

**An Interaction of Economy and Environment in Dynamic Computable General
Equilibrium Modelling with a Focus on Climate Change Issue in Korea :
A Proto-type Model**

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I. INTRODUCTION

This study addresses on interactions of economy and environment in a perfect foresight dynamic computable (or applied) general equilibrium (CGE) with a focus on greenhouse gas (GHG) mitigation strategy in Korea¹. The primary goal of this study is to evaluate greenhouse gas mitigation portfolios of changes in timing and magnitude with a particular focus on developing a methodology to integrate the bottom-up information on technical measures to reduce pollution (the characteristics of the abatement techniques) into a top-down multi-sectoral computable general equilibrium framework. To this end, a dynamic computable general equilibrium model is constructed including pollution and abatement as a proto-type of the model. The dynamic setting is essential, as most of the major interactions between the economy and the environment are essentially dynamic in nature and capital formation is a typically dynamic phenomenon. Climate change issue is a good example needed to dealt with in dynamic way in that the policy perspectives are in nature to cover long-term, usually at least more couple of decades, adaptation and impact forecasting. Optimisation or simulation is two broad approaches taken for the dynamic analysis on economic interest in general and climate change issue in particular. This study takes simulation approach : It compares consequences of GHG reduction schemes.

The CGE model is kept relatively simple, to allow maximum focus on the dynamic interactions between economy and environment. The model describes a national economy with three ordinary production sectors, one abatement sector and two consumer groups (in the current model version, there is no international trade). The two primary production factors are capital and labour.

Standard CGE models do not pay explicit attention to the characteristics of the technologies involved, but use smooth, continuous production and utility functions. This is a common critique by mostly technically oriented scientists on these top-down economic models. On the other hand, most models that do take into account the technical aspects of changing economic structures do not model the indirect economic effects of these technologies (*i.e.* they adopt a partial framework). The large number of technological options available for pollution reduction precludes the use of discrete technology modelling in broad empirical environmental-economic analysis. Therefore, in this article a new methodology is introduced² in which the advantages of the top-down approach are combined with the main information of the bottom-up approach.

This study concentrates on the economic consequences of pollution and abatement, while environmental stocks and damages by poor environmental quality on the economic system or on welfare are not taken into account in this proto-type model, remains further works. The environmental sub-model is purely represented by the pollution levels and abatement activities. In policy terms to secure certain level of emission, the model cannot be used for Pigouvian analyses, where the optimal tax rate is determined by the trade-off between abatement costs and

¹ For details, see Joh et al.(2000).

² Essentially the same methodology is used in a static framework in Dellink *et al.*(1999).

damage costs, but rather for Baumollian exercises where the cost-effective way to reach a predetermined policy target is analysed (Baumol, 1977).

Pollution is controlled by the government through a system of tradable ‘pollution rights’, which the producers and consumers can buy from the government. Producers and consumers have the endogenous choice between paying for their pollution by buying pollution rights or spending resources on pollution abatement activity, and will always choose the least-cost of the two.

The abatement cost curves, which describe the marginal abatement costs, are translated for each producer / consumer and environmental theme into an ‘iso-output curve’ of pollution and abatement, *i.e.* the abatement possibilities are presented as a function of pollution (a downward sloping curve). Then, a constant elasticity substitution (CES) function is calibrated to best fit the iso-output curve, and the CES-elasticity thus estimated describes the sector- and environmental theme-specific possibilities to substitute between pollution and abatement.

It should be noted that the model provides insight into the least costs of achieving a predetermined environmental policy objective, but cannot calculate the optimal rate of pollution control, as the damages caused by pollution are not taken into account.

II. MODEL STRUCTURE

As for production sector, nested CES functions were used in this model to permit different substitution elasticities between pairs of inputs. Major modifications to the general CGE model structure were made for this analysis.

First, in this model, energy sectors, which are intermediate inputs, are separated from other intermediate inputs. Energy sectors are distinguished clean- or dirty energy based on where they emit GHG or not. They, then, are made flexible inputs rather than a fixed proportion input so that substitution of clean- with dirty-energies vis-à-vis with other inputs is possible when the energy price increases due to an output tax on the energy.

Second, it is assumed that producers make a cost-effective choice between purchasing pollution permits or paying pollution taxes and spending on abatement activity.

Emission sector and abatement sectors are substituted each other in the model so that fictitious environmental services sector in this model is composed of residual of emission after abatement of the emission generated by production activity. As previously noted, in this proto-type model no environmental impact of emission residual specified and remains further works. Equation 1 represents production function and environmental service sectors in general functional form (for a definition of indices see Table 1).

$$Y_{j,t} = CES(Y_{1,j,t}^{ID}, \dots, Y_{J,j,t}^{ID}, K_{j,t}, L_{j,t}, ES_{1,j,t}, \dots, ES_{E,j,t}; \sigma_j^1, \dots, \sigma_j^V) \quad \text{for each } (j,t) \quad ^3$$

(1)

Table 1. Definition of indices

Indices		
Label	Entries	Description
j and jj	$1, \dots, J, A$	Production sectors, including Abatement producer (A) $j = \{\text{High-polluting sector, Low-polluting sector, Abatement producer}\}$
H	$1, \dots, H$	Consumer groups $h = \{\text{Private households, Government}\}$
E	$1, \dots, E$	Environmental themes $e = \{\text{Climate change, Acidification}\}$
V_J	$1, \dots, V_J$	'CES-knots' in production functions $v_j = \{\text{Economic inputs, Environmental inputs, Production}\}$
V_H	$1, \dots, V_H$	'CES-knots' in utility functions $v_h = \{\text{Goods, Environmental inputs, Consumption}\}$
T	$1, \dots, T$	Time periods $t = \{1998, 1999, \dots, 2030\}$
Parameters		
Symbol	Description	
g_L	Exogenous growth rate of labour supply	
$apei_{e,t}$	Autonomous pollution efficiency improvement; assumed equal across all agents	
δ_K	Depreciation rate	
r	Steady-state interest rate	

³ As usual, '...' is used to indicate all items within the range as given by the items listed before and after.

A general nested CES production function with for example 4 inputs and 2 levels can be written as:

$Y = (a_1 X_1^\rho + a_2 X_2^\rho + a_{34} X_{34}^\rho)^{1/\rho}$, and $X_{34} = (a_3 X_3^\psi + a_4 X_4^\psi)^{1/\psi}$ for some parameters $a_1, a_2, a_{34}, a_3, a_4$, where $\rho = (\sigma - 1)/\sigma$ and $\psi = (\varphi - 1)/\varphi$. A convenient notation is: $Y = CES(X_1, X_2, X_{34}; \sigma)$; $X_{34} = CES(X_3, X_4; \varphi)$.

I^S	Base level investments (calibrated to steady-state)
K^S	Base level capital stock (calibrated to steady-state)
$\overline{L}_{h,t}$	Exogenous labour supply by consumer h in period t
$\overline{E}_{e,h,t}$	Endowments of pollution permits for environmental theme e by consumer h in period t
ι_j	Input share of good j for investments (by origin)
$\tau_{K,j}$	Tax rate on capital demand by sector j
$\tau_{L,j}$	Tax rate on labour demand by sector j
$\tau_{jj,j}$	Tax rate on input of good jj by sector j
$\tau_{j,h}$	Tax rate on consumption of good j by consumer h
$\tau_{K,h}$	Tax rate on the supply of capital by consumer h
$\tau_{L,h}$	Tax rate on the supply of labour by consumer h
τ_h^{LS}	Lumpsum transfer from government to consumer h , with $\sum_{h=1}^H \tau_h^{LS} = 0$ and $\sum_{h=1}^H \tau_h^{LS} \cdot \alpha_t^{LS} = 0$
τ^{SUB}	Lumpsum transfer from (excess) private households to the subsistence consumer
σ_j^v	Substitution elasticities between inputs combined in knot v_j in production function for sector j
$\sigma_{e,j}^A$	Substitution elasticities between pollution and abatement for environmental theme e in production function for sector j
σ_h^v	Substitution elasticities between consumption goods combined in knot v_H in utility function for consumer h (within same time period)
$\sigma_{e,h}^A$	Substitution elasticities between pollution and abatement for environmental theme e in utility function for consumer h
σ_h^{Util}	Intertemporal substitution elasticities in utility function for consumer h (between time periods)
Variables	

Symbol	Description
$Y_{j,t}$	Production quantity of sector j in period t
$Y_{jj,j,t}^{ID}$	Demand for input jj by sector j in period t
$L_{j,t}$	Labour demand by sector j in period t
$K_{j,t}$	Capital demand by sector j in period t
$I_{j,t}$	Investment originating in sector j in period t
$I_{h,t}$	Investment by consumer h in period t
$\Pi_{j,t}$	(Net) profits in sector j in period t (equal to zero)
$E_{e,j,t}^U$	‘Unabatable’ emissions of environmental theme e by sector j in period t
$E_{e,j,t}^A$	‘Abatable’ emissions of environmental theme e by sector j in period t
$A_{e,j,t}$	Investment in abatement of environmental theme e by sector j in period t {note that $\sum_{e=1}^E A_{e,j,t} \equiv Y_{A,j,t}^{ID}$ }
$ES_{e,j,t}$	Emission services of environmental theme e by sector j in period t
$E_{e,h,t}^U$	‘Unabatable’ emissions of environmental theme e by consumer h in period t
$E_{e,h,t}^A$	‘Abatable’ emissions of environmental theme e by consumer h in period t
$A_{e,h,t}$	Investment in abatement of environmental theme e by consumer h in period t {note that $\sum_{e=1}^E A_{e,h,t} \equiv C_{A,h,t}$ }
$ES_{e,h,t}$	Emission services of environmental theme e by consumer h in period t
$W_{h,t}$	Welfare level of consumer h in period t

U_h	Total welfare of consumer h over all periods
$C_{j,h,t}$	Consumption of good j by consumer h in period t
$S_{h,t}$	Savings by consumer h in period t
$\overline{K}_{h,t}$	Capital supply by consumer h in period t (in ‘flow’ terms: capital services)
$p_{j,t}$	Equilibrium market price of good j (including A) in period t
$r_{K,t}$	Equilibrium market rental price of capital in period t
$p_{L,t}$	Equilibrium market wage rate in period t
$p_{e,t}$	Equilibrium market price of pollution permits for environmental theme e in period t
$p_{h,t}^W$	Equilibrium price of the ‘utility good’ (consumption bundle)
α_t	Endogenous change in existing tax rates to offset government income from sale of pollution permits in period t
α_t^{LS}	Endogenous change in lumpsum transfers to offset government income from sale of pollution permits in period t
$Taxrev_h$	Endogenous tax revenues for consumer h in period t (only nonzero for Government)

The zero profit constraint for all modeled outputs requires that the after tax revenue for the output is equal to the total costs of all primary inputs, fixed intermediate inputs, energy sectors, abatement expenditure(Equation 2).

$$\begin{aligned}
0 = \Pi_{j,t} = & p_{j,t} \cdot Y_{j,t} - \sum_{jj=1}^J (1 + \tau_{jj,j}) \cdot p_{jj,t} \cdot Y_{jj,j,t}^{ID} - (1 + \tau_{A,j}) \cdot p_{A,t} \cdot Y_{A,j,t}^{ID} \\
& - (1 + \tau_{L,j}) \cdot p_{L,t} \cdot L_{j,t} - (1 + \tau_{K,j}) \cdot r_{K,t} \cdot K_{j,t} - \sum_{e=1}^E p_{e,t} \cdot E_{e,j,t} \quad \text{for each } (j,t)
\end{aligned}
\tag{2}$$

Emission is treated here as a joint product along with other ordinary goods. Emission output is produced emission input less abatement. Thus, emission out is an unabated residual and magnitude of emission abated is dependent upon abatement activity. Pollution is generated through production activities as well as consumption activities such that emission services

Production functions are defined for goods and consumption agents, household and government(Equations 3 and 4).

$$ES_{e,j,t} = CES(E_{e,j,t}^U, CES(E_{e,j,t}^A, A_{e,j,t}; \sigma_{e,j}^A); \sigma_{e,j}^{ES}) \quad \text{for each } (e,j,t), \text{ with } \sigma_{e,j}^{ES} = 0 \quad (3)$$

$$ES_{e,h,t} = CES(E_{e,h,t}^U, CES(E_{e,h,t}^A, A_{e,h,t}; \sigma_{e,h}^A); \sigma_{e,h}^{ES}) \quad \text{for each } (e,h,t), \text{ with } \sigma_{e,h}^{ES} = 0 \quad (4)$$

In energy sector, autonomous technology in abatement is generally expected defined as a ratio of emission generated to goods produced, which can be called emission intensity. The model employs a parameter called autonomous pollution efficiency improvement (apei) assumed equal across all agents(Equations 5-8).

$$(E_{e,j,t+1}^A / Y_{j,t+1}) = (1 - apei_{e,t+1}) \cdot (E_{e,j,t}^A / Y_{j,t}) \quad \text{for each } (e,j,t) \quad (5)$$

$$(E_{e,j,t+1}^U / Y_{j,t+1}) = (1 - apei_{e,t+1}) \cdot (E_{e,j,t}^U / Y_{j,t}) \quad \text{for each } (e,j,t) \quad (6)$$

$$(E_{e,h,t+1}^A / W_{h,t+1}) = (1 - apei_{e,t+1}) \cdot (E_{e,h,t}^A / W_{h,t}) \quad \text{for each } (e,h,t) \quad (7)$$

$$(E_{e,h,t+1}^U / W_{h,t+1}) = (1 - apei_{e,t+1}) \cdot (E_{e,h,t}^U / W_{h,t}) \quad \text{for each } (e,h,t) \quad (8)$$

Emission service function takes a CES function with nesting CES to choose cost-effective way to decide how much to abate and how much to pay for emission. Again, in order to fulfill this intention, an environmental service function needs to be specified.

Consumers maximize their utility subject to budget constraints. Consumption utility is composed of market goods and environmental services here emission residual for individual period(Equation 9). The aggregate utility over whole period in concern is for also CES type with inter-temporal substitution elasticities(Equation 10). Budget constraints are concerned at income-expenditure balance for each period(Equation 11) and the expenditure-income for the total period is given in Equation 12.

$$W_{h,t} = CES(C_{1,h,t}, \dots, C_{J,h,t}, ES_{1,h,t}, \dots, ES_{E,h,t}; \sigma_h^1, \dots, \sigma_h^V) \quad \text{for each } (h,t) \quad (9)$$

$$U_h = CES(W_{h,1}, \dots, W_{h,T}; \sigma_h^{Util}) \quad \text{for each } h \quad (10)$$

$$p_{h,t}^W \cdot W_{h,t} = \sum_{j=1}^J (1 + \tau_{j,h} \cdot \alpha_t) \cdot p_{j,t} \cdot C_{j,h,t} + p_{A,t} \cdot A_{e,h,t} + \sum_{e=1}^E p_{e,t} \cdot E_{e,h,t} \quad \text{for each } (h,t) \quad (11)$$

$$\begin{aligned} \sum_{t=1}^T p_{h,t}^W \cdot W_{h,t} + p_{K,T} \cdot K_{h,T} = & (1 - \tau_{L,h} \cdot \alpha_t) \cdot p_{K,1} \cdot \frac{\overline{K_{h,1}}}{(r + \delta)} + \sum_{t=1}^T (1 - \tau_{L,h} \cdot \alpha_t) \cdot p_{L,t} \cdot \overline{L_{h,t}} \\ & + \sum_{t=1}^T \sum_{e=1}^E p_{e,t} \cdot \overline{E_{e,h,t}} - \sum_{t=1}^T \tau_h^{LS} \cdot \alpha_t^{LS} + \sum_{t=1}^T TaxRev_{h,t} \end{aligned} \quad \text{for each } h \quad (12)$$

In this model, government budget is fixed regardless of revenue change due to sale of pollution permits. It is carried out by introduction of two instruments: α_t , Endogenous change in existing tax rates to offset government income from sale of pollution permits in period t and α_t^{LS} , Endogenous change in lumpsum transfers to offset government income from sale of pollution permits in period t .

The capital stock in period t equals to the capital stock at the start of the previous period less depreciation plus investment in the previous period (Equation 13). The terminal condition on capital follows a transversality condition (Equation 14). Changes in population are treated exogenous (Equation 15).

$$p_{K,t} = (1 - \delta_K) p_{K,t+1} + r_{K,t} \quad \text{for each } t \quad (13)$$

$$\sum_{h=1}^H K_{h,T} = (1 + g_L) \cdot \sum_{h=1}^H K_{h,T-1} \quad (14)$$

$$\overline{L_{h,t+1}} = \overline{L_{h,t}} \cdot (1 + g_L) \quad \text{for each } (h,t) \quad (15)$$

Government expenditure is defined that changes in government expenditure for each period is identical to that of private household (Equation 16).

$$\frac{W_{government',t}}{W_{government',0}} = \frac{\sum_{\substack{h=1 \\ h \neq 'gov.'}}^H W_{privatehouseholds',t}}{\sum_{\substack{h=1 \\ h \neq 'gov.'}}^H W_{privatehouseholds',0}} \quad \text{determines } \alpha_t \text{ and } \alpha_t^{LS} \quad (16)$$

Conventional approach is applied to the market clearance rules for goods, capital, labor,

pollution permits, and savings-investment (Equations 17-21).

$$Y_{j,t} = \sum_{jj=1}^J Y_{j,j,t}^{ID} + Y_{j,A,t}^{ID} + I_{j,t} + \sum_{h=1}^H C_{j,h,t} \quad \text{for each } (j,t); \text{ determines } p_{j,t} \quad (17)$$

$$\sum_{j=1}^J K_{j,t} + K_{A,t} = \sum_{h=1}^H \overline{K_{h,t}} \quad \text{for each } t; \text{ determines } r_{K,t} \quad (18)$$

$$\sum_{j=1}^J L_{j,t} + L_{A,t} = \sum_{h=1}^H \overline{L_{h,t}} \quad \text{for each } t; \text{ determines } p_{L,t} \quad (19)$$

$$\sum_{j=1}^J E_{e,j,t}^U + \sum_{j=1}^J E_{e,j,t}^A + E_{e,A,t}^U + E_{e,A,t}^A + \sum_{h=1}^H E_{e,h,t}^U + \sum_{h=1}^H E_{e,h,t}^A = \sum_{h=1}^H \overline{E_{e,h,t}} \quad \text{for each } (e,t) \quad (20)$$

determines $p_{e,t}$.

$$\sum_{h=1}^H S_{h,t} = \sum_{j=1}^J p_{j,t} \cdot I_{j,t} \quad \text{for each } t \quad (21)$$

The policy instruments

The models as specified above are employed to analyse greenhouse gas mitigation portfolios in terms of timing and magnitude: It compares economic consequences of GHG reduction schemes with changes in “when and how much”. These scenarios are not based on actual climate change policy in Korea. They are just numerical example, chosen to give insight into the dynamic workings of the model specifications. Note that under simulation approach like current study, more attention is paid into results of individual scenario, rather than making comparison and giving priority among policies. Each scenario is viewed separate in policy analysis.

Two types of scenarios are selected for the simulations. The first type is to follow United Nations Framework of Climate Change Convention (UNFCCC) commitment period schemes, whose is five year term starting from years 2008 through 2022. We have set arbitrary five mitigation portfolios. The common structure of the schemes are to keep business-as-usual (BAU) emission until starting the commitment period then reduce certain percentage of BAU level, keep the fixed level of 2000 after the end of commitment.

Scenario 8-12_30 : Keep BAU level for 2000-2007, then 30% reduction of BAU for 2008-2012 and fixed level of 2000 after 2012.

Scenario *13-17_30* : Keep BAU level for 2000-2012, then 30% reduction of BAU for 2013-2017 and fixed level of 2000 after 2017.

Scenario *18-22_30* : Keep BAU level for 2000-2017, then 30% reduction of BAU for 2018-2022 and fixed level of 2000 after 2022.

Scenario *13-17_40* : Keep BAU level for 2000-2012, then 40% reduction of BAU for 2013-2017 and fixed level of 2000 after 2017.

Scenario *18-22_50* : Keep BAU level for 2000-2017, then 30% reduction of BAU for 2018-2022 and fixed level of 2000 after 2022.

While the above five scenarios are simulated just on differentiating timing and amounts of emission reduction for each commitment period, the second type of reduction plans assume same period and same amount in GHG reduction options then compare results of changes according to the way that the society takes action in order to fulfil the commitment. The period in concern is for 10 years 2013-2022, which covers the 2nd and 3rd commitment period. The amount to be allowed to emit the pollutions is 11 units during 10 years. Unlike the first mitigation type, a society is free to allocate mitigation timing and amounts as long as 11 units emitted during 10 years. It assumed that all three schemes are ruled by keeping BAU level for 2000-2012 and after the given commitment period 80 percentage of emission compared to 2000 is enforced for the remaining periods.

The first scenario adopted here is to keep BAU for 2000-2012 then shares the emission permits even during the 2013-2022, and fixed at 80 percentage of 2000 level from 2023. It is called 'equal strategy'.

The second one is to emit pollution in linearly decreasing manner so as to secure given 11 unit of emission. It is called 'smooth strategy.'

The third one is to apply to keep 2012 level until 2017 then emission is linearly decreasing. It is called 'sudden strategy.'

III. RESULTS

The proto-type model here assumes forward-looking behaviour of the consumers: households maximise the total present value of all current and future consumption. Consequently, the model is solved for all periods together and the growth path in the periods between the initial steady-state equilibrium and the new equilibrium is endogenously determined.

The GDP changes in the first types of simulation give a good example that a society's economic decision is based on the future foresight (figures 1 and 2). Since the society knows the information that in the future there will be enforced reduction of pollution emission implying increase in the prices, they consume more now before the prices go up. Then it results in GDP

increases until the mandatory reduction takes place. It applies to all five cases. What the society consumes more compared to BAU means the future consumption of society is borrowed. Note that in the forward-looking model economic resources are free to move between the whole periods. The primary reason for the increase in the present GDP is of course relevant to a discounting rate. From sustainability perspective, it can be interpreted that the consumption of current generation is closely related to sacrifice of the future generation. It is about middle of the period around after 2050 that the GDP keeps falling down and turn upward (figure 1). With focusing on 2000-2030, figure 2 zooms in the trends of the GDPs.

Figures 1 and 2 about here

Compared to a recursive-dynamic model, it is expected that the forward-looking behaviour will lead to a more ‘smooth’ development of economic growth and utility, as consumers anticipate on reductions in the number of pollution permits allowed in later periods (for empirical results see Dellink, 2000).

As previously described, the second type of policy scenarios assumes that the amounts of emission for all three cases are identical. With this framework, main purpose of the scenarios adopted here is to compare consequences of mitigation strategies relevant to the way of reduction; equal reduction, smooth reduction, and sudden reduction. Figures 3 and 4 show the GDP changes for 2000-2100 and 2000-2030, respectively. The figures indicate that a society’s GDP in all cases increases until the reduction starts to be effective then falls when reduction takes place. Of particular interest is to compare GDP change paths. Until the middle period year 2019, the magnitude of GDP decrease is larger in order of “equal strategy”, “smooth strategy”, and “sudden strategy.” After then, the orders are reversed by “sudden strategy”, “smooth strategy”, and “equal strategy.” The paths of three cases are similar at those of reductions, since GDP is closely related with reduction policy implemented.

Figures 3 and 4 about here

The economic interpretation is that consumers know in advance that environmental policy will be stricter in a certain time, and they react by increasing current consumption in the early periods. Due to the time preference, this has a relatively large positive influence on total economic utility (which is optimised in this model). Naturally, this can only be achieved by decreasing their savings and hence decreasing investments. This is reflected by a lower interest rate in the early periods. Then, immediately following the high consumption levels in

the early periods, the savings/investment level increases rapidly, accompanied by lower consumption levels. These high investment levels are needed to assure long-term growth of the economy and are induced by the low price of capital (the low interest rate). The combined effects of the changes in consumption and investment levels govern the changes in GDP.

Following general analysis of the model results, we focus on what has driven such changes with a focus on linkages of GDP, prices, outputs, and others. First, of special interest is the relation between output changes. The simulation results reveal that due to delimit to emission, dirty energy sector Y2 shares the largest burden as expected. The outputs decrease for a whole period. While due to infinite substitution with dirty energy, clean energy Y3 increases for a while then decreases also but in less degree than dirty energy sector. The reason for the output contract is responsible of decrease in GDP. Among others, decrease of Y1 and consumption sectors have caused both energy sectors to reduce outputs. Abatement sector YA may include direct and indirect activities as long as they are related at emission reduction. They, for instance, are to cover pollution mitigation equipment and energy efficiency devices. In this model, no taxes on labour and capital utilized for the sector, this is a strong assumption. The underlying interpretation for this is the environmental industry sector is free of government fiscal policy: No taxes are imposed on the sector. In dynamic sense, this assumption is beneficial or not to the sector. When government reaps more revenue from selling the pollution permits, the tax rates on the primary inputs labour and capital are automatically reduced. Note that in this model, we assume endogenous tax rate. That is, when tax rate goes down implying decrease in production cost, it means relative costs with the abatement sector are reduced, *in vice versa*.

The particular point of the model is the introduction of pollution permits and abatement sector. With this structure, polluting agents here Y1, Y2 and private household choose whether to pay pollution tax or spend resources on abatement in a way the society is to meet a target designated. Keep in mind that the allocation of reduction is decided through least cost effective way from a society perspective. As we are interest in individual sector dimension, we might put constraints on the sector in concern, then it, however, does not guarantee efficient mitigation points.

In this model, abatement prices and pollution rates indicate relative prices in each period divided by private welfare index. The results show that abatement cost is decreasing while endogenous pollution tax is increasing (figures 5-8). No changes in pollution taxes take place during BAU and the rates go up suddenly when reduction options take place and keeps increasing.

Figures 5-8 about here

The abatement cost increases until the beginning of the reduction then goes down in a large degree and recovers the price increase very slowly and starts to decrease. In this model total

output of pollution permit “goods” is set exogenously according to a policy goal such that relative prices of permit which is equivalent to pollution tax rates, goes up when supply of permits decrease. Keep in mind that BAU implies that the economy is in equilibrium. The prices suddenly go up with implementation of reduction policy and measures and shows proportional paths to reduction schemes. The sudden change is related to the following reasons. First, no banking system is assumed in this model. If we introduce the banking system here, the degree of price changes might be different under the current forward-looking framework. Second, as emission levels are capped to 2000 level after the policy period, the amounts of pollution that a society has to reduce keeps increasing over time. The BAU assumes emission increases following economic growth less autonomous pollution efficiency improvement.

Welfare measurement

To analyse the economic impacts of various policies, better performance indicators than GDP levels are wanted. Welfare changes are an obvious candidate for performance analysis: if total welfare in the economy improves, the policy is socially beneficial. The changes in welfare can in practice not be measured directly, as utility cannot be measured (or at least not in a cardinal sense). Therefore, approximations of welfare changes like Marshallian consumer surplus are often used to evaluate policies (Varian, 1992); these approximating indicators contain both an income and substitution effect of the policy, while the exact welfare change is given only by the substitution effect.

In a computable general equilibrium framework, using the specification of the utility function, some exact measures of welfare changes can be calculated (because the characteristics of both the old and new equilibria can exactly be calculated). The mostly used indicator for welfare changes is the sum (over consumers) of the present values of equivalent variations (see for example Shoven and Whalley, 1992). The Equivalent Variation (EV) of a policy is defined as the change in income, with prices remaining at their old levels, that would be equivalent to the proposed price change, in terms of its welfare impact on the consumer. In formula, for one consumer and one good, the EV can be written as $EV = (Q^{new} - Q^{old}) \cdot P^{old}$, where Q^{new} and Q^{old} are the new and old quantities (or real income), respectively, and P^{old} is the old equilibrium price.

In the multi-sectoral dynamic CGE model, these concepts of Equivalent Variation and Compensating Variation can both be calculated. The model specification uses a fictitious production sector (the Welfare producer) that produces ‘utility goods’ using the consumption goods as inputs. The consumers then demand not the consumption goods themselves, but rather the utility good. Note that the utility function in effect becomes a production function; the utility function actually used in the model is confined to the consumption of the utility good. This set-up has no impacts on the model results, as it is perfectly similar to a set-up where consumer directly demand consumption goods. The main advantage of the set-up is that real welfare

changes of the consumer can directly be read from the model as the real changes in the welfare producer. In technical terms: the left-hand side of the income balance equation is part of the welfare production sector, whose income is made up of selling the ‘utility goods’, while the right-hand side of the income balance equation belongs to the consumer, who spends it on buying utility goods. The EV and CV of the policies can be derived directly from the change in activity of the welfare producer, using the old-equilibrium and new-equilibrium price of the ‘utility goods’ as the price index.

In the analyses above, damages by poor environmental quality on the economic system and on welfare are not taken into account. The environmental sub-model is purely represented by the pollution levels and abatement activities. The absence of environmental quality in the utility function has a major consequence: the utility function is no longer a good measure of welfare. The welfare measurement is confined to the economic sources of welfare: consumption. However, in reality, welfare also depends on other issues, like environmental quality. Environmental policy will in general lead to a lower level of consumption and hence a downward pressure on welfare. This represents the economic costs of environmental policy. On the other hand, the impacts of environmental policy on environmental quality will be positive. This higher environmental quality is not captured in the proto-type models, and the ‘environmental sources’ of welfare cannot be taken into account as this would entail a valuation of environmental quality in money terms. Such valuations are not broadly available.

Instead of confining the analysis to the economic sources of welfare, one could attempt to augment the models to include environmental welfare effects. These environmental welfare effects should at least include a damage function (negative impacts of low environmental quality on the availability of economic goods) and the amenity value of environmental quality (high environmental quality induces welfare *per se*, even without the use of the environment in the economic process).

In an empirical study, it would seem too ambitious to include environmental damages and the amenity value of environmental quality. However, in the proto-type models it is possible to add the most relevant theoretical augmentations needed. This is however beyond the scope of the current paper.

Consequently, the models described above are incapable of studying true welfare effects, and must be confined to the economic indicators of utility change, the Equivalent Variation and Compensating Variation, based on the development household income. The results are presented in Table 2.

Table 2. Policy evaluation criteria

	EV_TOTAL	D_EMIS-30	D_EMIS
First Type			

8-12_30	-0.476	18.403	524.906
13-17_30	-0.439	15.927	522.431
18-22_30	-0.394	12.261	518.765
13-17_40	-0.451	16.707	523.211
18-22_50	-0.417	14.069	520.573
Second Type			
13-22_EQ	-0.498	16.985	537.489
13-22_SM	-0.498	16.985	537.489
13-22_SD	-0.502	16.985	537.489

The EV_TOTAL indicates Equivalent Variation summed over whole period 2000-2100(see for detailed definition, GAMS code in appendix). Comparing scenarios 8-12_30 (reduction takes place 2008-2012 with 30% BAU) with 13-17_40 (2013-2017 with 40% BAU) or 18-22_50 (2018-2022 with 50% BAU) are typical subject of simulation. The second (D_EMIS-30: reduction total 2000-2030) and third terms (D_EMIS: reduction total 2000-2100) indicate amounts of emission reduced by implementing policy alternatives.

The second type reveals interesting points in that reduction strategy with “equal” and “smooth” fashion reveals the same results but both cases bring about less cost “sudden” way. Here, the reduction amounts for the three cases are same by definition: we assumed 11 units of emission is allowed during 2013-2022. More in-depth analysis will be required to give explanations on the results.

VI. CONCLUSION

A conclusion that can be drawn from the analysis is that the dynamic specification of the model is highly relevant. Not only are the numerical results influenced significantly by the model specification, the main interactions between economy and ecology can also be better specified in a dynamic context. Even with a simple specification of the abatement sector, there are dynamic interactions that influence the costs of abatement for the polluters, the price of the pollution permits and the economic impacts of the environmental policy.

The primary findings from the numerical examples are as follows:

The gross domestic product (GDP) changes in the first types of simulation is consistent with a foreword looking framework adopted for the model, implying that a society’s economic

decision is based on the future foresight. Since the society knows the information that in the future there will be enforced reduction of pollution emission, they consume more now before the prices go up, resulting in GDP increases until the mandatory reduction takes place.

For the second type of policy scenarios assuming the amounts of emission for all three cases are identical, the results indicate that a society's GDPs in all cases increase until the reduction starts to be effective then it falls when reduction takes place. Of particular interest is to compare GDP change paths. Until the middle period year 2019, the magnitude of GDP falls are larger in order of "equal strategy", "smooth strategy", and "sudden strategy." After then, the orders are reversed by "sudden strategy", "smooth strategy", and "equal strategy." The paths of three cases are similar at those of reductions, since GDP is closely related with reduction policy implemented. The economic interpretation is that consumers know that environmental policy will be stricter in a particular time, and they react by increasing current consumption in the early periods. Due to the time preference, this has a relatively large positive influence on total economic utility which is optimised in this model.

The simulation results reveal that due to delimit to emission, dirty energy sector Y2 shares the largest burden as expected. The outputs decrease for a whole period. While due to infinite substitution with dirty energy, output of clean energy sector Y3 increases for a while then decreases also but in less degree than dirty energy sector. The reason for the output contract is responsible for decrease in GDP. Among others, the decreases of Y1 and consumption sectors have caused both energy sectors to reduce the outputs. Abatement sector YA may include direct and indirect activities as long as they are related at emission reduction. They, for instance, are to cover pollution mitigation equipment and energy efficiency devices. In this model, no taxes on labour and capital utilized for the sector, this is a strong assumption. The underlying interpretation for this is the environmental industry sector is free of government fiscal policy: No taxes are imposed on the sector. In dynamic sense, this assumption is beneficial or not to the sector. When government reaps more revenue from selling the pollution permits, the tax rates on the primary inputs labour and capital are automatically reduced. Note that in this model, we assume endogenous tax rate. That is, when tax rate goes down implying decrease in production cost, it means relative costs with the abatement sector are reduced, *in vice versa*.

The particular point of the model is the introduction of pollution permits and abatement sector. With this structure, polluting agents here Y1, Y2 and private household choose whether to pay pollution tax or spend resources on abatement in a way the society is to meet a target predetermined. In this model, the abatement cost is decreasing while endogenous pollution tax is increasing. No changes in pollution taxes during business-as-usual (BAU) and the rates go up suddenly when reduction options take place and keeps increasing. The abatement cost increases until the beginning of the reduction then goes down in a large degree and recovers the prices increase very slowly and starts decreases. In this model total output of pollution permit "goods" is set exogenously according to a policy goal such that relative prices of permit which is equivalent to pollution tax rates, goes up when supply of permits decrease. The prices suddenly go up with implementation of reduction and shows proportional paths to reduction schemes. The

sudden change is related to first, no banking system is assumed in this model and second, as emission levels are capped to 2000 level after the policy period, the amounts of pollution that a society has to reduce keeps increasing over time.

The magnitude of equivalent variations (EVs) for the second type indicates that reduction strategy with equal and smooth fashion reveals the same results but both cases bring about less cost “sudden” way. Here, the reduction amounts for the three cases are same by definition: we assumed 11 units of emission is allowed during 2013-2022. More in-depth analysis will be required to give explanations on the results.

For a policy design associated with GHG reduction plan, the problem are narrow downed “when,” “how much”, and “how”. All three factors are interrelated in policy decision process. However, it can be said that “when and how much “ to reduce is a main concern in international perspective, while “how” to comply the given amounts of reduction in a certain timing way is more pertinent to domestic interest.

This study is to give answers to three policy design criteria in a simulation basis. The eight scenarios employed here shed an informative light on policy design. As CGE is for in nature quantitative analysis, the results give specific numbers associated with policies implemented with keeping economic theory. The comparison of policy alternatives is possible through numerical iteration in a way to give best results for policy evaluation criteria such as EV. Based on the study results, we assert that sudden mitigation of GHGs brings in more cost to the society: it is of “how” issue. In climate change issue, it is very difficult to find out best solution to “how much and when,” let alone considering three factors simultaneously. There exist strong assumptions and uncertainties required in order to set the model framework: Main components to be considered include, among others, technology change, multi-country behaviour, and emission trading and the prices. Therefore, it is in more reality to set-up policy scenarios based on certain criteria such as political feasibility, technical feasibility, international negotiation, and so forth. Then the model simulates with the given sets of policy scenarios so as to enable to compare the results and find the best policy among the scenarios.

The model presented here is a proto-type such that for the empirical analysis, some works are required. Introduction of environmental components is one of them. In the present model, only amounts of emission linked with economic activities are represented. Biophysical relationship of emission changes and the corresponding impact on the economic sector is not specified in this model. From a perspective of sustainability issue, the explicit representation of physical environment is of special importance. As long as the current model is to keep CGE framework, it seems expected to make a choice of trade-off: Whether to keep perfect foresight structure in disaggregated micro-sectors or to simplify economic sectors with introduction of environmental module. As a background knowledge and process to model an interaction of economy and environment, of particular points are how to integrate flow-based emission into stock-based framework vis-à-vis environmental impact of short term and local consequences versus long term and global ones. In economic sectors, it seems not much free from having strong

assumptions adopted in the proto-type model more realistic. Some critical points in concern are economic and population growth rate. Currently the model assumes economic growth rates are identical among all economic sectors for the whole period. Sector-specific and period specific growth assumption would bring out the model results more acceptable. Population growth rate which is implicitly linked with productivity growth need to be based on their own figures. Specific structure of the model will be dependent data availability and possibility of obtaining model solutions.

In parallel to constructing a model, collecting data for the model is big constraint to be overcome. For Korea study, official input-output data base of 1995 which was published by The Bank of Korea will be utilized and other data such as elasticity values and capital stock will come from the previous studies. Forecasting data on economic growth will be mainly dependent on studies by Korea Development Institute. Sensitivity analysis will be carried out with some significant input values.

Making policy scenarios in context of climate change issue is of another importance for the study. Because this study takes simulation approach, designing realistic and feasible scenarios are critical and starting line for the study. Taking among others, economic, political, social, international circumstances into consideration would come to secure the policy chosen more socially acceptable.

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Figures

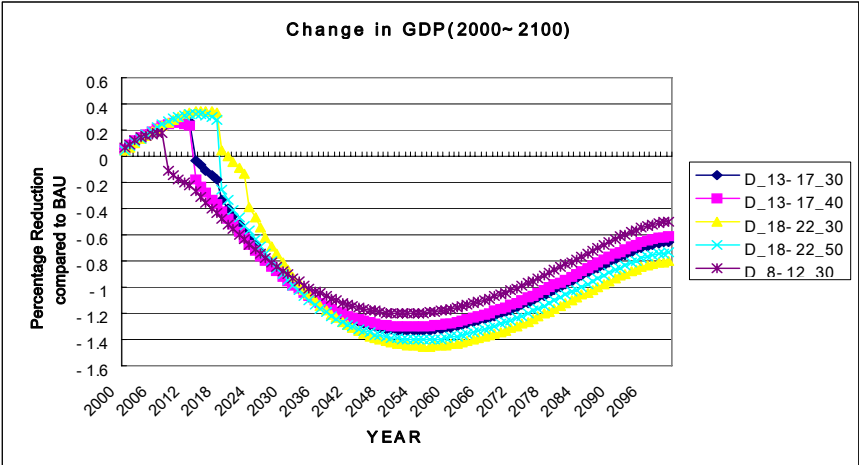


Figure 1. Results for GDP changes in mitigation schemes- The first type(2000-2100)

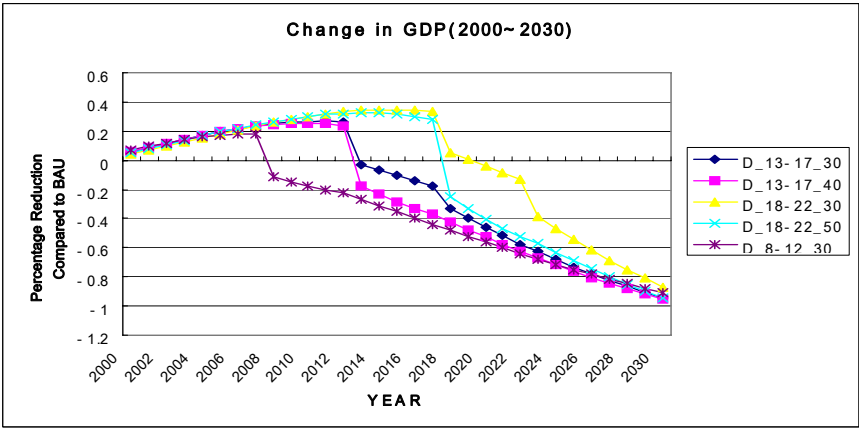


Figure 2. Results for GDP changes in mitigation schemes-The first type(2000-2030)

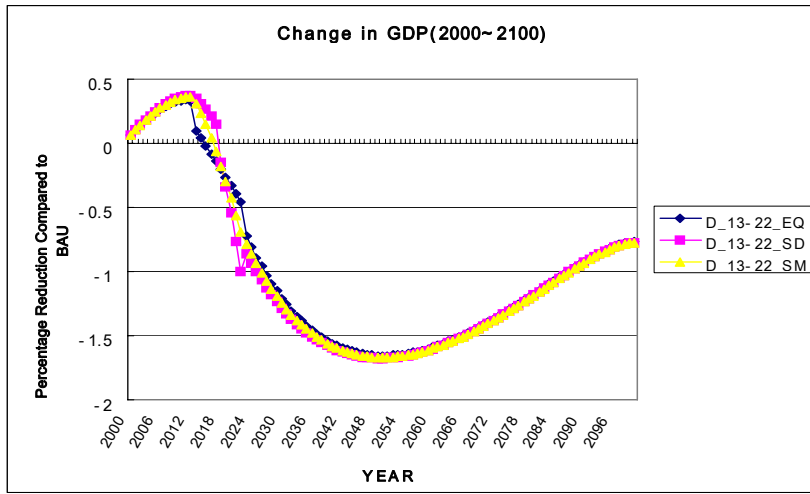


Figure 3. Results for GDP changes in mitigation schemes-The second type(2000-2100)

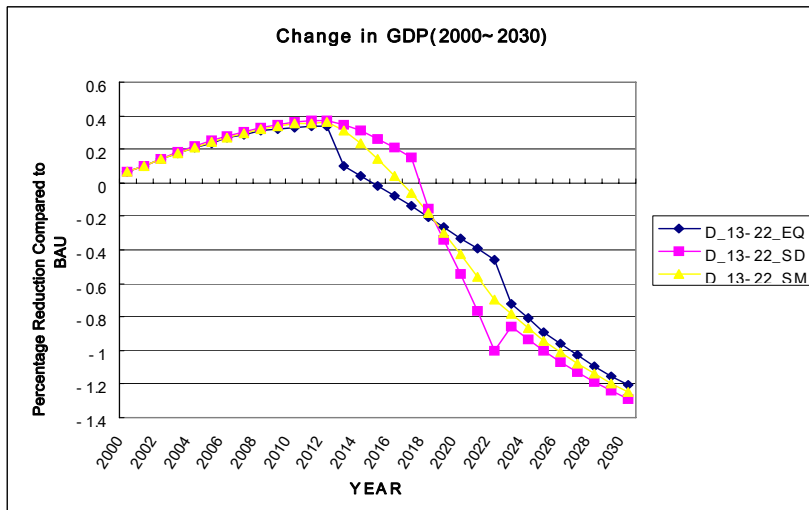


Figure 4. Results for GDP changes in mitigation schemes-The second type(2000-2030)

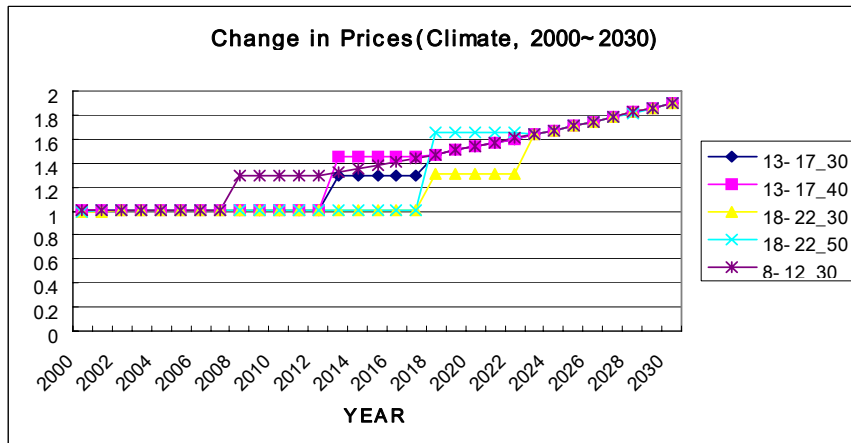


Figure 5. Pollution tax rate changes-The first type(2000-2030)

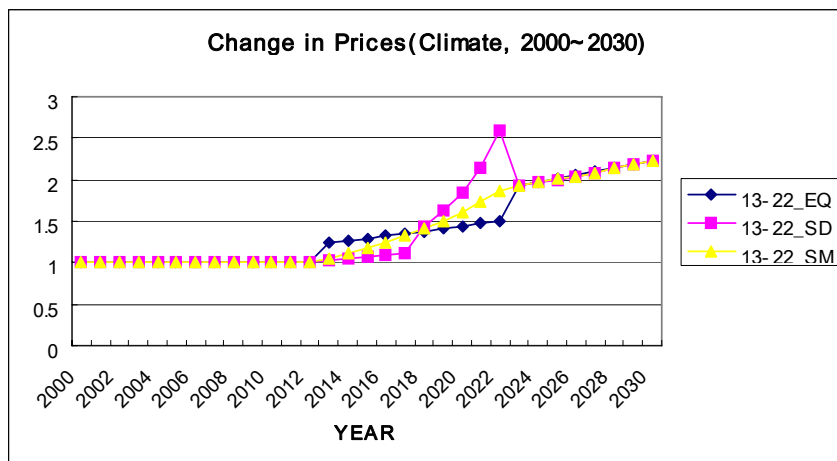


Figure 6. Pollution tax rate changes-The second type(2000-2030)

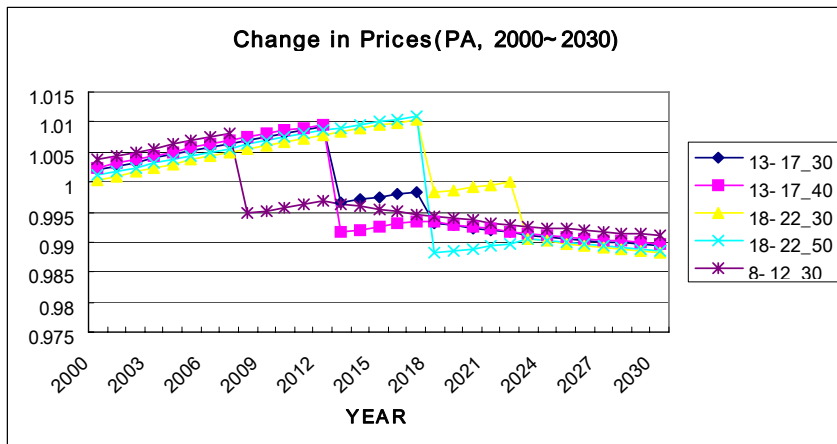


Figure 7. Changes in unit abatement cost- The first type (2000-2030)

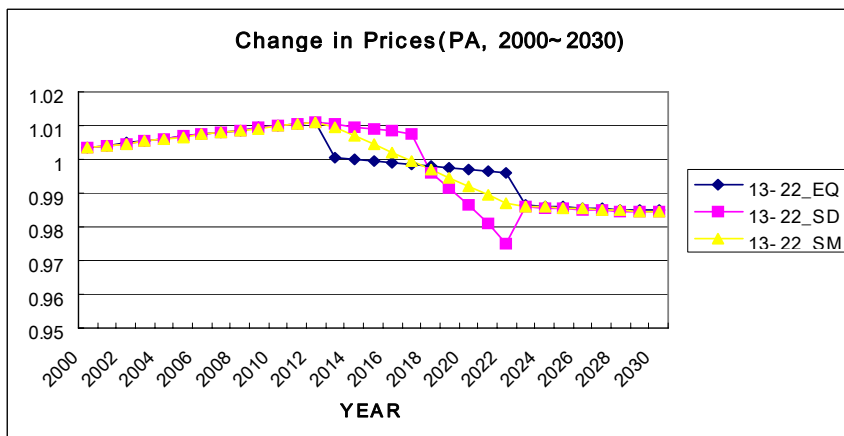


Figure 8. Changes in unit abatement cost- The second type (2000-2030)