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Second Generation Model for Korea

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ABSTRACT

South Korea is one of 13 world regions in the Second Generation Model (SGM), an energy-economy model designed specifically for analysis of carbon mitigation policy. Each region in the SGM can be run independently or as part of a global emissions permit trading system. Significant enhancements have been made to SGM-Korea over the past several years to better describe the impact of a carbon price on the Korean economy and energy system. This paper provides an overview of the SGM modeling framework, the structure of SGM-Korea, output from the Korea reference scenario, and results of some simple carbon price scenarios.

1. INTRODUCTION

This paper documents recent developments in the Second Generation Model (SGM) with a focus on SGM-Korea. The Korea module is one of 13 regional modules in the SGM modeling system. The original SGM technical specification is found in Edmonds, et al. (1993). Hibiki and Sands (1996) provide a description of SGM-Japan, while Fisher-Vanden, et al. (1997) provide analysis using SGM-India. Several of the regional modules, including SGM-Korea, have recently been extended to include five energy-intensive industries and two transportation sectors.

SGM has been particularly useful in understanding differences in carbon abatement costs across regions. This relationship between the price of carbon and the reduction in carbon emissions is captured in a marginal abatement curve. Some regions have higher costs, indicated by a steep marginal abatement curve, than do other regions. Knowing these marginal abatement curves, one could simulate carbon emissions trading among regions for any given set of emissions targets. A good example of the use of marginal abatement curves in carbon policy analysis is found in MacCracken, et al. (1999).

Marginal abatement curves summarize the carbon abatement opportunities in a model such as SGM. One of the goals of our recent development effort is to tell a more complete story about the changes to an economy in the presence of a carbon policy. Energy-intensive industries, as well as transportation, are affected more than other sectors. These products will become more expensive and their output will likely fall. In addition, these sectors will substitute other inputs, such as labor and capital, for expensive energy inputs.

The SGM is a top-down model, and therefore simulates price-induced technical change as a smooth tradeoff between inputs. Assumptions about the rate that one input can substitute for another, summarized as an elasticity of substitution, are important in determining the steepness of the marginal abatement curve. Technical change over time is represented as an exogenous reduction in the amount of an input needed to produce the same amount of output. All of the elasticity and technical change assumptions that determine this SGM-Korea reference case and its response to a carbon price are listed in this paper.

2. MODEL OVERVIEW

The SGM is a computable general equilibrium (CGE) model that projects economic activity, energy consumption, and carbon emissions over time for thirteen world regions. It is designed specifically to address issues associated with global change with special emphasis on the following types of analysis:

- Project baseline carbon emissions over time.
- Find the least-cost way to meet any particular emissions constraint.
- Provide a measure of the carbon price, in dollars per metric ton.
- Provide a measure of the overall cost of meeting an emissions target.

The SGM is an example of a dynamic recursive model. Recursive models are essentially a sequence of static models with rules for determining the amount of savings and therefore the total amount of new capital constructed in each time period. The trade balance is exogenous in the SGM. In the base year of 1990, each region is given its historical trade balance for 1990. In subsequent model years, the modeler can either leave the trade balance at its 1990 level or bring the trade balance gradually to zero.

2.1 Regions

Table 1 lists the regions in the SGM modeling system. Seven of the regions represent countries listed in Annex I of the Framework Convention on Climate Change (FCCC). Models of these seven regions are especially useful for simulating international trade in carbon emissions rights. The 'Rest of World' region includes Latin America other than Mexico, Africa, and other Asian countries.

Table 1. Regions in the SGM

Annex I	Non-Annex I
United States	China
Canada	India
Western Europe	Mexico
Japan	South Korea
Australia and New Zealand	Middle East
former Soviet Union	Rest of World
Eastern Europe	

2.2 Single-Region Operation

All SGM regions were originally developed as single-region models with a base year of 1985. The base year was recently moved to 1990 for all thirteen regions. Each regional model operates with five-year time steps and a forecast horizon up to the year 2050. Most of the single-region models were developed in collaboration with experts from that country using local data. The SGM can be run either as a single-region model or as global model with market clearing in selected international markets, including a market in carbon emissions permits.

These modes of operation allow the model user to limit the amount of endogeneity in SGM, especially for scenarios with fixed time paths of world energy prices. The single-region mode is especially useful for development of SGM regions and for country-specific analysis.

For each SGM region, all produced goods are classified as being tradable, non-tradable, or traded at a fixed quantity. When SGM regions are operated independently, a fixed world price is assumed for certain tradable goods; regions may import or export as much of that good as desired at that fixed world price, subject to an overall balance of payments constraint. For all non-tradable goods, the quantity of trade is fixed in advance.

One sector must be selected as the numeraire. In SGM, "services" is the numeraire. The price of the numeraire is set to 1 during each time period and the numeraire good is tradable. Except for the Middle East, all regions are price takers with respect to oil and natural gas. For single-region operation, the prices of oil and natural gas must be set exogenously. Land and labor are always nontradable. All other sectors are either nontradable or have the quantity of trade set in advance.

An exogenous balance-of-payments constraint is specified in advance for each region. Most regions are assumed to move linearly from a historical trade balance in the base year to balanced trade sometime in the future. Given a trial set of prices, the SGM computes supply and demand for all producing sectors and primary factors of production. Markets for the nontradable goods and goods traded at fixed quantities are brought into equilibrium by searching for a set of prices that equate supply and demand.

2.3 Production Sectors in SGM-Korea

Table 2 lists inputs to production and the goods produced in SGM-Korea. Note that crude oil and natural gas are inputs to production but are not produced domestically. The electricity sector contains five subsectors that represent different ways to produce electricity. The final column in Table 2 lists 22 sectors that serve as a template for newly extended SGM regions, which we call SGM 2000.[2] None of the SGM regions are populated with data for all 22 sectors, but Table 2 shows that we have populated most of the sectors in SGM-Korea. The most notable missing sector in SGM-Korea is sector 16, "other industry and construction". This sector is still combined with "services" in SGM-Korea.

[2] The following SGM regions have been extended from the original ten producing sectors to match most of the sectors in the SGM 2000 template: United States, Japan, China, India, and South Korea.

Table 2. Production sectors and subsectors

Sector No.	SGM-Korea Inputs to Production	SGM-Korea Producing Sectors	SGM-Korea Subsectors	SGM 2000 Sector Template
1	Other Agriculture	Other Agriculture		Other Agriculture
2	Services, Other Industry, Construction	Services, Other Industry, Construction		Services
3	Crude Oil			Crude Oil
4	Natural Gas			Natural Gas
5	Coal	Coal Production		Coal
6				Coke
7				Commercial Biomass
8	Electricity	Electricity Generation	Oil Gas Coal Nuclear Hydro	Electricity Generation
9	Refined Petroleum	Oil Refining		Oil Refining
10	Town Gas	Gas Distribution		Gas Distribution
11	Paper and Pulp	Paper and Pulp		Paper and Pulp
12	Chemicals	Chemicals		Chemicals
13	Cement	Cement		Cement
14	Iron and Steel	Iron and Steel		Iron and Steel
15	Nonferrous Metals	Nonferrous Metals		Nonferrous Metals
16				Other Industry and Construction
17	Passenger Transport	Passenger Transport		Passenger Transport
18	Freight Transport	Freight Transport		Freight Transport
19	Crops	Crops		Crops
20	Animal Products	Animal Products		Animal Products
21	Forestry	Forestry		Forestry
22	Processed Food Land Labor Capital	Food Processing		Food Processing

2.4 Data Requirements

Three types of data are used to construct and calibrate each region of the SGM:

- economic and demographic data
- energy balances
- technology descriptions.

Economic data include input-output tables and supplemental information from the national income accounts. SGM uses population projections from the United Nations. Energy balance

tables are obtained either from the International Energy Agency or from government agencies within a region.

Input-output tables describe, in value terms, the flow of goods between industries and consumers in an economy. However, a model concerned with quantities of carbon emissions must also be concerned with quantities of energy. An input-output table alone is not sufficient to determine the quantities of oil, gas, coal, electricity, and refined petroleum that are produced and consumed. Supplemental information on energy quantities is required to map currency units from an input-output table to energy units needed to calculate levels of carbon emissions. We combine economic input-output tables with energy balance tables to create a hybrid input-output table with units of joules for energy products and real currency for all other products. Miller and Blair (1985) provide a general description of, and the motivation for using, hybrid input-output tables. Individual energy technologies are characterized by the annualized cost of providing an energy service. Data needed to determine the annualized cost include capital cost, equipment lifetime, annual fuel requirements, the interest rate, and other annual maintenance and operating costs.

Most input data require some form of processing before being used in the SGM. When constructing a new SGM region, or updating an existing region to a new base year, the majority of time is spent obtaining and processing the necessary data. Usually, available data will not exactly match our requirements and modeler's judgment is often needed to reconcile differences. This is especially true for multi-country regions. Table 3 lists some of the required data sets.

Table 3. Data Transformation in SGM

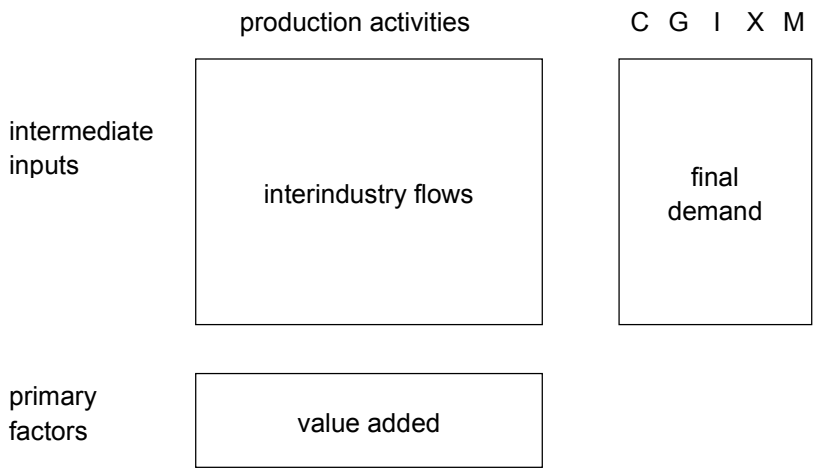
Original Data	**Derived Data for SGM**
1990 Economic Input-Output Table 1990 Energy Balance Table	Hybrid Input-Output Table
Annual Investment Data by Sector	Capital Stocks by Sector
Data on Fossil Fuel Resources	Resource Grades
Electricity Supply: generation, installed capacity, energy consumption, capital costs, operating costs	Input-output representation of electricity generation by fuel
National Income Accounts	Tax rates, Savings rates

The most important data set to be collected is a base-year input-output table of the economy. This forms the basic economic framework that all of the other data conform to. Multi-country regions present a particular challenge because input-output tables are not available for all countries in the region, and each country has its own currency. It may be necessary to build an

input-output table based on data from the national income accounts and from patterns in other input-output tables. For single-country regions, the units are local currency, such as Korean won or Indian rupees. United States dollars are used as a common currency for multi-country regions.

An economic input-output table has three major sections: interindustry flows, value added, and final demand. An input-output table is organized with inputs as rows and activities as columns. Inputs include intermediate inputs (those derived from a production process) and primary factors of production. The primary factors of production are labor, capital, and sometimes land. Activities that use inputs are industries, consumption by consumers, consumption by government, investment, and net exports (exports minus imports). Figure 1 shows the structure of a typical input-output table. In the final demand component, column C is consumer demand, G is government consumption, I is investment, X is exports, and M is imports.

Figure 1. Typical Input-Output Table



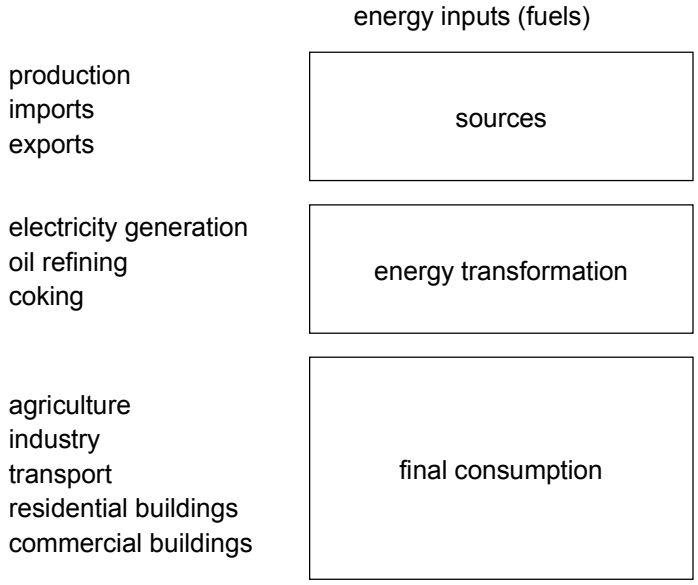
Each column in the input-output table represents an activity, while ach row represents a different input. An input-output table is balanced in the sense that the value of goods produced must equal the value of all uses of that good. If there are *n* production activities and *n* corresponding inputs, then the *n* row sums must equal the *n* column sums.

An economic input-output table is a snapshot of an economy, in value terms, for one particular year. Input-output tables contain varying amounts of sectoral detail, depending on the country, with anywhere from 30 to over 500 producing sectors. The tables are aggregated to the level of

detail that best matches the structure of SGM. Usually, an input-output table contains the same number of producing sectors as there are intermediate inputs. This does not have to be the case, however, because some industries may produce more than one product and some inputs might not be produced domestically and must be imported.

Input-output tables provide essential data on the value of transactions, but they provide little information on the physical quantities of goods produced and consumed. Since the SGM is an energy model as well as an economic model, attention is paid to maintaining energy balances as the model operates through time. An energy balance table provides the necessary quantity data on energy. Figure 2 shows the structure of a typical energy balance table.

Figure 2. Typical Energy Balance Table



An energy balance table is essentially an *energy* input-output table in physical units. However, the role of rows and columns is reversed relative to an economic input-output table. Rows represent activities and columns represent inputs in a typical energy balance table. An energy balance table contains nothing comparable to the primary factors of production in an economic input-output table. Energy balances are used for base-year calibration of energy production and consumption. The original units might be tons of coal equivalent (China), tons of oil equivalent (International Energy Agency statistics), or calories (Japan). In the SGM, we convert all energy units to joules, expressed as either petajoules (PJ) or exajoules (EJ).

2.5 Production Functions

The SGM uses non-nested CES production functions, with one elasticity parameter per production function.[3] However, production within each sector is divided into vintages; each vintage represents five years of investment. This allows SGM to have both short-run and long-run elasticities of substitution; the long-run elasticity applies to new capital vintages, while the short-run elasticity applies to old vintages. These elasticities of substitution determine the response of energy demand by producers to a change in relative prices.

The SGM contains a large set of parameters that can be used to simulate technical change over time for any given production sector. These parameters influence the rate of change in efficiency of all inputs to production. Separate parameters are available for each input to each production process. Furthermore, these rates of change in input efficiency can be varied at each five-year time step in SGM. The energy productivity parameter in SGM is similar to the Autonomous Energy Efficiency Improvement parameter (AEEI) found in some other models.

Labor productivity parameters are the primary determinant of economic growth in SGM and are used to influence the time path of GDP in a reference case. These two sets of parameters, energy efficiency and labor productivity, assist in constructing reference or business-as-usual scenarios. Labor productivity parameters are used to determine a time path for GDP and the energy efficiency parameters are used to determine consumption of energy by fuel.

The production function used in SGM is shown in equation (1), where x_i is the amount of input i used to produce output q. Each input has an associated alpha parameter used to control productivity growth for that input over time.

$$q(\mathbf{x}) = \alpha_0 \left[\sum_{i=1}^{N} (\alpha_i x_i)^{\rho} \right]^{1/\rho} \tag{1}$$

Rho is a parameter that determines the elasticity of substitution, sigma, as shown in equation (2).

[3] The CES, or constant-elasticity-of-substitution, functional form is commonly used in energy-economy models.

$$\sigma = \frac{1}{1-\rho} \tag{2}$$

Equation (2) is used during model calibration to calculate rho, given some value of sigma determined through econometric estimation or modeler's judgment. A modeler must select both a long-run and short-run elasticity of substitution for each production process. The long-run elasticity of substitution must be greater than or equal to the short-run elasticity of substitution. New capital operates under the long-run elasticity, but all older vintages of capital operate under the short-run elasticity. This model structure, with different elasticities of substitution between old and new capital, provides a way to simulate dynamics in marginal abatement curves. Carbon prices must be driven higher in the short run than in the long run to meet any given carbon emissions target. This is the primary motivation for including vintages of capital stocks in SGM.

A wide range of price response is available by selecting various combinations of long-run and short-run elasticities of substitution. The four types of price response are putty-putty, putty-semiputty, putty-clay, and clay-clay.

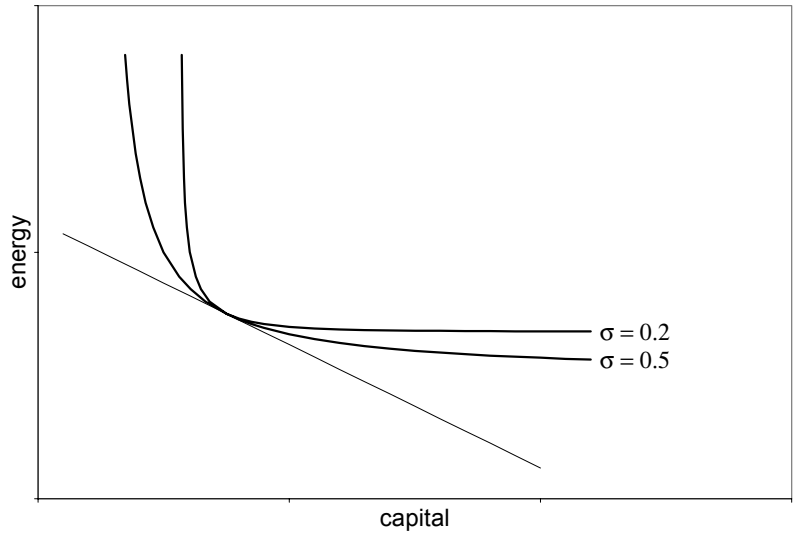
A *putty-putty* technology uses the same elasticity of substitution for both new and old capital. New capital and old capital respond in the same way to changes in price.

A *putty-semiputty* technology provides a lower elasticity of substitution in old capital than in new, and both elasticities of substitution must be greater than zero. In this case, the choices of new capital provide greater flexibility in input substitution than does a particular type of capital once it has been constructed.

A graphical representation of a putty-semiputty technology, using CES production functions, is shown in Figure 3. Two representative isoquants are plotted in Figure 3, each with a different elasticity of substitution. An isoquant is a line, usually drawn convex to the origin, showing all combinations of two inputs that will produce one unit of output. Two dimensions are plotted on Figure 3 and the axes could represent any pair of inputs, say capital and energy. An isoquant represents the physical tradeoffs available between the two inputs while holding output constant. The isoquant with the greater elasticity of substitution, sigma, allows greater flexibility for one input to substitute for the other as relative prices change. For a given set of prices, only one point on an isoquant will minimize the cost of production. At that point, the isoquant is tangent to a

line showing all combinations of equal expenditure on inputs. The slope of this line is the ratio of prices for the two inputs.

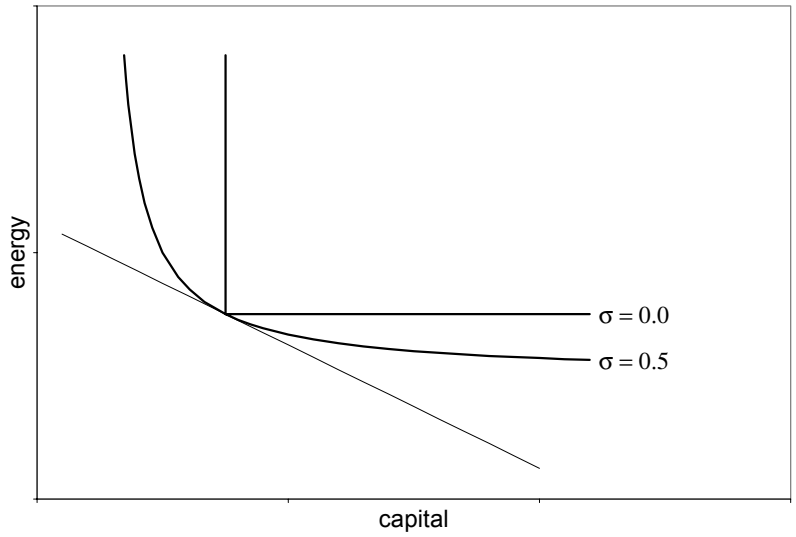
Figure 3. Putty-Semiputty Isoquants



New capital is formed during each SGM time period. At the time of capital formation, the isoquant with the greater elasticity of substitution is used. However, at the end of the SGM time period, capital is converted from a higher to a lower elasticity of substitution. Once capital is constructed in SGM, substitution possibilities between inputs are limited.

A *putty-clay* technology assumes that old capital is fixed-coefficient and the input-output coefficients do not respond to price. The input-output coefficients reflect relative prices that were in effect when the capital was created. Therefore, new capital is responsive to prices, but input-output coefficients are locked into place as the capital is converted from new to old. Isoquants for a putty-clay technology are shown in Figure 4. The elasticity of substitution between inputs in a fixed-coefficient (or Leontief) technology is zero.

Figure 4. Putty-Clay Isoquants



Some technologies are considered to be fixed-coefficient whether new or old, and are completely unresponsive to prices. This technology is referred to as *clay-clay* or simply *clay*. This assumption is sometimes used in the energy transformation sectors, especially oil refining, where the ratio of energy input to energy output is fixed in advance by physical processes and cannot respond to changes in price.

We are particularly interested in the own-price elasticity of demand for energy because of its importance in determining model response to a carbon policy. The own-price elasticity of demand for energy is the percentage change in energy demand in response to a percentage change in the price of energy. This parameter is set directly in the SGM for consumers, but indirectly through the elasticity of substitution for producers. The own-price of elasticity of demand for any input *i* can be computed by knowing the elasticity of substitution sigma and that input's value share in production S_i.

$$\varepsilon_{ii} = \sigma(S_i - 1) \tag{3}$$

For inputs with small value shares in total output, the own-price elasticity of demand is approximately equal to the elasticity of substitution, with a change of sign. The cross-price elasticity of demand, or the percentage change in demand for input *i* with respect to a change in the price of input *j*, is given by equation (4).

$$\varepsilon_{ij} = \sigma S_j \tag{4}$$

3. DATA SOURCES FOR SGM-KOREA

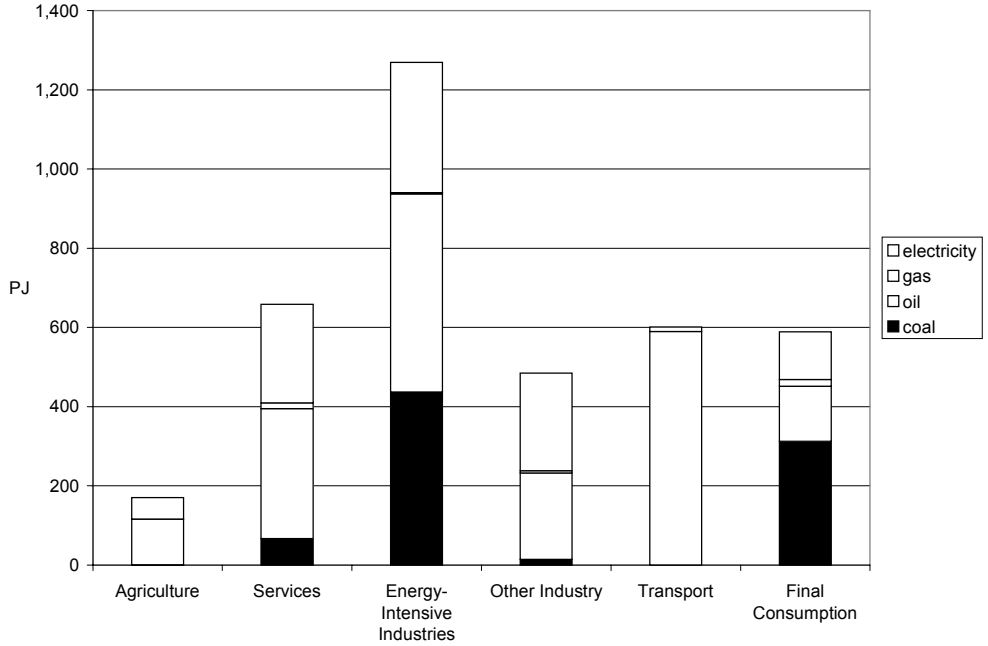
A 1990 input-output table for South Korea was aggregated to the SGM sectors listed in Table 2. The input-output table is in units of million Korean won. SGM-Korea operates exclusively in local currency, but uses the 1990 market exchange rate of 708 won per U.S. dollar to convert international prices to won.

The Korea Energy Economics Institute (KEEI) provided an energy balance table that is consistent with the data in the KEEI *Yearbook of Energy Statistics* (1998), but also includes supplemental data on energy consumption by industry. Energy consumption by fuel was first converted from original units to tons of oil equivalent, and then to petajoules for use in SGM.

Energy consumption by sector in 1990 is shown in Figure 5. Units are petajoules and electricity is plotted as its primary equivalent. This plot clearly shows the importance of energy-intensive industries in Korea. The "agriculture" sector includes food processing; "other industry" includes construction.

SGM-Korea uses population projections from the United Nations. Working-age population, defined as everyone between 15 and 64 years of age, is the primary determinant of labor supply in SGM. Working-age population is projected to increase until 2020 and decrease thereafter.

Figure 5. Final Energy Consumption by Sector in 1990



4. REFERENCE CASE

Table 4 lists the annual percentage rate of change for the productivity parameters in SGM-Korea. These rates of change are applied directly to the corresponding alpha parameter in equation (1). As the alpha productivity parameter increases over time, less of that input is needed to produce the same level of output. Note that energy productivity is assumed to increase at 0.5% per year, except for the energy transformation sectors such as electricity generation and oil refining. Energy productivity parameters for electricity and oil refining do not change much over time in any of the SGM regions so that the ratio of energy input to energy output stays in a narrow range. Also note that the capital productivity parameter does not change over time to keep the capital-output ratio relatively constant over time. Labor productivity is assumed to grow at a rate of 2% per year in SGM-Korea. We assume a high rate of labor productivity growth in developing countries such as Korea, and much lower rates for developed countries such as the United States. The growth rate of gross domestic product (GDP) turns out to be greater than any of the productivity growth rates shown in Table 4, especially in the early years of model simulation. GDP growth in the SGM-Korea reference case starts out with an average of 5.5% in the early years and falls gradually to 2% by 2030.

Table 4. Autonomous Productivity Assumptions (annual rate of change)

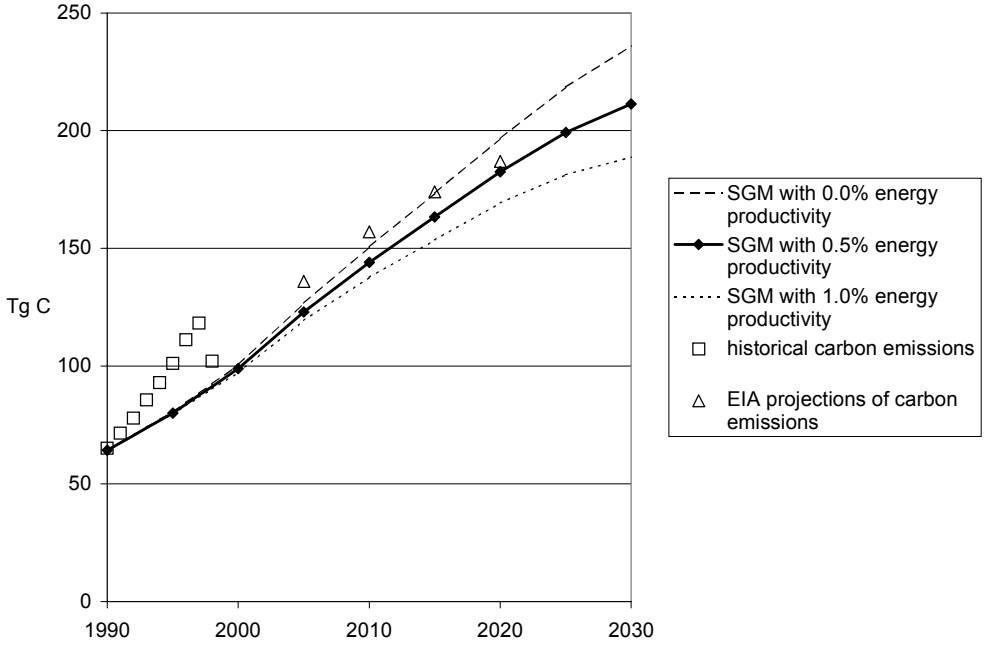
	Capital	Labor	Energy	Materials
Energy Transformation	0.0%	2.0%	0.0%	0.5%
Energy-Intensive Industries	0.0%	2.0%	0.5%	0.5%
Other	0.0%	2.0%	0.5%	0.5%

All of the SGM regions start with a base year of 1990 and are calibrated to exactly match energy consumption and production from a 1990 energy balance table. Therefore, the SGM-Korea reference case matches historical energy consumption and carbon emissions in 1990, but values after 1990 are determined by SGM input assumptions.

Figure 6 shows reference case carbon emissions from SGM-Korea, historical carbon emissions from 1990 through 1998, and projections of future carbon emissions from the U.S. Energy Information Administration (EIA) (2000). Note the very large increase in historical carbon emissions from 1990 to 1997 in Korea, but with a sharp drop from 1997 to 1998. Projections of carbon emissions from 2005 through 2020 by EIA are slightly higher than the SGM-Korea reference case. Carbon emissions are reported in teragrams of carbon (Tg C), which is the same as million metric tons of carbon.

Figure 6 also shows the sensitivity of reference case carbon emissions to the exogenous rate of improvement in energy productivity. The annual rate of energy efficiency improvement is 0.5% per year in the reference case. The SGM reference is also sensitive to assumed rates of productivity improvement in labor and materials. A higher rate of labor productivity indirectly leads to higher energy consumption though a higher GDP growth rate. Using materials more efficiently, especially energy-intensive materials, tends to reduce projections of future carbon emissions.

Figure 6. SGM-Korea Carbon Emissions with varying Energy Productivity



Generating capacity of hydroelectric and nuclear power plants is set exogenously over time in the SGM reference case. Nuclear power is growing rapidly over time, while hydroelectric capacity stays relatively constant. The carbon intensity of electricity generation is falling over time in the reference case, primarily because of increased investment in nuclear power.

International trade in energy-intensive goods is set exogenously to base-year quantities in SGM-Korea. This assumption holds for both the reference and carbon policy cases.

5. CARBON POLICY

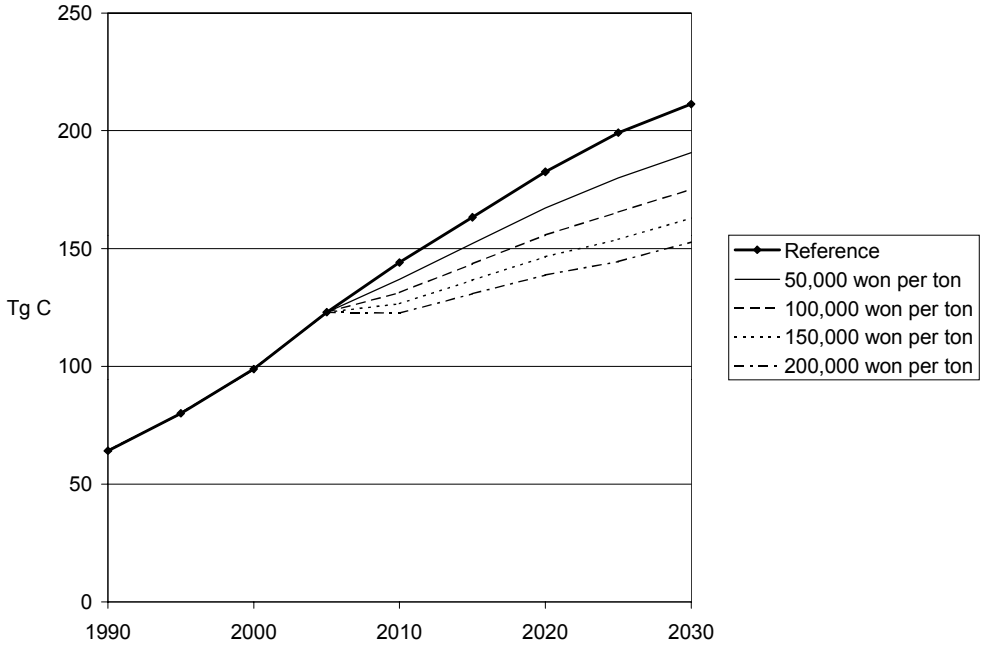
Productivity parameters from Table 4 determine the rate of change for all input-output ratios, in the absence of changing relative prices. However, relative prices will change between time periods, especially with a carbon policy. The SGM uses a large set of elasticity parameters that determine producer and consumer response to price changes. These parameters are listed in Table 5.

Table 5. Producer and Consumer Elasticities

Sector No.	Activity (producers), consumption good (consumers)	Long-run elasticity of substitution for producers	Short-run elasticity of substitution for producers	Own-price elasticity of demand for consumers	Income elasticity of demand for consumers
1	Other Agriculture	0.30	0.10	-0.38	0.32
2	Services, Other Industry, Construction	0.40	0.10	-1.02	1.01
3	Crude Oil	0.28	0.10	-0.21	0.50
4	Natural Gas			-0.21	0.50
5	Coal			-0.21	0.50
6					
7					
8	Electricity	0.10	0.00	-0.21	0.50
9	Refined Petroleum	0.10	0.00	-0.21	0.50
10	Town Gas	0.10	0.00	-0.21	0.50
11	Paper and Pulp	0.28	0.10	-1.02	1.01
12	Chemicals	0.28	0.10	-1.02	1.01
13	Cement	0.28	0.10	-1.02	1.01
14	Iron and Steel	0.28	0.10	-1.02	1.01
15	Nonferrous Metals	0.28	0.10	-1.02	1.01
16					1.01
17	Passenger Transport	0.28	0.10	-1.02	1.01
18	Freight Transport	0.28	0.10	-1.02	1.01
19	Crops	0.28	0.10	-1.02	1.01
20	Animal Products	0.28	0.10	-1.02	1.01
21	Forestry	0.28	0.10	-1.02	1.01
22	Processed Food	0.28	0.10	-1.02	1.01

A series of flat carbon prices was applied to SGM-Korea to determine the model's response to increases in the carbon price. The SGM translates a carbon price into additive charges for oil, gas, and coal depending on the carbon content of these fuels. Since SGM-Korea has a base year of 1990, carbon prices are in 1990 currency. Converting the carbon prices into current won would require a GDP deflator for South Korea. Figure 7 provides a plot of SGM-Korea's reference carbon emissions and emissions under four levels of carbon price. The carbon prices were applied in 2010 and held constant through 2030.

Figure 7. SGM-Korea Carbon Emissions with Carbon price Applied in 2010



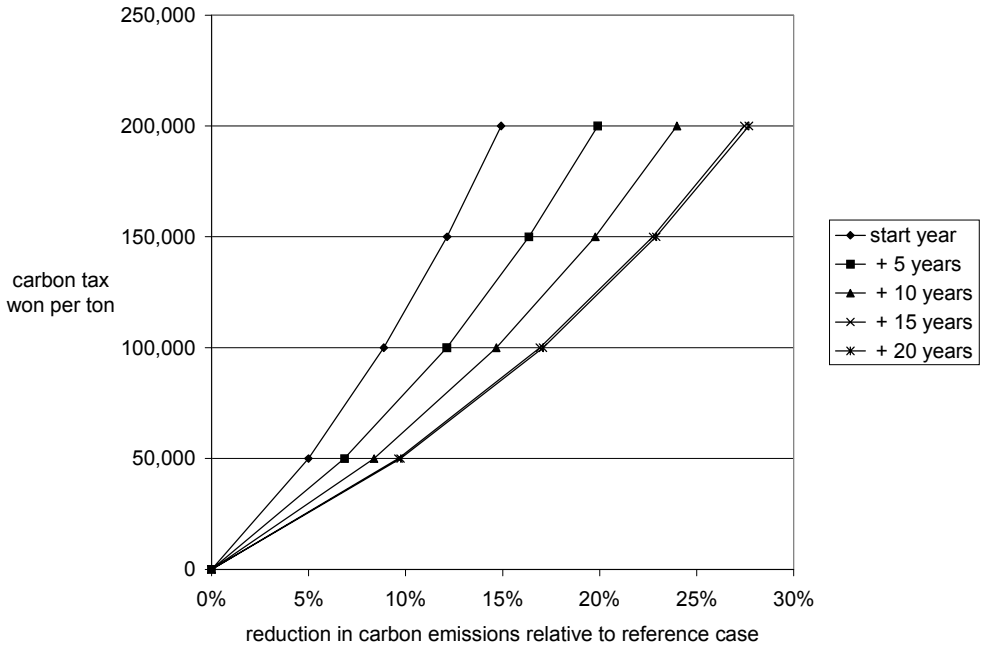
5.1 Marginal Abatement Curves

Figure 8 provides a different view of SGM-Korea's response to a carbon price with a series of marginal abatement curves. Reductions in carbon emissions are shown on the horizontal axis as a fraction of reference emissions. The horizontal axis can be drawn either in terms of absolute reductions in carbon emissions, measured in metric tons of carbon, or as a percentage reduction from the reference case. All of the information needed to plot the marginal abatement curves in Figure 8 can be obtained from Figure 7.

The main point of Figure 8 is to show that the marginal abatement curve is steeper in the first time period of a carbon price than in later years because it takes time for capital stocks to adjust. In this case, the first year of the carbon price is 2010. Each SGM time step represents five years, so a carbon price applied in 2010 actually covers five years, say 2008 through 2012. Most production sectors in SGM use a capital lifetime of 20 years, which requires four SGM time steps for a complete turnover in capital stock.

Therefore, we see four distinct marginal abatement curves in Figure 8. By 2025 and 2030, the marginal abatement curves have reached a steady state in terms of the percentage reduction from reference emissions. The full impact of a carbon policy is not felt until several years after the start of the policy.

Figure 8. Marginal Abatement Curves



Marginal abatement curves provide a very useful summary of SGM-Korea's response to a carbon price. The steepness of the marginal abatement curves in Figure 8 depends on the elasticity assumptions from Table 5, especially the elasticities for energy inputs to production and consumption. A higher elasticity (in absolute value) shifts the marginal abatement curves to the right. Similar curves have been constructed for all SGM regions and they can be used to simulate international trade of carbon emissions rights. In fact, a reduced-form SGM can be constructed with (1) families of marginal abatement curves expressed as a percentage reduction in carbon emissions, (2) projections of reference carbon emissions, either from SGM or a separate source, and (3) exchange rates for converting U.S. dollars into local currency.

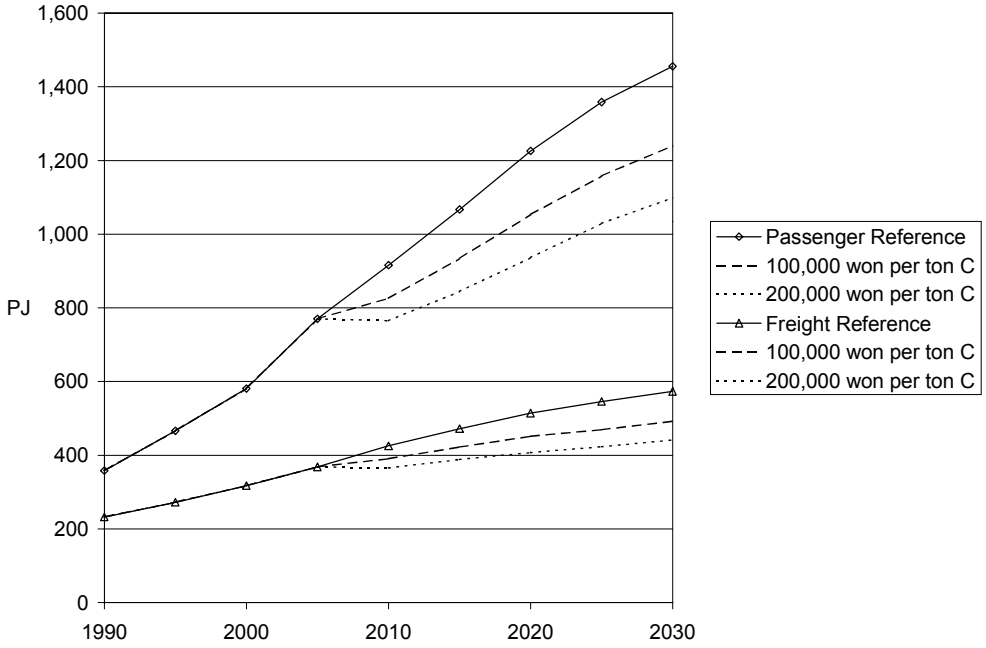
6. TRANSPORT SECTOR

We report results from the SGM-Korea transportation sector to illustrate recently added capabilities. The same types of plots can also be created for any of the energy-intensive industries. Figure 9 shows energy consumption for the passenger and freight transport sectors in the reference case and two carbon policy cases. Energy consumption in transportation is almost completely in the form of refined petroleum and is reported in units of petajoules.

Rising incomes in SGM-Korea create a rapidly rising demand for passenger transportation services. Households in SGM-Korea purchase energy services in the form of passenger-kilometers, to be supplied by the passenger transport production sector. Therefore, households purchase energy for transportation indirectly through passenger transport services. The model must therefore keep track of capital stocks needed to provide transportation services, and the production function for transportation services provides a convenient way to simulate productivity improvements in the capital stock.

Carbon prices have a significant impact on transportation energy consumption in SGM-Korea. Two components contribute to the decline in energy consumption. First, the demand for transportation services is lower because of the increased cost faced by consumers of those services. The second component is a shift away from expensive energy inputs in the production processes that provide transportation services.

Figure 9. Energy Consumption in Transportation



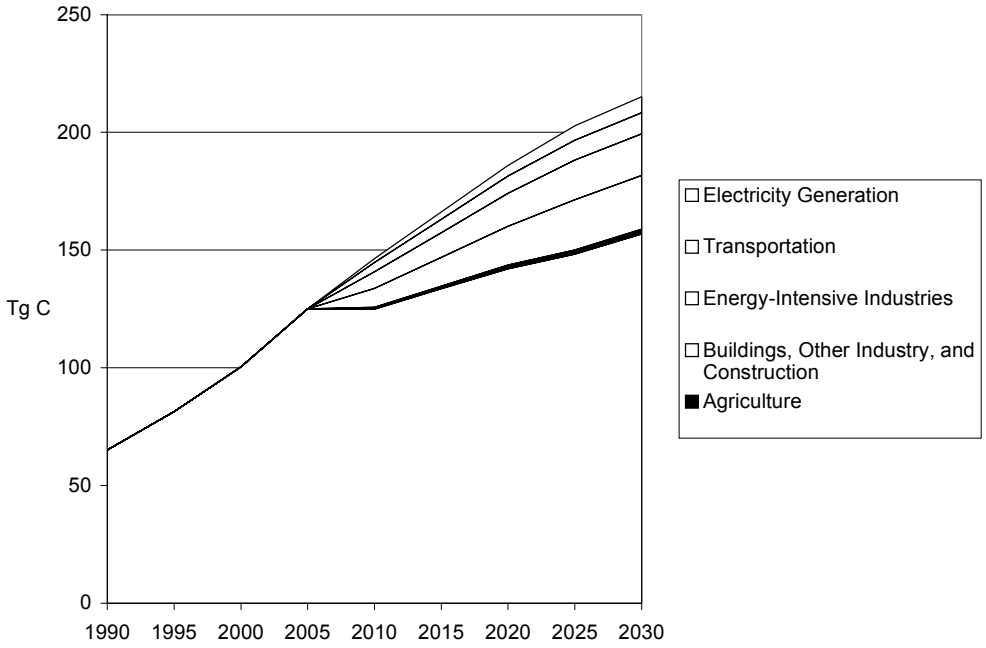
7. COMPONENTS OF CARBON MITIGATION

One of the goals of developing SGM-Korea is to identify the sectors and technologies that hold promise for filling the gap between a reference scenario and a carbon policy scenario. SGM-Korea now includes sufficient number of sectors to decompose a simulated reduction in carbon emissions into end-use sectors as shown in Figure 10. The policy scenario in this figure is a 200,000 won per ton carbon price beginning in 2010.

The first step in this decomposition is to calculate carbon emissions for each end-use sector in SGM-Korea. For oil, gas, and coal, the amount of energy consumed was multiplied by the corresponding emissions coefficient. A carbon emissions coefficient was computed for electricity as the amount of carbon emitted per joule of electricity generated in 1990. For industries other than electricity generation, this emissions coefficient was fixed at its 1990 level and used to convert electricity consumption to tons of carbon emitted. Each sector's contribution to filling the emissions gap was calculated as the difference between reference carbon emissions and emissions with a carbon price.

The carbon content of generated electricity decreases over time in the reference case, and decreases further in the scenario with a carbon price. The difference between reference carbon emissions and carbon emissions with a carbon price is the electricity generation sector's contribution to filling the emissions gap in Figure 10.

Figure 10. Carbon Mitigation by Sector with 200,000 Won Carbon Price



Results shown in Figure 10 are a first step in identifying the most likely places that reductions in carbon emissions could occur in Korea. Further analysis requires us to take a closer look at the transportation and energy-intensive industries to determine whether technical change and substitution parameters in SGM-Korea are plausible.

8. DISCUSSION

One objective for the development of SGM-Korea is to simulate carbon emissions over time in a way that is consistent with population trends and plausible assumptions on technical change. Model simulations begin in 1990, so we have almost one decade of historical data after that to compare with our simulations. The SGM-Korea reference case will be modified as more data on

GDP growth and carbon emissions becomes available, primarily through the technical coefficients displayed in Table 4.

SGM-Korea has been used to construct national marginal abatement curves as shown in Figure 8. These are expressed as a percentage reduction in emissions from the reference scenario because of the many uncertainties, such as the rate of economic growth, affecting projections of future emissions. Figure 8 actually contains a family of four distinct marginal abatement curves to help describe the timing of emissions mitigation. The marginal abatement curve furthest to the right in Figure 8 represents the steady state response of the Korean economy to a step increase in a carbon price. This assumes that the carbon price is implemented in SGM at least three time steps previously. Shorter time frames require the use of steeper marginal abatement curves.

Another goal of the SGM-Korea development effort was to increase the number of producing sectors, allowing a more complete picture of the opportunities for carbon mitigation. We have made significant progress with the new sectors covering energy-intensive industries and transportation.

We have made very simple assumptions regarding international trade in energy-intensive goods, and therefore have not examined the impact of a carbon policy on trade in these goods. This remains a future task. The model development process is a joint effort among staff in the Global Climate Change Group at Pacific Northwest National Laboratory and analysts from South Korea. Other goals for future work include identifying promising energy technologies and their impact on national carbon emissions, adding sectors for residential and commercial buildings, and simulating emissions of non-CO_2 greenhouse gases from agriculture.

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