends of capital stock in low and high elasticity cases respectively. K/LH-CES and K/LH-CDG show ratios of capital stock to professional labour in low and high elasticity cases respectively.

in developing regions are relatively moderate than those in developed region except for AFR and TME. In AFR, although the chemical products industry (CPG) increases under global carbon control policies, other manufacturing industries lose market. In the case of TME, most of the industry sectors decrease except for the social service sector (SSR). In other words, the carbon control policy could expand the discrepancy in economic activity especially among developing regions.

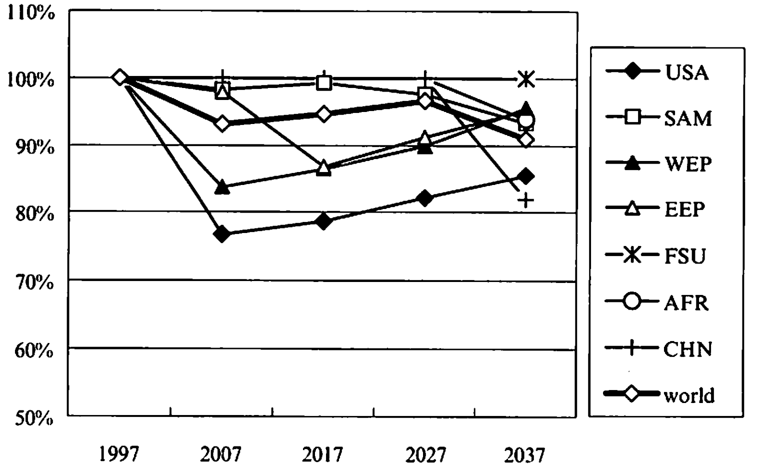
5 Conclusion

In this paper, we described the outline and some simulation results of the dynamic multi-sectoral multi-regional integrated model THERESIA. Our current findings are as follows: first, the economic loss of carbon control policy appears relatively large in developed regions. Second, economic damage in such capital related industry as iron and steel, machinery and construction are relatively high while those in service industries are low. Third, if we assume that the professional labour is strongly embodied in the capital, through the shift to the low capital intensive structure, economic dameges caused by the carbon control policy could be mitigated.

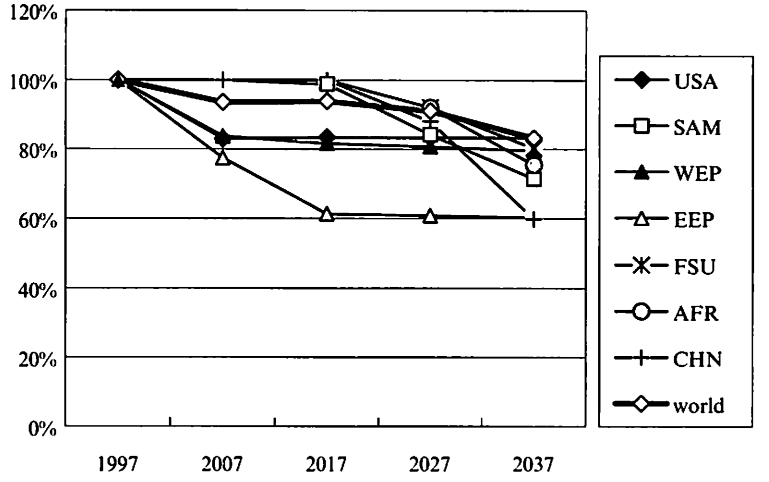
THERESIA currently leaves many assumptions caused by lack of information. For instance, the projection of input-output coefficients is mostly needed. Although we have proposed a method applying multivariate analysis (Yoda (2001)), its performance has not been well discussed. The estimation of capital coefficient matrix and its projection are mostly needed to see the industry transfer in details. Other constraints or modifications of the equations would be considered to reflect the societal changes in reality.

Nonetheless, we would conclude that the model framework of THERESIA we

Figure 12: Comparison of ratio of professional labour demand to potential supply



(a) low substitution elasticity case (CES-BAU)



(b) high substitution elasticity case (CDG-BAU)

*) In other regions, professional labour is fully employed through the period.

proposed here provides useful insights of this field.

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