UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

DATE

The Honorable Stephen L. Johnson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB Advisory on EPA's Second Generation Model

Dear Administrator Johnson:

In 2004, EPA's Office of Atmospheric Programs (OAP) requested that the Science Advisory Board (SAB) provide advice on a principal economics-based computer model used by the EPA to perform analysis of potential U.S. climate change policies. This model, known as the Second Generation Model (SGM), is a computer program that simulates the economic interactions and contributions to greenhouse gas emissions of 14 regions of the world. The model contains detail on the functioning of labor markets, energy fuels markets, and commodity markets in each region. Its general-equilibrium framework attempts to integrate consistently the behavior of these markets both within and across regions. The model is designed to simulate such climate policies as carbon fees, greenhouse gas allowance trading, and incentives for accelerated energy conservation. For each policy simulated, it indicates potential impacts on a range of economic and other variables, including labor demand, investment, industrial output, GDP, energy use, emissions, and government revenue. The model indicates policy impacts not only in the near term but at various points in the future as well.

Subsequent to OAP's request, the Science Advisory Board Staff Office solicited expertise in a *Federal Register Notice* published July 9, 2004. The Second Generation Model Advisory Panel was formed and met in its first face-to-face meeting on February 4, 2005. Since that time, the SGM Advisory Panel has had several discussions with EPA staff and other developers of the SGM, leading to the production of the enclosed Advisory.

The Advisory contains the SGM Advisory Panel's recommendations for improving the model. The Panel believes that these improvements are necessary to make the SGM a fully credible tool for policy simulations. The recommended changes are extensive and would require significant funds. The EPA should consider the benefits from this use of funds as well as the potential benefits from investments in other climate policy models.

The recommendations pertain to the model's documentation, the empirical basis and comprehensiveness of the model's data, the model's structure, and the reporting of the model's output. The Panel's main recommendations include the following:

- Improve the documentation of the model's data, parameters, and structure. It is important to make clear the empirical basis for the choice of parameter values that influence the results of the model. It is also important to clarify major aspects of the model structure, so that the internal consistency of the model can be evaluated.

- Update the model's data set. Much of the existing data set relates to stocks and flows of economic variables dating back to 1990 or before. For the model to generate more reliable policy assessments, it is important that the initial conditions or benchmark data be closer to current conditions. In addition, some consideration should be given to replacing the several current data sources with a different and more comprehensive data source, the "GTAP" data set.

- Improve several aspects of the model's structure:

    - The model's current treatment of household behavior does not allow for theoretically consistent assessments of the impacts of policies on human welfare. Household behavior needs to be modeled in a way that allows for consistent assessments of welfare impacts.
    - The current specification for industry production opportunities is relatively inflexible and should be replaced with a more flexible and realistic representation of production. Without a more flexible specification, the model is likely to give misleading predictions for the impact of climate policies on employment levels, investment, and the prices and outputs of various commodities.
    - The model's current treatment of international trade is far too rigid in that U.S. policies do not influence the pattern and volume of trade. A flexible, theoretically consistent treatment of international trade should be included in the model. Without these changes the model could give a very distorted picture of the impacts of climate policies.
    - Further detail is needed in the SGM's treatment of the electricity and forestry sectors, so that users can capture important ways that climate policies can affect these sectors.
    - The model's treatment of greenhouse gas emissions should be improved. In the current model, climate policies endogenously affect only the emissions of one greenhouse gas – carbon dioxide. The model should be extended to capture impacts on emissions of other greenhouse gases.

    Introducing each of these model structure changes will substantially improve the model's ability to capture the impacts of climate change policies.

- Improve the reporting of the model's results. Previous applications of the model have not sufficiently revealed the extent to which the results are sensitive to changes in various data or parameter inputs. Such "sensitivity analysis" is crucial to evaluating various policy options. In addition, the model needs to provide more information for the uncertainties underlying the values for its inputs, and the associated uncertainties in the policy outcomes.

In summary, the Panel finds that the SGM has considerable potential, but currently requires major improvements in order to be a fully credible, effective policy evaluation tool. The Panel believes that the SGM will achieve its potential as a policy tool only if the recommended changes are made.

Sincerely,

Dr. Granger Morgan, Chair	Dr. Larry Goulder, Chair
EPA Science Advisory Board	SGM Advisory Panel

U.S. Environmental Protection Agency
Science Advisory Board

ADVISORY
on the
SECOND GENERATION MODEL

By the
Second Generation Model Advisory Panel

7/17/06

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Introduction

In 2004, EPA's Office of Atmospheric Programs (OAP) requested that the Science Advisory Board (SAB) provide advice on a principal economics-based computer model used by the EPA to perform analysis of potential U.S. climate change policies. This model, known as the Second Generation Model (SGM), is a computer program that simulates the economic interactions and contributions to greenhouse gas emissions of 14 regions of the world. The model contains detail on the functioning of labor markets, energy fuels markets, and commodity markets in each region. Its general-equilibrium framework is geared toward integrating consistently the behavior of these markets both within and across regions. The model is designed to simulate such climate policies as carbon fees, greenhouse gas allowance trading, and incentives for accelerated energy conservation. For each policy simulated, it indicates potential impacts on a range of economic and other variables, including labor demand, investment, industrial output, GDP, energy use, emissions, and government revenue. The model indicates policy impacts not only in the near term but at various points in the future as well.

An extensive and detailed documentation of SGM's structure, parameters and assumptions, as well as a shorter overview paper, may be found on EPA's OAP's Web site at http://www.epa.gov/air/sgm-sab.html

Subsequent to OAP's request, the Science Advisory Board Staff Office solicited expertise in a Federal Register Notice published July 9, 2004. The Second Generation Model Advisory Panel (the Panel) was formed and met in its first face-to-face meeting on February 4, 2005. Since that time, the SGM Advisory Panel has had several discussions with EPA personnel and developers of the SGM. These discussions addressed the charge questions posed by the OAP (at http://www.epa.gov/sab/pdf/sgm_charge_questions_111804.pdf) and have led to the production of the enclosed Advisory Report.

In response to initial comments and information requests from the Panel, the SGM team provided the Panel with three documents:

The SGM: Comparison of SGM and GTAP Approaches to Data Development
The SGM: Data, Parameters, and Implementation
The SGM: Model Description in Theory

The Panel considers these documents and the model improvements described in them to be very useful initial steps toward improving the SGM model. In this report, we refer to these three documents respectively as papers 1, 2, and 3.

This Advisory contains the SGM Panel's recommendations for improving the model. The recommendations pertain to the model's documentation, the empirical basis and comprehensiveness of the model's data, the model's structure, and the reporting of the model's output. The two main parts of this report separate the recommended improvements that the

Panel believes can be made in the near term (perhaps within the next 6-9 months) from the improvements that would require more time to accomplish.

Part I: Recommended Immediate Improvements

A. Improvements to Documentation

i. General

The recent documentation provided in response to the Panel's initial requests for information (papers 1-3 listed in the introduction above) helped clarify the data, structure, and outputs of the SGM model. However, the Panel believes that significant further improvements to the documentation are warranted. In general, the documentation should be organized in a more coherent way. One possible organization is as below:

- **Model Structure --** household behavior, producer behavior, energy sector specification, international trade specification, technological change, government behavior, dynamics, emissions modeling, agents' expectations, representation of climate policies, disaggregation (of sectors, regions, resources)

- **Model Inputs --** data and parameters

- **Model Outputs and Reporting --** reporting of prices and quantities; measurement of costs, welfare measures; treatment of uncertainties in outcomes; sensitivity analysis; model validation

- **Solution Method**

ii. Model Structure

The Panel recommends improvements in the model's documentation of model structure along the following lines:

1. Clarify how the various aspects of the model – production, household demand, trade, government sector -- are connected. Readers should be able to see all of the excess demand equations and count them up. From there the reader should be able to trace back the equations determining each of the elements on the supply and demand side of each of the excess demand equations. The documentation should make clearer which prices are exogenous and which are endogenous. The number of endogenous prices should match the number of excess demand equations.

2. Include a "Derivation of Behavioral Equations" section as an appendix to the SGM documentation. This section should make clear the theoretical basis for the structural equations determining producer and household behavior. If a given equation involves a departure from accepted theory, the documentation should acknowledge the departure.

3. Make clear the nature of the central case and indicate which of the many off/on features of the model are off or on in the central case. When are prices in the "everything else" sector exogenous, and when are they endogenous? When do land prices play a role, and when do they not? Which production sectors use Leontief technology, and which use CES? What is the central assumption about price-expectations? Which of the various technological change parameters (related to labor, energy, etc.) are activated?

4. Improve the nomenclature to make it more consistent.

5. Confirm that the model is set up to check that Walras's Law is satisfied at every iteration of the solution algorithm. (If necessary, the model itself should be extended so that it indeed checks for Walras's Law in every application.)

6. Clarify how the model treats the ETE "everything else" sector. In particular, it is important to:

> a. Make clear how this sector fits into the rest of the model, and which price is set to 1 for this sector. It is important to indicate what is in, and what is not in, the ETE sector by region.
>
> b. Clarify the attributions of emissions to the "everything else" sector in Table 3.2 by defining the activities and their relation to the ETE. For example, what is activity ODSSub and why does only the service sector emit HFCs from this activity? It seems like many emissions ought to be tied to industrial production. Also, it is unclear whether and how abatement costs and GHG prices feedback to higher prices for ETE goods.
>
> c. Clarify the relationship between P, Pi, and Pr. Pi_{ETE} seems to be the numeraire but sometimes it is subscripted by the sector to which the good is sold, and at other times it is not.
>
> d. Clarify the consequences of using the ETE sector as the numeraire. To the extent Walras's Law is verified there should be no effect on quantities.
>
> e. Compare choices about sectoral detail to other Integrated Assessment Models.

iii. Model Inputs – Data and Parameters

1. Provide a detailed comparison of the SGM base year data with the GTAP data (Hertel, 1997). Many researchers working on the issues related to climate change use the GTAP data set, and virtually all researchers undertaking global trade policy modeling use it. The GTAP data includes detailed accounts of regional production and bilateral trade flows, currently covering 87 regions and 57 sectors in each country.

2. Indicate the extent to which the parameterized model replicates the benchmark data.

We encourage the model developers to provide source links for all data and parameters in the current version of SGM and to continue to do so as they move to update these inputs.[1]

3. Paper 1 (one of three papers listed in the introduction) provides a comparison of the SGM and GTAP approaches to fitting the IO table and energy balances for China. It would be very useful to add a similar comparison for other regions where IO data is not as questionable as in China. For example, a comparison for regions such as USA or Europe could be provided as well.

4. Paper 1 does not provide any comparison with the GTAP energy data. There is a discussion of GTAP volume data (price times quantity), the IO table of China (price times quantity), and IEA energy data (quantity), but the GTAP also provides energy data derived from the IEA statistics.

5. A comparison between the SGM economic (i.e., not just energy) data and the GTAP economic data at an aggregate level for all SGM regions should be provided, to see how they balance globally. This international and global perspective is fundamental to the modeling of the effects of major energy policies, and cannot be ignored.

6. The documentation should provide sources for the data on greenhouse emissions. It also should report aggregate numbers for CO_2 and other greenhouse gases in some form. In Paper 2 (page 12) there is a mention of the kind of data needed for non-CO_2 gases tracked in the model. The documentation lacks a reference to the database used.

7. The following additional documentation would be very useful:

a. A discussion of the specific EIA data and refinements needed to compile Table 2.5.
b. Documentation of the base year non-CO_2 emission (or emission factor) values and their sources.
c. The sources for Table 3.1
d. The source(s) for the MACS curves. Also, clarify their assignment to sectors.
e. A reference for the derivation of equations 3a–6.

8. In response to initial recommendations by the Panel, PNNL recently provided a master list of parameters in the theory sector as requested. This should be expanded to include benchmark parameter values, sources, and any refinements to arrive at them with a cross listing to model equations. A master list should be provided for all other data inputs.

9. The documentation could use improvement in its discussion of choices made regarding data for hydroelectric and nuclear energy. In particular, it should explain why EIA rather than IEA data were used.

[1] In response to initial recommendations by the Panel, PNNL has already made some very useful improvements to its documentation of data and parameters, for example by providing links for input-output data sources. At the same time, the Panel was unable to get any detail on data from outside the U.S. Documentation of such data is crucial to the credibility of the model.

10. The documentation should explain why the investment accelerator is set at 1.2 (page 28).

11. An inconsistency regarding the variable P_N should be eliminated. In the theory chapter P_N is the rental price of capital; in the documentation it is the price of the numeraire.

iv. Model Outputs and Reporting

Existing documentation reveals almost no sensitivity analysis. This severely reduces the ability to evaluate potential policy outcomes. To the extent that some sensitivity experiments have already been performed, the results of these experiments should be displayed. Further sensitivity analysis should be given high priority, as indicated in Part I below.

v. Solution Method

The documentation should refer to its chosen software and solution algorithm, and compare its choices with other algorithmic tools for the CGE modeling (such as GAMS, or GAMS-MPSGE software with an MCP algorithm).

B. Initial Improvements to Data and Parameters

The three papers recently provided by the model developers (listed in the introduction) indicate that the model developers have recently taken some significant steps toward improving the model's data and parameters. However, some significant further improvements are called for. Two of these can be accomplished in the near term. The recommended additional short-term improvements are as follows.

1. The model developers should seriously consider making greater use of GTAP data. The developers have indicated a preference for SGM data because it preserves physical units for energy. However, it is not clear that GTAP could not be adjusted in this manner. Also, it is not clear that most of the SGM model data could be updated as often as GTAP without incurring high (and duplicative) costs.

2. Appendix A offers a list of studies obtaining econometric estimates of demand elasticities. The Panel recommends that the model developers examine these estimates and consider the extent to which the elasticities resulting from the SGM model are consistent with these estimates. Parameters should be adjusted accordingly.

C. Further Sensitivity Analysis

Existing documentation reveals almost no sensitivity analysis. This severely reduces the ability to evaluate potential policy outcomes. Further sensitivity analysis should be given high priority. In the near term, simple sensitivity analysis could be conducted, in which policy outcomes are generated under different values for key parameters. Section D of Part II indicates the Panel's recommendations for a more extensive and informative sensitivity analysis procedure that generates probability distributions for policy outcomes.

Part II: Recommended Subsequent Improvements

A. Further Improvements to the Data

i. Updating the Data Set

The Panel wholeheartedly supports the model developers' intention, stated on pp. 8-9 of paper 2, to strengthen the empirical basis of the model and to automate the data updating process. Such an update would reflect changes in economic conditions, technology in critical sectors, and would allow comparability with other data sets. The base year of the data in the SGM model is 1990. Many counties and regions have had substantial changes in economic conditions and technology since 1990. The base year should be updated to reflect these changes, particularly in critical sectors for the analysis of carbon policies.

ii. Greater use of GTAP data

As mentioned earlier, the model developers should seriously consider using the GTAP data set. The SGM documentation (Paper 2) states that "the majority of time is spent obtaining and processing the necessary data." The SGM developers should consider using the GTAP data set to save the time spent in obtaining and processing the data. Many researchers working on the issues related to climate change use this data set, and virtually all researchers undertaking global trade policy modeling use it. The GTAP data includes detailed accounts of regional production and bilateral trade flows, currently covering 87 regions and 57 sectors in each country. The dataset also includes supplemental energy data in physical terms, which is linked to the economic data. The base year for version 5 of GTAP is 1997, and for version 6 it is 2001. The GTAP data set is available at extraordinarily low cost. Details on the GTAP data can be obtained from http://www.gtap.agecon.purdue.edu, and extensive documentation of version 5 is provided by Dimaranan and McDougall [2002].

The GTAP data may be accessed with either GEMPACK software provided with the data package, or through GAMS using tools developed by Thomas Rutherford (http://www.mpsge.org/gtap6). In either case the available software provides flexible aggregation schemes, to allow the user to match the GTAP data to their own needs, rather than carry along the complete detail in the full data set. The GTAP data set is illustrated in applications contained in Hertel [1997], although one does not need to use the GTAP models in order to use the GTAP data set.

Whether or not the model developers ultimately decide to use the GTAP data set, the Panel urges the developers at a minimum to provide a comparison between the SGM data and the GTAP data. For the energy data these comparisons should be in value terms and in physical flows. The use of constrained optimization routines to facilitate such updates has a venerable tradition, and has become much more common in recent years (see Stone, Champernowne and Meade [1942] and Harrison, Rutherford, Tarr and Gurgel [2004; p.297]).

One disadvantage of the GTAP dataset for carbon policy analyses is that the electricity sector is currently a single aggregated sector. Therefore, this sector would have to be disaggregated further, to reflect alternative energy supply technologies such as coal, hydro-power, nuclear, wind, biomass, etc. Such disaggregation would not be difficult (e.g., the IEA provides detailed energy balances for many countries).

In summary, the Panel suggests two feasible scenarios for updating the SGM data set. One possibility is that SGM developers use the current procedures they use for data collection and calibration, update the data to 1997 or 2001, and provide a detailed comparison with GTAP data being used by other modelers. The other is that SGM developers use the GTAP data with additional disaggregation of electricity sector. The Panel tends to prefer the latter option, but the best path will depend on information obtained by the model developers as they examine and compare the data sets.

B. <u>Model Structure Improvements</u>

i. Household Utility Modeling and Welfare Calculations

The Panel urges the model developers to improve the specification of individual household behavior. Currently, such behavior is not derived from an explicit utility function. This prevents the use of theoretically consistent measures of the welfare impacts of policies.

The discussion below focuses only on the general representation of consumer demand functions, and on the use of demand functions to construct welfare measures. This section does not include a discussion of specific issues relevant to inter-temporal decision making, such as providing a utility theoretic basis for the allocation of income among current versus future consumption through savings/borrowing, nor the allocation of time among labor/leisure. These are significant topics involving specialized issues that are deserving of separate consideration, but are not covered below.

The simplest approach for creating a utility theoretic basis for an aggregate model is to apply the notion of the "representative consumer". Here, aggregate (or average) demand is treated as if it were generated from a single utility maximizing individual (see, for example, Deaton and Muellbauer, 1980, p 149-158). The representative consumer approach can a pragmatic way to assess welfare effects. This could be the first major improvement to the modeling of consumer behavior.

However, the representative consumer approach has been widely criticized by economists. (See for example, Kirman, 1992; Stoker, 1993; Slesnick, 1998.) Constructing an aggregate demand function that is “rationalized” by a particular utility function either implies placing strong restrictions on preferences or implies market demand functions that are not logically consistent with the aggregation of a set of disaggregate consumer demand functions.

As a potential subsequent step, the Panel recommends that the SGM be modified to include multiple representative consumers, one representative consumer for each of several socio-demographic groups. This would partly address the theoretical objections to the representative consumer approach. The use of multiple representative consumers also has the appeal of allowing one to estimate distributional effects of policies across various consumer groups.

The challenge faced in extending the model to multiple representative consumers is to identify data adequate to specify demand functions for separate representative consumers (e.g., a representative low income vs. middle income vs. upper income individual). The Computable General Equilibrium literature has several examples of models based on multiple representative consumers, involving anywhere from small to very large numbers of separate representative consumers (e.g., Piggott and Whalley, 1985; Cockburn, 2001; Cogneau and Robillard, 2000; Harrison, Rutherford, Tarr and Gurgel, 2005).

ii. Production

General Recommendation

The Panel’s main recommendation is that the model developers replace the flat CES production specification with a more flexible specification such as a nested CES structure.

Spe**ci**fically, the Panel recommends that the developers survey the recent literature (e.g., Burniaux and Truong 2002) and employ a nested-CES production structure more in line with existing CGE models and parameterized based on empirical data. Model choice (as well as documentation) should pay particular attention to issues, such as short-run complementarity versus long-run substitutability of capital and energy, highlighted in the literature. In the future, the modeling team should consider exploring other functional forms (maintaining global regulatory) and making their own empirical parameter estimates using updated data.

Background

The goal of production modeling is a flexible, parsimonious, practical representation grounded in empirical data. Flexibility and parsimony refer to models that capture the full range of theoretically consistent, local substitution possibilities. A practical representation, referred to as global regularity, is one that defines consistent demand behavior (positive, downward sloping) for all combinations of positive prices. Finally, empirical data refers to the need to have simulated behavior match historic experience as much as possible.

A fully-flexible representation is one that provides a second-order differential approximation to an arbitrary twice continuous differentiable cost or production functions

(Diewert and Wales 1987). That is, it can accommodate any pattern of local substitutability / complementarity of inputs about the initial benchmark prices. Examples of such functions in the literature include the translog and generalized Leontief, as well as a number of other less common forms.

A key concern in these functions is regularity. That is, downward sloping input demand curves for all inputs (and linear combination of inputs). Global regularity for all non-negative input (and input combinations) is especially hard to guarantee when the second-derivatives are complex functions of both parameters and inputs. For simulations to be meaningful, regularity is theoretically necessary only over the range of equilibrium prices and quantities—however narrowly or widely they vary. In practice, however, most computational algorithms have trouble with non-globally regular functions—in the course of finding the equilibrium, prices and quantities can wander far beyond the eventual equilbrium. Therefore, local regularity about an equilibrium (or range of equilibria) is not generally sufficient.

In response to this, Perroni and Rutherford (1995) propose a non-separable CES functional form that can represent local second-order flexibility and remains globally regular. Their formulation does not provide a unique representation (many representations match the same second-order conditions), however, and has not been widely implemented.

More common approaches in the CGE modeling literature focus on more structured, less flexible production models, in part because of the difficulty in parameterizing a fully flexible model (which will have n x $(n - 1) / 2$ parameters, where n is the number of inputs). These models typically employ nested CES functions, where the nests represent sets of inputs that are separable from other inputs—in contrast to the above, non-separable model required for full flexibility. In its simplest form, without any nests, the CES requires one parameter to describe the common elasticity of substitution among all inputs. A few examples of nesting structures are given at the end of this section. In particular, we see examples with materials separated from a capital-labor-energy aggregate, versus all four groups together in one tier. We also see with the capital-labor-energy aggregate either a capital-energy sub-tier or a capital-labor sub-tier.

The choice of nesting structure depends both on the questions being asked and empirical data. Analysis of climate change policies, for example, requires considerable energy detail as all of the referenced models demonstrate, and energy is typically in its own sub-tier. It should, however, be an empirical question whether capital and labor are more likely separable, versus energy and capital. Sources of empirical elasticity estimates are cited elsewhere in this report (see, for example, Burniaux et al. 1992).

Appendix B provides examples of nested structures for production.

iii. International Trade

General Recommendation

The panel feels that the model's treatment of international trade significantly limits its ability to evaluate climate change policies. The treatment of international trade is currently exogenous in that domestic policies do not influence the volume and composition of international trade. An endogenous treatment of international trade is crucial for understanding the principal impacts of climate change policy. This is obvious if the policy being evaluated involves other countries than the United States, such as proposed multilateral or joint policies such as Kyoto-type policies (e.g., Harrison and Rutherford [1999] and Pinto and Harrison [2003]). But it is equally important if the policies are only "domestic" in orientation, since the effects may be dramatically muted if trade offsets them.[2] The SGM modeling team has indicated that it uses the SGM model in two ways. Some applications focus on impacts on the U.S., and employ a "USA-only," stand-alone, version of SGM. Other applications make use of the full, global SGM model. The Panel believes that improvements to the treatment of international trade are crucial for both applications.

There are two ways in which the trade component of the model could be improved. The first method is a near-term step, which is applicable to the stand-alone, "USA-only" version of SGM. Our recommendation is to transform the current single-region closed-economy model into a single-region open economy model that is "closed" with a trade sector that allows for substitutability between domestic and foreign produced goods, but that treats the global terms of trade as fixed.[3]

The second method is part of a longer-term strategy of model development, and applies to the full-blown multi-region version of SGM. Our recommendation is to extend the current structure—which is currently little more than a collection of closed-economy models which can engage in trade in emission rights—to be a truly global model, by explicitly including bilateral trade in commodities between regions.

Both of these approaches have long traditions in the broader general equilibrium modeling literature, and the strengths and weaknesses of each are well known. The second approach is needed if one is to seriously consider modeling global policies: relying on other models and modelers to fill in critical simulations is perilous, even if it sounds like the diplomatically correct thing to do. This is particularly true if the other models are unavailable for public scrutiny, as appears to be the case with the partners chosen by SGM. On the other hand, building a global model may be a lot of work if the SGM team insists on constructing its own database. A move to the GTAP database would dramatically reduce these costs.

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[2] The literature is full of studies of these effects. For example, Harrison and Kriström [1998a][1998b] consider the effects of unilateral carbon tax increases in Sweden, and find that they could actually *increase* global carbon emissions, which is the very opposite of the intended environmental objective. The logic is simple: increases in carbon taxes in Sweden cause a substitution away from Swedish-produced goods towards foreign-produced goods, and if foreigners are more carbon-intensive in their production processes then emissions increase. Since Sweden has considerable nuclear and hydro power, and there are many countries that it trades with, such as Denmark, Poland and China, that do not, this trade-induced effect is quite likely for Sweden.

[3] The global terms of trade is a trade-weighted average of the relative prices of imports and exports to a given country. The assumption of fixed global terms of trade means that no given country has sufficient market power to affect the prices of its imports relative to its exports.

Specific Elements of a First Approach

Therefore, we focus the bulk of our discussion on incorporating trade using the first approach, which is to treat the United States as a small open economy.[4]

The specific structural changes involved are as follows:

1. Imports of each commodity should be specified as a constant-elasticity of substitution (CES) function of aggregate imports, a variable whose dual is specified as the price of foreign exchange.
2. Aggregate exports should be specified as a constant-elasticity of transformation (CET) aggregation of the quantities of exports of the individual commodities in the model. As in point (1), the dual of aggregate exports is the price of foreign exchange.
3. The production of commodities in each traded sector should be specified as splitting gross output between domestically-produced and exported varieties using a CET function.
4. All traded commodities should be represented as Armington (CES) composites of imported and domestically-produced varieties. The associated dual variables are the Armington goods prices, which serve as the prices of commodity inputs to intermediate and final demand.
5. Aggregate imports and exports should be linked by a balance-of-payments constraint.

We emphasize that these alterations can be implemented immediately, and the new structure numerically calibrated using the existing social accounting matrix.[5]

A major consequence of explicitly representing trade is the issue of what trade elasticities to specify. There is a long-standing debate in the literature on this issue: the econometric estimates are "too low" in relation to the *a priori* belief that many (particularly small) countries have zero market power on global markets. Low trade elasticities imply that the country has some market power. This debate is reviewed in Harrison, Rutherford and Tarr [1996]. We recommend that the SGM use two sets of trade elasticities, one "high" and one "low," to reflect the uncertainty in the literature. This uncertainty is an obvious input into a systematic sensitivity analysis of policy results, as recommended elsewhere.

[4] This is actually a plausible assumption, despite the fact that the US economy is large. Moreover, if there is some concern that US policies might influence global terms of trade, those effects can be estimated "outside of the SGM" and evaluated parametrically within SGM. Harrison and Kriström [1998b] illustrate how one can take changes in the global terms of trade from some other model and evaluate domestic carbon tax policies with and without that global context. This requires some modest efforts at pairing up sectoral aggregations across models, but is not as difficult as it might seem *a priori* since the pairings do not need to be exact or one-to-one.

[5] The detailed specification of such a structure is described in De Melo and Tarr [1992] and Rutherford, Rutström and Tarr [1997]. Detailed specifications for comparable multi-region trade structures are available in Rutherford and Paltsev [2000; pp. 10-17, 21-28].

The Panel has some concerns about the SGM modeling team's use of calibrated logistic share equations to simulate the partitioning of the aggregate uses of each commodity into imported and domestic varieties. We would recommend instead an Armington trade specification. The Armington specification has three key benefits:

- Flexible demand functions for domestic output and imports
- An abundance of econometric estimates of the elasticity of substitution in different industries—e.g., for North America, Stern, Francis, and Schumacher (1976), Shiells, Stern, and Deardorff (1986), Reinert and Roland-Holst (1992), Shiells and Reinert (1993), and Gallaway, McDaniel and Rivera (2003).
- Global regularity, in the sense of Perroni and Rutherford (1995)

The alternative approach proposed by the modeling team would not only fail to capitalize on these advantages, it would also introduce significant additional work on their part, which can be avoided. To see this, assume that the aggregate use of good *i*, A_i, is produced from imported and domestic varieties D_i and M_i, respectively, according to an aggregation technology, f_i:

$$A_i = f_i(D_i, M_i)$$

The aggregate price of *i*, p_i, is determined by the dual cost function c_i, denominated over the prices of imported and domestic varieties, p_i^D and p_i^M:

$$p_i = c_i(p_i^D, p_i^M)$$

Presumably the share equation to be employed will be similar to the following:

$$(1) \qquad S_i^M = \frac{p_i^M\left(\frac{\partial c_i}{\partial p_i^M}\right)}{p_i^D\left(\frac{\partial c_i}{\partial p_i^D}\right) + p_i^M\left(\frac{\partial c_i}{\partial p_i^M}\right)} = \frac{\exp\{\alpha_i^M + \beta_i^{DM}\ln p_i^D + \beta_i^{MM}\ln p_i^M + \gamma_i^M \ln A_i\}}{\left(\begin{array}{l}\exp\{\alpha_i^D + \beta_i^{DD}\ln p_i^D + \beta_i^{DM}\ln p_i^M + \gamma_i^D \ln A_i\} \\ \quad + \exp\{\alpha_i^M + \beta_i^{DM}\ln p_i^D + \beta_i^{MM}\ln p_i^M + \gamma_i^M \ln A_i\}\end{array}\right)},$$

where S^M is the import share of the value of aggregate use of commodity *i*, p^D and p^M the prices of domestic and imported varieties of *i*, *A* represents the (Armington) aggregate demand for *i*, and α^D, α^M, β^{DD}, β^{MM}, β^{DM} and γ^D and γ^M, are estimated parameters.

In the general, *n*-input case the logit share equation does not contain an analogue of the elasticity of substitution. This threatens to complicate analysis of the sensitivity of traded industries to climate change mitigation measures, as there is seemingly no way to evaluate the responsiveness of these sectors' activity levels to different degrees of fungibility between domestic and imported varieties. However, Considine (1989: 934-938) shows that in the 2-input case, eq. (1) is very similar to the CES function in its properties and behavior. This result both highlights the utility of our recommended approach and implies that the modeling team can avoid reinventing the wheel by simply following our original guidance.

Finally, the Panel is not comfortable with the SGM modeling team's justification for using the logistic approach, namely, that it will preserve energy *quantities* in the aggregation process. The premise of this justification seems problematic. In the case of *quantity* rather than *cost* shares, i.e.,

$$\tilde{S}_i^M = \frac{\partial c_i / \partial p_i^M}{\partial c_i / \partial p_i^D + \partial c_i / \partial p_i^M},$$

the degree to which the logistic model retains its global properties is uncertain, as there does not appear to be a well-posed dual form which can be easily integrated into the price-endogenous equilibrium structure of a CGE model. What is certain is that the analogue of the elasticity of substitution vanishes, with the result that sensitivity analysis becomes a complicated task.

In our judgment it is far better to improve the model using economically meaningful approaches rather than sacrifice the economics for the sake of getting energy quantities right. We feel strongly on this point, particularly given that other models (e.g., GTAP in GAMS, MIT EPPA) are able to employ the Armington specification without it having much of an adverse impact on the calculation of energy trade volumes.

iv. Electricity and Agriculture/Forestry Sectors

The Panel is impressed by the SGM model's high degree of sectoral as well as regional disaggregation. However, it concludes that refinements to modeling of the electricity and agriculture/forestry sectors would significantly improve the model's ability to evaluate climate policies.

Electricity Sector

The electricity sector represents an important aspect of the model because it is the source of a large portion of greenhouse gases and because it is the sector that is expected to provide a large portion of emission reductions under various climate policies. Three features differentiate the electricity sector from the rest of the economy in ways that may be important to SGM. One is that capital investments are very long-lived. Second, half the nation still uses cost-of-service regulation to determine electricity prices and a large part of the nation that is ostensibly under competition also has regulated aspects to the determination of price. Third, the sector is the target of many other environmental and technology policies that affect its performance with respect to GHG emission reductions and cost of those reductions.

<u>Rate of capital turnover</u>. The Panel believes that the assumed lifetimes of capital in the SGM model in this sector are too short. The lifetime of capital in the model is 20 years. This implies overlapping generations of technology with improvements for 25% of the capital stock every five years. This implies that policies could lead to a 100 percent turnover of capital in twenty years. In the electricity sector, capital lifetimes are significantly longer than specified by

the model, and as a result the SGM model may imply too much flexibility in capital and under-represent the cost of climate policy. The Panel urges the model developers to consider refining the capital lifetimes in the electricity sector to make them more consistent with empirical evidence.

Regulated prices. The long-run significance of economic regulation is partly to affect the pace of technological change and partly to affect the role of risk in investment decisions. But for SGM, the most important effect is the differentiation of price from marginal cost by time of day and the effect this has on choice of technology for electricity generation. The current structure of demand reflects prices that do not differ by time of day for most customers, thereby providing no incentive to change the time of electricity consumption. If time of day pricing becomes common, one would expect to see a shift away from peak to baseload consumption. This suggests a smaller role for gas and a larger role for nuclear and coal-fired generation.

Policy capabilities. The electricity sector is a target of policies such as renewable energy portfolio standards, benefit programs promoting end-use conservation, tax incentives favoring one or another technology. These policies have important vintage effects. SGM needs to be able to characterize technology choices that may differ from least cost choices according to predicted market prices over time. Perhaps this can be done with a shadow price adder that reflects calibration to current data.

Agriculture and Forestry Sectors

The agricultural and forestry sectors are essential sources and sinks of CO2. Agriculture is also a significant source of non-CO2 GHGs. Agricultural and forest sectors of both developed and developing nations are subject to extensive policy interventions that influence the amount of land crops, pasture, and forests, the types of commodities produced, and production practices that affect carbon fluxes and non-CO2 GHG emissions. An example receiving much attention is the Conservation Reserve Program (CRP) in the U.S. The CRP pays farmers to take crop land out of production. The lands are left unplowed and planted to a cover crop. Because of the CRP, GHGs from the use of farm machinery are eliminated, carbon releases that occur with tillage are eliminated, and carbon sequestered by soils increases. In addition to affecting carbon fluxes and non-CO2 emissions, agricultural and forest policies influence the marginal costs of sequestration in agricultural and forest land, and thus the potential participation of and gains from agriculture and forestry in carbon trading or other carbon policies.

The SGM model is without agricultural and forest policies. More importantly, the highly simplistic specification of the agriculture/forest sector in the model does not facilitate the effects of agricultural and forest policies, or policies directly addressing GHGs, on key variables influencing carbon fluxes in these sectors or non-carbon GHGs. The overall utility of the model for GHG policy analysis is correspondingly limited.

Recommendations elsewhere in this report call for revisions of the production structure of the model to use nested CES production functions. The revisions of the production structure would offer an opportunity as well for revisiting the specification of the combined agriculture and forestry sector to increase the capacity of the model to reflect the influences of agricultural and forest policies on GHGs and the marginal costs of mitigation policies. Dissaggregation of the combined agriculture and forest sector into separate sectors, and possible further dissagregation of the agricultural and forest sectors into subtypes useful for policy analysis (e.g., crops, livestock) would increase the capacity of the model. Further, because of the importance of land and land policies to both sectors, and the importance of land cover to GHGs, inclusion of land as an input in the production of these products would increase the utility of the model for agricultural and forest policy analysis.

v. Greenhouse Gas Emissions

The Panel recommends the following improvements in the treatment of non-CO2 greenhouse gases:

1. In the SGM model, the CO2 emissions mitigation options are endogenous (i.e., the model responds to a carbon price via change in demand, supply, technology change, investment decisions, etc.). However, for non-CO2 emissions the SGM uses the exogenous curves relating percent reduction in non-CO2 emissions to the carbon price; this stunts the full range of general equilibrium effects. We recommend endogenizing the non-CO2 emissions as other models of a similar type have done. One possible way to implement endogenous mitigation options is as follows:

- incorporate non-CO2 emissions mitigation into the production structure;
- incorporate non- CO2 emissions mitigation into consumption;
- take the base year GHG and economic data, and generate activity-specific emissions coefficients for each gas; and
- generate region- and sector-specific time trends in emissions coefficients.

GHG mitigation activity levels will differ according to flows of inputs (e.g., fossil fuel combustion, fertilizer use), flows of outputs (e.g., rice cultivation, natural gas transmission), and stocks of inputs (number of ruminating animals, landfill volume).

2. The existing documentation states that for the non-CO2 emissions, there are more than a dozen sources, which makes “the process modeling used for CO2 impractical.” However, in the SGM all nitrogen sources share a common cost curve, as do all high global warming potential (GWP) sources. In actuality, mitigation differs greatly across most of these sources. We recommend that the SGM move toward incorporating different cost curves for the different nitrogen sources and high GWP sources.

3. The SGM documentation should provide references to CO2 and other GHG databases used in the model. It also should provide aggregate numbers for all GHG gases for the base year for all SGM regions."

4. In the SGM, the "exchange rate" between carbon prices and other GHG prices is determined by global warming potential (GWP). It should be noted that the use of GWP implies constant rates of exchange through time, which some authors consider a problematic assumption. (See, for example, Eckaus (1992), Reilly and Richards (1993), Schmalensee (1993), Reilly et al. (1999).)

C. <u>Dealing with Uncertainty</u>

The Panel believes that the absence of sensitivity analysis seriously compromises the model's ability to evaluate climate policies. Focusing alone on simulation results based on central or best-guess values of parameters or favored structural assumptions gives no information as to the fragility or robustness of policy outcomes. In Part I we indicated an initial approach to sensitivity analysis that could be introduced immediately. Here we offer and recommend the use of Monte Carlo techniques to provide greater information as to the robustness of policy outcomes.

i. Applying Monte Carlo Simulation in the Sensitivity Analysis

Uncertainties about parameter values

Modern computing capabilities make it relatively easy to use Monte Carlo techniques. We first discuss these techniques as applied to parameters. Under Monte Carlo simulation, the user specifies a range of possible distributions that each parameter or modeling assumption can take. In performing policy simulations, the model then randomly draws from the posited probability distributions of each parameter, repeatedly solving the model under different randomly drawn sets of parameters. The probability distribution of policy outcomes can then be characterized by simple and well-known statistical procedures. The key insight is to move away from *ad hoc* sensitivity analyses that only perturb one elasticity or set of elasticities at a time, since they do not adequately convey a sense of the fragility of policy simulations from general equilibrium models.

In principle, the probability distributions for the model parameters should be joint distributions, allowing for covariances across parameters. However, it may be difficult to obtain information on such covariances, in which case it is reasonable to assume the probability distributions of parameters are independent.

The existing literature provides ready guidance for how one might set up these sensitivity analyses for parameter estimates (e.g., Harrison and Kimbell [1985], Pagan and Shannon [1987], Harrison and Vinod [1992] and DeVuyst and Preckel [1997]). For example, one might use an elasticity of substitution with a point estimate provided by an econometric study, and typically that study will also provide an estimate of the standard error. One can then assume a *t*-distribution for the parameter estimate, assume that it has no covariance with other parameter estimates, and use this information to guide the random draws for the Monte Carlo simulations.

In this manner the random draws will automatically put greater weight on those values of the estimate that are more likely given the distribution of parameter estimates from the econometric study.

If no estimate of the standard error is available, one can be assumed *a priori*. If system-wide estimates are available, either of demand systems or supply systems, then the econometric study will also provide a covariance matrix that can be used to allow for the correlation between estimates; facilities for multivariate random number generation are readily available. The SGM model should contain a default set of distributional assumptions for all key parameters, and perhaps a scalar that can be used to inflate or deflate sets of elasticities. This would allow researchers to “turn off” the uncertainty about trade elasticities, for example, and see what the contribution is from uncertainty about other elasticities.

Although the literature has naturally focused on uncertainty about elasticities, since that is what typically drives the intuition of economists and the policy debates, one could readily extend these idea to uncertainty about other data used in the model (e.g., perturbations in raw transactions data could be considered, providing one had a re-balancing routine that ensures micro-consistency once accounts were not in balance, say by solving for the nearest set of data that satisfies those micro-consistency constraints and minimizes some metric of deviation from the initial data).

Monte Carlo sampling methods of Harrison and Vinod [1992] have been widely employed in models that are solved in “level form” and do not entail significant additional programming. The Gaussian quadrature methods of DeVuyst and Preckel [1997] are likely to be more efficient in terms of the number of solutions required for a given estimate of the distribution of policy effects, but will require slightly more up-front programming. Neither is onerous, in relation to the other demands of modeling. Specialized methods exist for models solved in “difference form,” as illustrated by Pagan and Shannon [1987], although these are not applicable for SGM.

Uncertainties in model specification

Although less common, the literature also shows how one can extend these ideas to include uncertainty about model specification (e.g., Harrison, Jones, Kimbell and Wigle [1993]). The idea is to posit two or more model specifications, treat the choice of these specifications as coming from a discrete distribution, and assign probability weights to each. An appropriately diffuse distribution would be to simply assign equal weight to each alternative. Alternatively, where model structures have familiar application in the literature, one could rely on expert elicitation techniques to assign probability weights. Or one could ascertain what weight has to be put on one alternative in order for the qualitative policy results to change. In any event, the computational logic is the same.

ii. Characterizing Uncertainty in the Presentation of Policy Results

The results of a systematic sensitivity analysis can be presented in several ways that would dramatically improve the plausibility of the policy analyses undertaken with SGM. To display the stability of model results with respect to policy recommendations, one popular method is to just display a histogram of the distribution of key results, along with information on the empirical 90% confidence intervals, or the probability that the sign of the policy variable is positive or negative. Policy-makers appreciate having some sense of the confidence in the predicted sign of a policy variable, just as one expects to see a p-value or t-statistic beside any statistical estimate of a policy effect.

Beyond these simple reporting advantages of conducting a sensitivity analysis, one could use the results to obtain insight into the determinants of the policy results. The outcome of the Monte Carlo simulations can be appropriately viewed as the data for a simple regression analysis, with the dependent variable being the calculated policy impact and the independent variables being the perturbations in parameters or dummy variables indicating which model specification had been used.

Another use of sensitivity analysis is to guide the allocation of resources in model refinement. Results of sensitivity analysis could be used to identify those variables that have the largest effect on propagating uncertainty in the outcome measures and policy recommendations. In the CGE model one can use the analysis to identify “key elasticities” that drive the policy results. Although it is true as a formal matter that every elasticity and parameter matters for the numerical results, it is almost always the case that uncertainty over several key numbers can generate widely divergent policy results. By highlighting those data that are relatively more important, the modeler is alerted to where it would be efficient to allocate effort to improve data.

D. Validation through “Backcasting” Exercises

The results obtained from large-scale simulation models such as SGM rest on many parameter estimates and model assumptions. To avoid these policy simulations becoming a “black box,” it is valuable to have a sense of their sensitivity to variations in estimates and assumptions.

Beyond sensitivity analysis, it is possible to gain a better sense of the validity of the model’s structure and inputs through “backcasting.” This involves running the model forward, starting from some point in the past, and observing how well the model tracks past history. The Panel urges the model developers to conduct this type of experiment.

Such validation exercises have been conducted, for example, by researchers at the Dutch Central Planning Bureau. Henri Theil applied this approach in the 1960s using an annual input-output model. These backcasting exercises will provide useful information to the model developers, information that can guide improvements to the model’s structure or data.

Appendices

Appendix A: Econometric Studies of Energy Demand Elasticities

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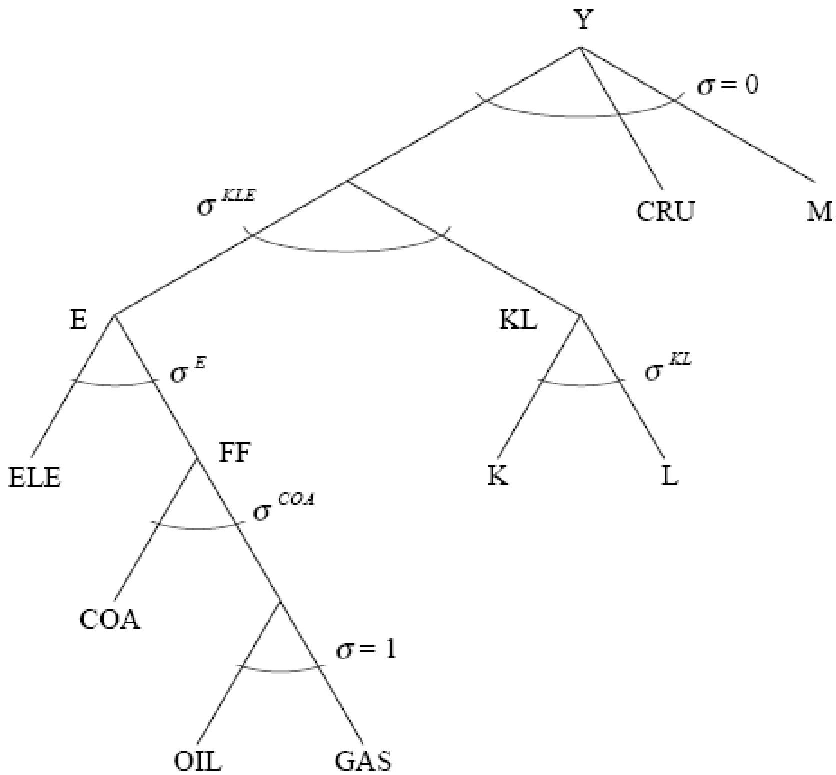
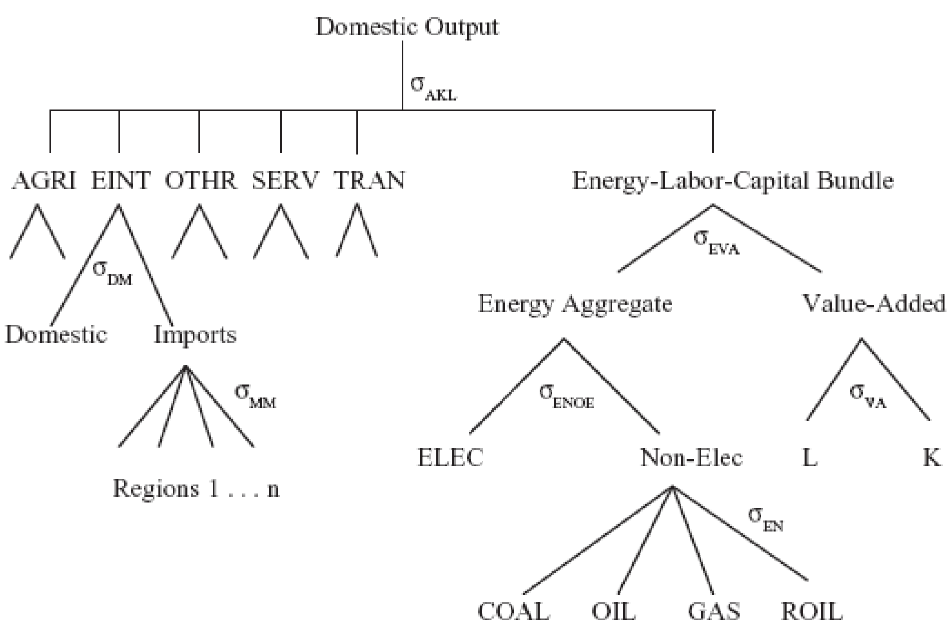
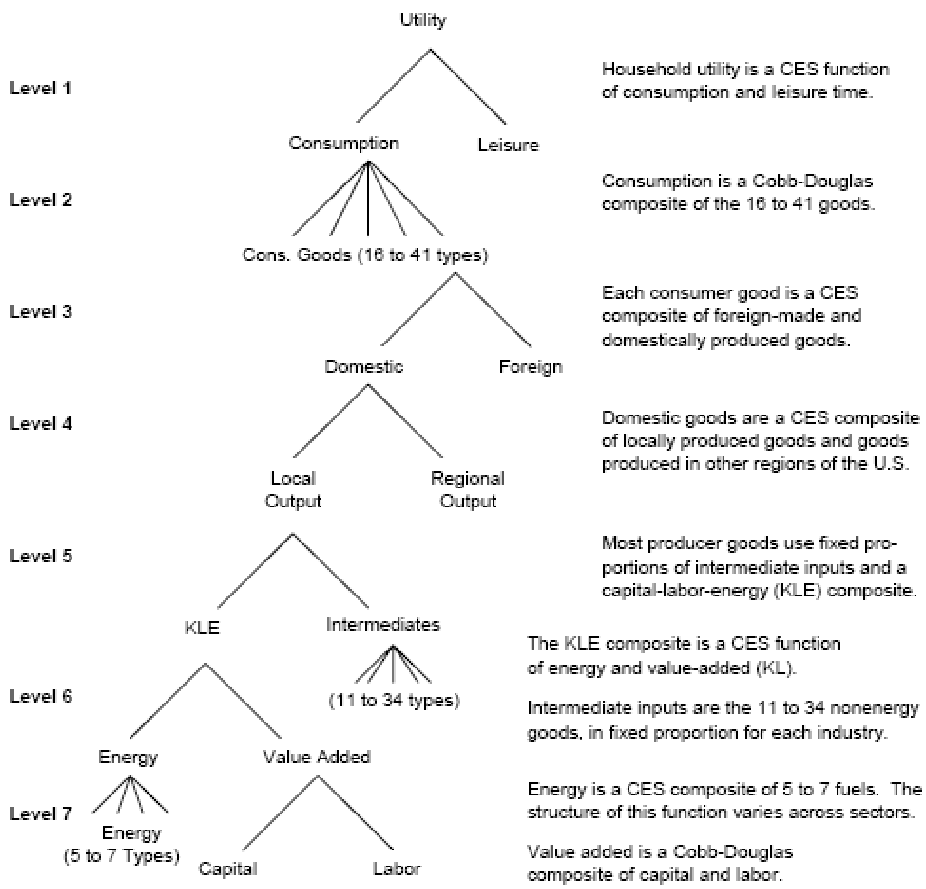
Appendix B: Examples of Nested Production Structures



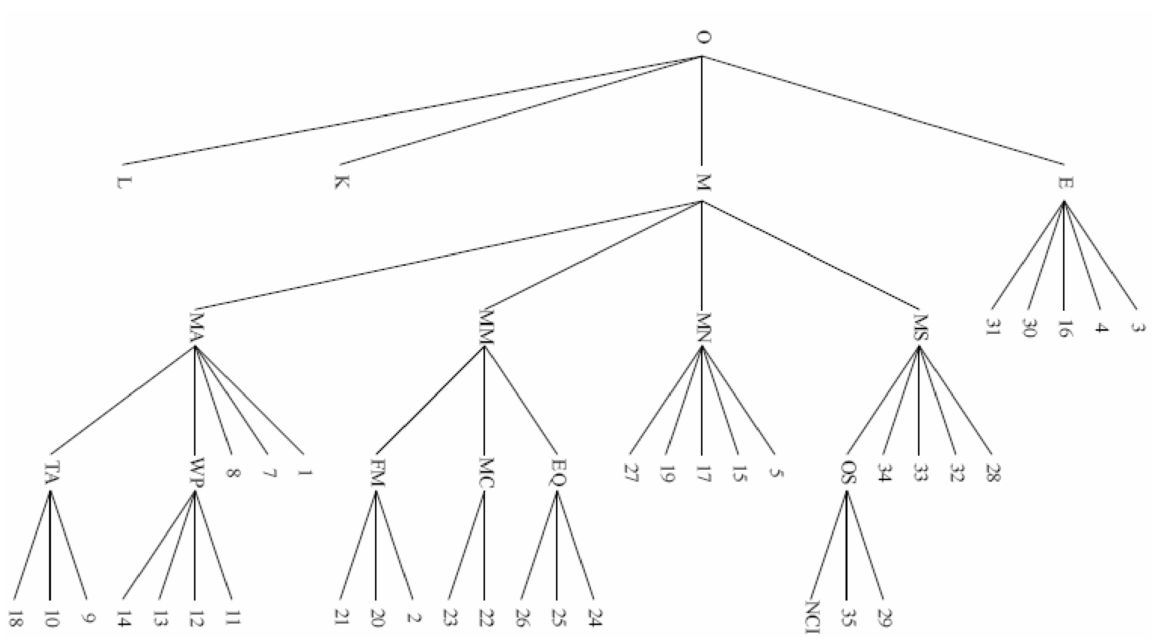
(Böhringer and Löschel 2004)



(Jacoby et al. 2004)

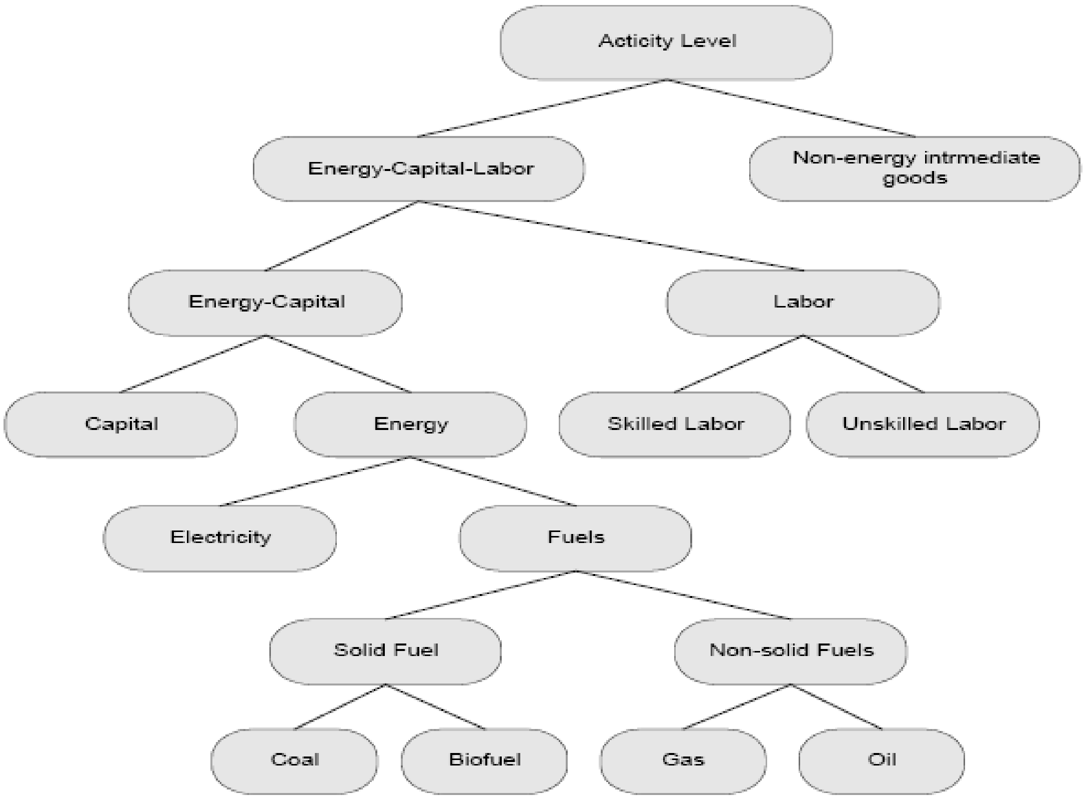


(RTI International 2004)



Node	Mnemonic	Interpretation	Components
1	O	Output	K,L,E,M
2	E	Energy	3,4,16,30,31
3	M	Materials & Services	6,MA,MM,MN,MS
4	MA	Agricultural Products	1,7,8,TA,WP
5	MM	Metal Products	FM,MC,EQ
6	MN	Nonmetallic Products	5,15,17,19,27
7	MS	Services	OS,28,32,33,34
8	TA	Textiles & Apparel	9,10,18
9	WP	Wood & Paper Products	11,12,13,14
10	OS	Other Services	29,35,N
11	FM	Primary & Fabricated Metals	2,20,21
12	MC	Machinery	22,23
13	EQ	Equipment	24,25,26

(Wilcoxen 1988)



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