U.S. Environmental Protection Agency
Science Advisory Board

INTERIM DRAFT COMMENTS
on the
SECOND GENERATION MODEL

By the
Second Generation Model Advisory Panel

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Introduction

In 2004, EPA's Office of Atmospheric Programs (OAP) requested that the SAB provide advice on a computable general equilibrium (CGE) model known as the Second Generation Model (SGM). This regionally disaggregated model of the global economy is a computer program that uses input-output relationships and simultaneous equations to simulate activities in multiple markets (e.g., labor markets, energy fuels markets, and final goods markets) in the economy. The SGM is a 14 region, 22 sector CGE model that can be used to project greenhouse gas emissions and determine the costs of various options for reducing greenhouse gas emissions (e.g. carbon fees or charges, allowance trading, accelerated energy conservation). 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 was formed and met in its first face-to-face meeting on February 4, 2005. The SGM Advisory Panel plans to turn its attention to answering the charge questions posed by the OAP (posted at http://www.epa.gov/sab/pdf/sgm_charge_questions_111804.pdf) in the fall of 2005 after portions of the advice contained in this Interim Draft Advisory are implemented.

This Draft makes three sorts of recommendations.

First, it identifies and requests improved documentation to clarify the nature of the model. Second, it recommends initial explorations of possibilities for data improvements. Finally, it provides preliminary suggestions as to improvements in model structure and model outputs, as well as indications of possible data improvements.

The Panel hopes that the EPA will be able to respond to the recommendations in parts I and II in the short term -- hopefully by the coming fall – by offering improved documentation of the model and providing information on the potential for data improvements. Based on this information, the Panel intends to modify the recommendations in Part III of this draft set of comments and offer a new report with revised recommendations for improvements to the model.

Part I: Recommended Improvements to Model Documentation

A. Model-Structure Documentation

The Panel received two types of documentation of the SGM Model: “Second Generation Model 2004: An Overview” (Overview) and “Model Documentation: The Second Generation Model” (Documentation). These documents contain useful information, but many important elements are missing. In addition, some of the descriptions of the model are written in a confusing manner and there is considerable need for clarification.

The Panel urges PNNL to substantially improve its documentation, making it more clear and coherent. In particular, the documentation should:

(1) Make clear how the various aspects of the model – production, household demand, trade, government sector -- are connected. The readers of the appendix 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. It should also be explicit about what are the endogenous prices (or interest rates, etc.) that clear the excess demand equations. The number of endogenous prices should match the number of excess demand equations.

(2) Include a "Model Derivation" 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. Table 2 in the appendix sort of reveals this by process of elimination, but it should be positively enumerated.

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 / how abatement costs / GHG prices feedback to higher prices for ETE goods. Include data inputs for MACs.

c. Clarify the relationship between P, Pi, and Pr. Pi_{ETE} seems to be the numeraire but sometimes it is subscripted by sector sold to at other times it is not. Does P_i vary across sector sold to?

d. Clarify the consequences of using the ETE sector as the numeraire. To the extent Walrus' law is verified there should be no effect on quantities. To the extent prices and values are rescaled by an aggregate price index, there should be no effect on those relative prices. Is this actually the case?

e. You might want to compare choices about sectoral detail to other Integrated Assessment Models. Does the current grouping, especially ETE, make sense? Please see **Appendix A: List of ETE Clarifications** at the end of this document. This list indicates specific places where ETE is mentioned and suggests particular needs for clarification.

(7) Address the issue of benchmark replication. It is a very important check that the model is well-constructed and consistent with the underlying data.

(8) Address the choices of chosen software and solution algorithm, and compare the choices the conventional tools for the CGE modeling (such as GAMS or GAMS-MPSGE software and MCP algorithm).

(9) 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.

(10) Organize the material 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 --** reporting of prices and quantities; measurement of costs, welfare measures; treatment of uncertainties in outcomes; sensitivity analysis
- **Solution Method**

All of this information is important for ascertaining the consistency of the SGM.

References:

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<u>B. Parameter and Data Documentation; Empirical Basis for Parameters</u>

In our summary we suggest ways to improve the documentation and ways to improve the empirical basis of the parameters, including references to sources in the literature. The Appendix is a summary of our inventory of the documentation of the sources of the data and parameters. Overall, we find the current documentation of parameters to be extremely sparse.

i. Documentation of Parameters

- Provide a master list of parameter names, symbols, benchmark year, updating frequency, and data source (author, date) and any critical assumptions (e.g., modifications transfer, use of expert judgment). Provide full bibliographical information for the citations in a separate “Data References” section. As in any scientific endeavor, a good target for documentation would be clarity and transparency that allows others to find, replicate, and, if applicable, easily update model inputs.

- Where primary data were collected by the SGM research teams, provide a description of the sources(s) and procedures(s).

- Where the parameters were estimated by the SGM team, provide a description of any source data and the estimation method, as well as measures of accuracy of the estimates (e.g., goodness of fit measures).

- Annotate the data presentation in the “Model Documentation” or “Appendix” for those parameters and for data sets that required further refinement or where further explanation is needed for the general reader (cross-reference this between “Documentation” and “Appendices”).

- Include benchmark year and dollar index (where applicable) for all data tables following table title (e.g., in current 1990 dollars).

- Where the tables present illustrative results of the model, this should be noted in some way in the table. Where these tables appear in the Appendices, they should be cross-referenced to the relevant equations in the “Documentation.”

ii. Empirical Basis of the Model

In general, the SGM modelers should consider other sources of empirical data and parameters such as GTAP and more recent reviews of the literature on elasticities. The latter would include a general review by Renger van Nieuwkoop and a review of trade elasticities by Balistreri, as well as more specific studies noted among other references below. Recommendations by Ray Kopp in his independent assessment of SGM parameters should be heeded as well.

In addition the empirical basis can be strengthened by clarifying the presentation, such as in the following examples:

- Appendix Table 1, row and column sums should be provided for final demand, value added, gross output, and gross outlay.

- App Table 1, the "Electricity Production Sub-aggregates should be listed as Table 1A.

- App Table 2, clarify meaning of the term "indicating which inputs of the input-output table are active"; don't Australia and Canada produce Wood products, Chemicals, Cement, etc.?

Please see **Appendix B: List of Possible Improvements in Model Documentation** at the end of this document for an inventory of specific places where the documentation could be improved.

In summary, the current documentation provides some information on the sources of the input-output tables and energy balances emission information, and the population projections. The model is calibrated to historical information on income and other variables. Historical information is needed to compute capital stock, however, it is less clear where such historical data come from. Behavioral parameters are more ambiguous. Elasticities of substitution and income and price elasticities for the production sectors have a vague empirical basis in general. For land and labor supply parameters, technical coefficients, and adjustments for capital by vintage, the picture gets foggier still. Here, if no parameters were formally estimated or available in the literature, some indication of the reasoning behind the parameter choices would be helpful.

References

Dahl is in the process of updating econometric estimates of demand elasticities. These are surveys of elasticities she has found published since 1990. Below is a list of references to energy demand surveys since 1990.

Atkins, Frank J. and S. M. Tayyebi Jazayeri (2004) "A Literature of Demand Studies in World Oil Markets," *Oil Demand Workshop, OPEC Secretariat, Vienna, Austria*, June 7-8, pp. 2-44

Atkinson, Jago and Neil Manning (1995) "Chapter 3. A Survey of International Energy Elasticities," included in *Global Warming and Energy Demand*. Edited by Terry Barker, Paul Ekins and Nick Johnstone, pp 47-105.

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Dargay, Joyce (2004) The Effect of Prices and Income on Car Travel in the UK, ESRC Transport Studies Unit Centre for Transport Studies University College London February, downloaded www.cts.ucl.ac.**uk**/tsu/papers/FESWCTR2004Final.pdf.

Goodwin, P. B., Joyce Dargay, and M. Hanly (2004) "Elasticities of Road Traffic And Fuel Consumption with Respect to Price and Income: A Review," *Transport Reviews*, 24(3) May, pp.375-292.

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Graham, Dan and Stephen Glaister (2002) "The Demand for Automobile Fuel: A Survey of Elasticities," *Journal of Transport Economics and Policy*, Vol. 36, Part I, January, pp. 1-26.

Graham, Dan and Stephen Glaister (2004) " Road Traffic Demand Elasticity Estimates: A Review and Fuel Consumption with Respect to Price and Income: A Review," *Transport Reviews*, 24(3), May, pp. 261-274.

Graham, Dan and Stephen Glaister. (forthcoming) "The Responses of Motorists to Fuel Price Changes: A Survey," *Journal Transport Economics and Policy*

Greening, L.A., D. L. Greene, and C. Difiglio (2000) "Energy Efficiency, and Consumption – The Rebound Effect – A Survey," *Energy Policy*, 28, 389-401.

Soderholm, Patrick (1998) "The Modelling of Fuel Use in the Power Sector: A Survey of Econometric Analysis," *Journal of Energy Literature*, IV (2), Dec. 98, pp.1-27

Part II: Recommended Initial Work for Improved Data

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. 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://debreu.colorado.edu/gtap5/index.html). 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.

The SGM documentation 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. It is not necessary that the SGM model use the GTAP data: the use of an alternative data set has merits. There is a slight danger that all models come to the same policy conclusions, but solely as an artifact of them using the same data. In our view this danger is not a serious one, or worth the trade-off in terms of resources needed to update parallel data and make comparisons of data. However, at the very least it is essential 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. For such a comparison, the SGM developers must develop a routine to update their data set to the GTAP base years 1997 or 2001. 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).

Part IIIA of this Interim Draft Advisory discusses updating the SGM data set, a related issue. Adopting GTAP data is one possible approach to updating the data set.

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Part III: Recommended Improvements to Model Structure and Output

A. Update the data set.

Many counties and regions have had substantial changes in economic conditions and technology in critical sectors since the SGM base year -- 1990. The base year should be updated to reflect these changes and to allow comparability with other data sets.

If the SGM developers retain the current procedures used for data collection and calibration, it would be useful to provide a detailed comparison with GTAP data being used by other modelers. See Part II discussion. Alternatively, the SGM developers can use the GTAP data with additional disaggregation of the electricity sector. We recommend the latter, but would minimally require the former.

B. Model simulations and "back-casting" exercises.

Nobody doubts that 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 would be valuable to have a sense of their sensitivity to variations in estimates and assumptions. Modern computing capabilities make it relatively easy to use Monte Carlo sampling designs to achieve this goal. These designs proceed by having the user specify a range of possible distributions that each parameter or modeling assumption can take, solving for a particular combination drawn at random, and then repeatedly solving for different random draws. The resulting distribution of policy results 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.

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. Thus the goal is not to find out that "any policy outcome is possible if you choose crazy parameter values," but to show how robust the policy outcome is to reasonable variations in the parameter values around their point estimate. 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).

The computational burden of undertaking systematic sensitivity analysis is relatively slight, given appropriate numerical or statistical methods. The 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.

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.

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.

Moving beyond sensitivity analysis, there are some other considerations that could be addressed. The larger issue is the reliability of the model: if the one makes a prediction that a policy intervention X has a large, or medium, or small monetary impact on consumers or firms in a certain industry, say, is this prediction reliable?

Many factors could affect the reliability of a model. Given the specific model structure, the particular numerical values of the model coefficients affect the reliability of the model predictions: these, however, are well tested through the Monte Carlo simulation exercises described above. Other issues touch on the validity of the model structure itself. The model embodies many assumptions – specific functional forms, a specific sectoral disaggregation, the assumption of a representative firm and a representative consumer, the representation of (exogenous or endogenous) changes in technology and preferences, changes in industry structure and composition, as well as larger issues about the validity of optimization versus behavioral approaches and comparative statics, or an equilibrium analysis versus approaches based on disequilibrium and out-of-equilibrium adjustment. The modeler makes the best assumptions she can, but there are limitations of data and modeling practicality, so there are always potential problems. Hence the desirability of performing some check beyond Monte Carlo sensitivity analysis to investigate the reliability of model predictions.

One approach which has been used occasionally, including by researchers at the Dutch Central Planning Bureau, is to take an economic model calibrated to some base period (say 2003-2005, for the sake of argument) and *backcast* – i.e., make predictions for the past, rather than the future: eg 1995-2000, 1990-1995, 1985-1990, 1980-1985 (or whatever the time step). When this was done by Henri Theil in the 1960’s using an annual input-output model, he found that the quality of the model’s backwards “predictions” degraded significantly after about 7 or 10 years (this is based on a recollection and will be verified). This could be due to changes in economic structure, sectoral composition, model parametrization: the backcasting by itself does not show what causes the temporal degradation in model performance (if any) but it alerts the users to qualifications about the weight to be placed on model predictions.

A second approach is to mimic the "comparative statics" functioning of the model by predicting the impact of a specific perturbation that occurred in the past and then checking whether the model prediction resembles what was actually known to have occurred subsequent to the perturbation. Again, if there is a divergence between what happened and what the model predicts, this by itself does not explain why the divergence occurs or what is its significance. The divergence could be due to some other concurrent changes that confound the comparison. But, it could also be due to some flaw in the model specification. The point is that it provides at least a preliminary caution to the user of the model and it indicates the need to investigate (offline) what accounts for the divergence.

The importance of addressing these different types of sensitivity analyses depends on what one expects to learn from the model. One view is that the model is designed to provide fairly specific quantitative predictions, at least with regard to order of magnitude. Another view is that the model is designed to provide essentially qualitative predictions about the sign of a derivative, rather than the magnitude. To the extent that the latter is the goal, and not the former, the types of backcasting described here would not be informative tests of the model. On the other hand, models built for the latter goal may also be used by policy-makers or commentators only interested in the former. Therefore backcasting can be a useful exercise to identify and circumscribe the practical uses of the model. The model may maintain internal consistency, and be quite informative about a qualitative direction for policy, without an ability to predict quantitative measures a few years in the past. Indeed, even if the model were brilliantly accurate for the near term, it is not likely to be able to forecast decades in the future when the structure almost certainly would become obsolete. However, the demonstrated stability of results to a wide variety of uncertainty specifications can go a long way toward convincing policy makers that key lessons are useful, even if point estimates are certain to be faulty.

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C. International trade.

Carbon tax policy demands an endogenous treatment of international trade. 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.[1]

The SGM model has no treatment of international trade, in the sense that the term is used in policy modeling. Rather, trade flows are treated as fixed and given and non-responsive to policy shocks. The conception of the SGM as a series of compatible, plug-in modules each representing stand-alone models of different countries is inadequate and still leaves unexplained which of the regional models account for trade flow changes.

There are two ways in which the trade component of the model could be improved. The first method is an interim, short-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 which 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.

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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[1] 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.

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.[2] 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 re-emphasize that these alterations can be implemented immediately, and the new structure numerically calibrated using the existing social accounting matrix.[3]

A major consequence of explicitly representing trade that we would draw attention to 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.

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De Melo, Jaime, and Tarr, David, *A General Equilibrium Analysis of US Foreign Trade Policy* (Cambridge, MA: MIT Press, 1992).

[2] 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.

[3] 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].

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D. Household Utility and Welfare.

The Panel believes that a utility theoretic basis should be provided for consumer behavior in the SGM model. 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 the allocation of income among current versus future consumption through savings/borrowing, nor on labor/leisure choices by consumers. 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 use 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, the discussion in Deaton and Muellbauer, 1980, p 149-158). As detailed below, the representative consumer approach has been widely criticized by economists. Nevertheless, we believe that the general approach can be a pragmatic tool for assessing welfare effects. In particular, we recommend that the SGM be modified to provide a utility theoretic basis by employing multiple representative consumers, one representative consumer for each of several socio-demographic groups. The discussion below focuses primarily on income, but the same logic holds with respect to other characteristics that vary across consumers and are important determinants of demand.

The challenge faced in extending to multiple representative consumers is to identify data adequate to specify a demand function for separate representative consumers (e.g., a representative low income vs. middle 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). A phased implementation may be appropriate, starting with a single representative consumer, which would later be extended to multiple representative consumers.

Discussion

As indicated above, the representative consumer model has been widely criticized by economists (see for example, Kirman, 1992; Stoker, 1993; Slesnick, 1998). The primary focus of the discussion below is on linear aggregation. We conclude with a brief discussion of nonlinear aggregation.

There are only special conditions under which a "representative consumer" exists. That is, microeconomic theory implies that we cannot expect aggregate demand functions to have the same properties as a disaggregate demand function resulting from utility maximization, except under very special circumstances. Secondly, even when the aggregate demand function behaves as if it were generated by a "representative consumer", preferences of the "representative consumer" need not be representative of the preferences of individual consumers. For example, Kerman shows that you can design cases where all individual consumers in society rank commodity bundle A above bundle B, but the "representative consumer" ranks commodity bundle B above bundle A. So even when a representative consumer exists, the preferences of the "representative consumer" need not be consistent with the preferences of the individual consumers.

It is widely known that one cannot recover "average" preferences (or welfare measures such as compensating or equivalent variation) from an aggregate demand function, except under very specialized conditions, termed exact linear aggregation. The most general form of disaggregate demand that allows for exact linear aggregation is the Gorman form (e.g., Deaton and Muelbauer, 1980; Varian, 1992), which has demand functions of the form:

$$x_i(P,m_i) = a_i(P) + b(P)\, m_i$$

where $x_i()$ is demand for consumer i, P is a vector of market prices, $a_i(.)$ is a function of prices that can vary over consumers, b(.) is a coefficient that is a function of prices but is the same for all consumers, and m_i is income for consumer i.[4] With a single representative consumer, the Gorman form implies linear Engle curves, with a slope that is constant across all consumers, so that a marginal dollar of income is allocated across goods in an identical manner, independent of the recipient of the income. In particular, rich people and poor people spend a marginal dollar on the same commodities. This violates basic intuition, and also severely limits the ability of the model to calculate the distributional implications of policies.

In order to overcome this strong assumption, we recommend adoption of an approach with multiple representative consumers, separated by income group, so that we have demand for each product category by a representative consumer within each income group. This implies that overall aggregate demand would be comprised of several sub-aggregates, one for each income class. The advantage of having separate representative consumers for each income group is that the income slope, b(P), can vary across income groups. So an individual within the low income group would spend a larger fraction of a marginal change in income on necessities, and an individual within the highest income group would spend a larger fraction of a marginal change in income on luxuries. In effect, the Engle curves become piecewise linear, where the slope varies across income groups.

This would greatly strengthen the ability of the model to calculate the distributional implications of policies across income groups. Note that strictly speaking a model based on multiple representative consumers has problems similar those for a single

[4] Note that the Gorman form implies a "representative consumer" with an indirect utility function of the form $u_i(P,m) = v_i(P)+w(P)m$ and an expenditure function of the form $e_i(P,u) = c_i(P)+ d(P)u$, which are highly restrictive. For example, the Gorman form allows marginal utility of income to depend upon prices, but not on income, and is constant for *all* consumers. The generality of the functional forms for the representative consumer need to be restricted further if one is to account for the fact that all consumers do not face a single, common price for each commodity.

representative consumer. Yet such a model may still be useful as a pragmatic tool to measure welfare effects, and in particular to examine distribution implications of policies across income groups.

With multiple representative consumers, the Gorman form becomes:

$$x_i^j(P, m_i^j) = a_i^j(P) + b^j(P) m_i^j$$

where j represents income group. Aggregate demand within each income group is:

$$\mathrm{X}^j(\mathrm{P}, \mathrm{M}) = \mathrm{A}^j(\mathrm{P}) + \mathrm{b}^j(\mathrm{P})\,\mathrm{M}^j$$

where the caps indicate the sum over all consumers in income category j, and representative (average) demand for category j becomes:

$$x^j(\mathrm{P}, \mathrm{m}^j) = a^j(\mathrm{P}) + b^j(\mathrm{P})\,\mathrm{m}^j$$

where x^j is average demand in income class j, $a^j(P)$ is the average of the a_i^j's and m^j is average income within income class j. There are many special cases of the Gorman form that have been applied to demand systems, including the Stone-Geary form.

Other empirical specifications for representative consumers are based on nonlinear aggregation, where representative income is not average (or aggregate) income, but might also include higher order moments of the income distribution. These approaches, sometimes termed "Generalized Linearity" (GL), are generally based on estimating budget share equations, rather than demand functions. Nonlinear aggregation includes specifications such as Price Independent Generalized Linearity (PIGL), the logarithmic form of PIGL (PIGLOG), the Almost Ideal Demand System (AIDS), etc. (see, for example, Deaton and Muellbauer, 1980).

GL represents an improvement over linear aggregation in that generalized linearity allows for nonlinear Engle curves, and it allows one to consider the impacts on consumption of changes in the distribution of income. However, to my knowledge it is not straightforward to recover welfare measures, such as aggregate compensating or equivalent variation from the budget share equations of the "representative" consumer resulting from nonlinear aggregation. Hence, while nonlinear aggregation is a definite improvement over linear aggregation for estimating aggregate consumption (in the form budget share equations), it is not useful for providing welfare measures.

In sum, nonlinear aggregation is a preferred approach for specifying aggregate consumption in a form that is consistent with utility theory. In this case, the representative consumer can have nonlinear Engle curves, and hence consumption patterns can depend upon the entire distribution of income, not just average (or aggregate) income. However, to our knowledge it is not straightforward to construct aggregate welfare measures, since the resultant budget share equations are not those for the "average" (or aggregate) consumer.

Linear aggregation has the advantage that the welfare measure for the representative consumer can be used to calculate aggregate compensating or equivalent variation. However, linear aggregation places very strong constraints on the utility functions, and in particular, the assumptions underlying exact linear aggregation preclude one from identifying distributional effects of policies across socio-demographic groups (e.g., income groups). This is presumably an important motivating factor for extending the SGM to include a utility theoretic basis for consumption.

Using exact linear aggregation, but specifying multiple representative consumers, one for each of various socio-demographic groups, allows one to calculate aggregate welfare measures, as well as welfare measures disaggregated across groups, so that distributional effects can be identified. While linear aggregation with multiple representative consumers faces the same qualitative conceptual difficulties, it may be a useful pragmatic tool for welfare measurement. For these reasons we recommend adoption of a utility theoretic model with multiple representative consumers.

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E. Production Functions.

In choosing a production function specification, an ideal objective is to obtain 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 function (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 and in the course of finding the equilibrium, prices and quantities can wander far beyond the eventual equilibrium. Therefore, local regularity about an equilibrium (or range of equilibria) is not generally sufficient.

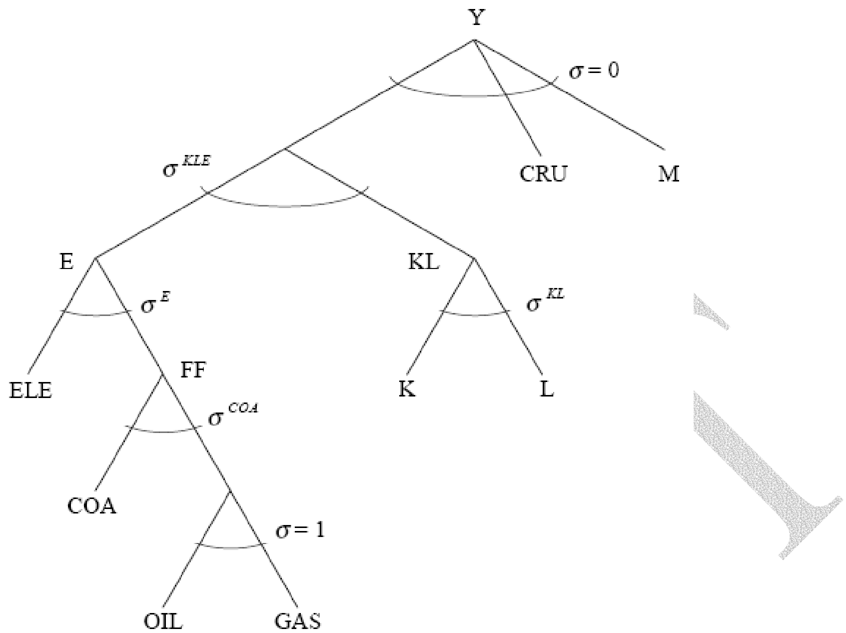
In response to this, Perroni and Rutherford (1995) propose a non-separable CES functional form that can represent local second-order flexibility and remains globally regular. Their formulation does not provide a unique representation (many representations match the same second-order conditions), however, 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. The latter case (Wilcoxen 1988) involves a fully flexible tier, rather than CES, making it less relevant for the SGM exercise. Within the more typical capital-labor-energy aggregate, we see either a capital-energy sub-tier or a capital-labor sub-tier.

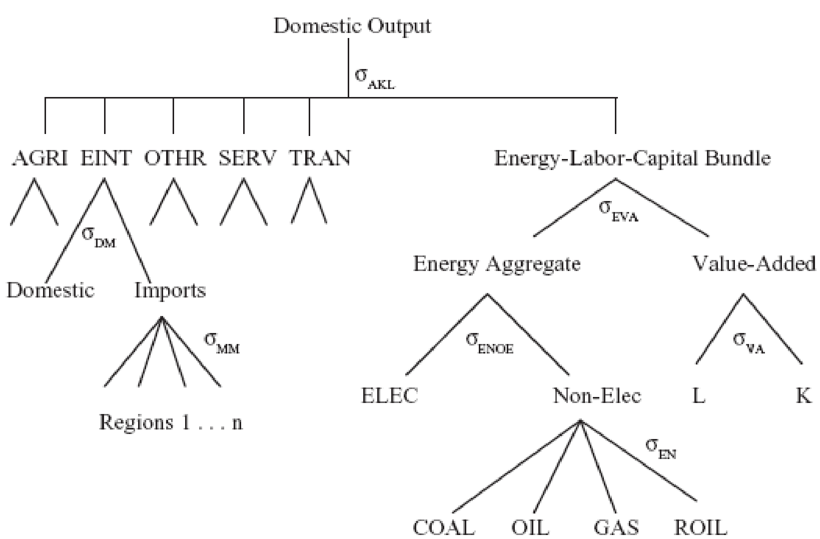
The choice of nesting structure depends both on the questions being asked and empirical data. Analysis of climate change policies, for example, requires considerable energy detail as all of the referenced models demonstrate, and energy is typically in its own sub-tier. It should, however, be an empirical 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).

Employ a nested CES production structure more in line with existing CGE models and parameterized based on empirical data. Where the nesting choice is unclear, consider both the relevance for particular questions (e.g., importance of energy-related capital for climate change analysis) as well as sensitivity to alternate choices. The lack of consensus in the literature over the correct nesting structure is not a justification for the complete absence of nesting.

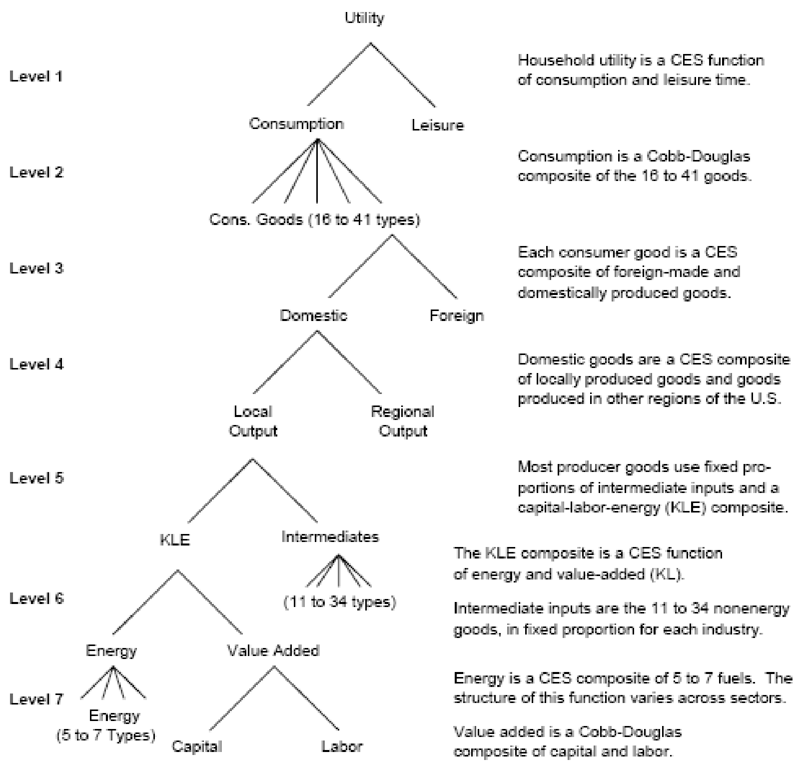
Examples of Nesting Structures



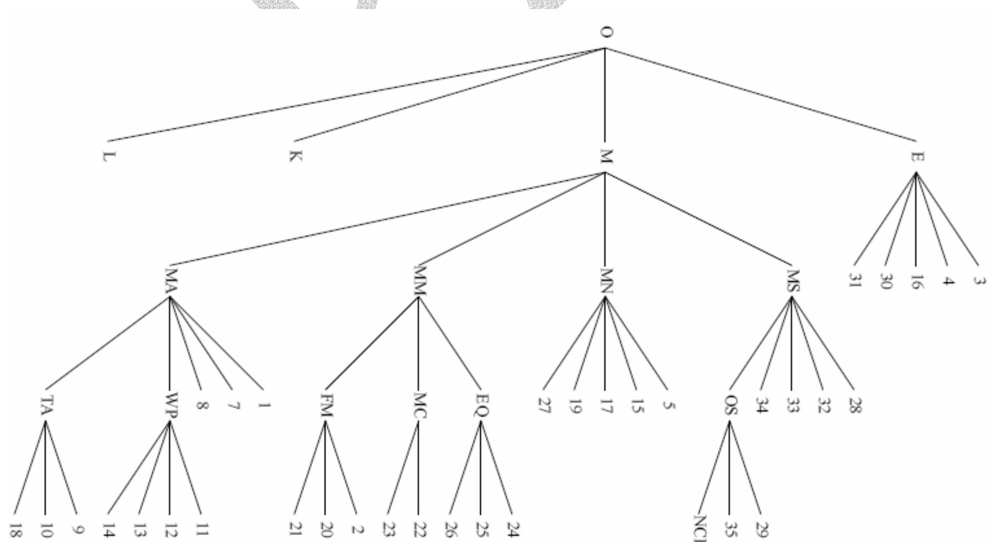
(Böhringer and Löschel 2004)



(Jacoby et al. 2004)

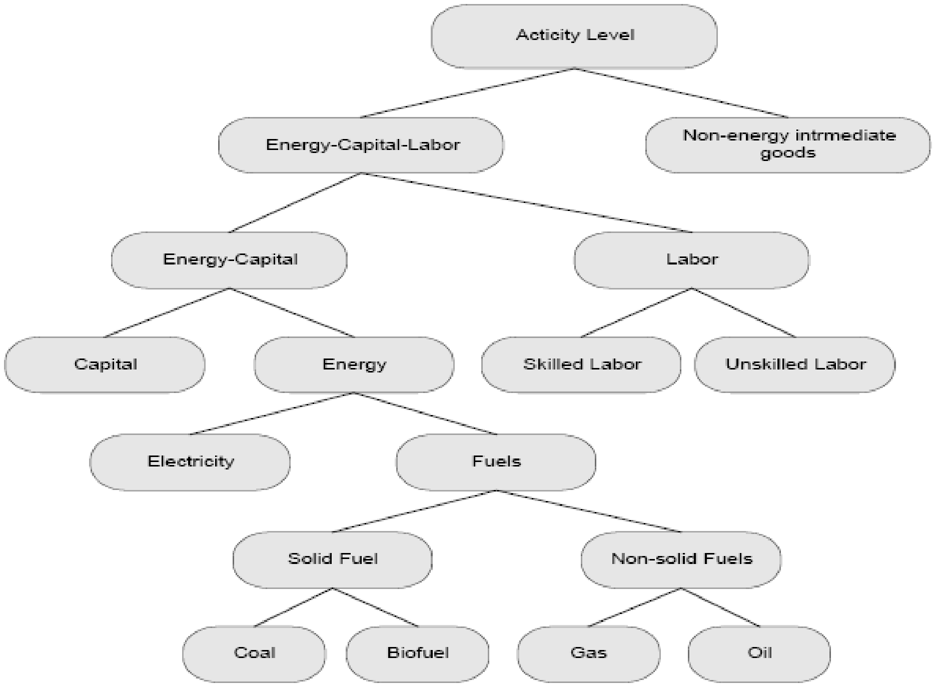


(RTI International 2004)



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)



(Hill and Kirström 2002)

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F. Other greenhouse gases.

We recommend 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 respond 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:

a) incorporate non-CO2 emissions mitigation into the production structure;
b) incorporate CO2 emissions mitigation into consumption;
c) take the base year GHG and economic data and generate activity-specific emissions coefficients for each gas; and
d) 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 (Table 26 of Appendix A). 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) Most of the non-CO2 sources are in the “Everything Else” sector of the SGM model. It is not clear why N2O emissions from industrial processes, PFC emissions from aluminum and semiconductor production, SF6 emissions from magnesium production are included in the “Everything Else” rather than in the “Industry or Manufacturing” sector. In addition, it is not clear what sectors of the economy are in the “Everything Else” sector. If non-CO2 emissions are associated with the “Everything Else” sector because some industrial sectors are there, then it would be desirable to disaggregate the “Everything else” sector into “Services” and “Other industries” sectors.

(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).)

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G. Sector-specific policies.

i. Electricity sector

The electricity sector represents an important aspect of the model because it is the source of a large portion of GHGs 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.

Long-lived capital:

In the SGM model, capital stocks are operated across their lifetime with no decrease or increase in technical efficiency. 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 would appear to give flexibility in the model to adjust to policies and changes in price so as to achieve 100% turnover of capital in twenty years.

The long-lived nature of capital in the electricity sector means that the fairly rapid turnover of capital that can be achieved in SGM may imply too much flexibility in capital. This would tend to under-represent the cost of climate policy.

Moreover, one of the primary questions of research and policy is the timing for climate policy. If technology turnover can be achieved rapidly, then it might make sense to wait until technology emerges that is advanced before imposing mandatory costs on the economy. However, if technology turnover is slow, then it may make sense to begin sooner so as to have a marginal effect on the current generation of capital that is put in place.

Another important phenomenon in the electricity sector is the change in technical performance of existing capital investments, which is especially important because capital investments are long-lived. This exacerbates the problem of capital life because, if existing capital becomes more efficient, it tends to survive even longer. Although it may appear as small technology improvements to existing capital, the primary effect is to contribute to the phenomenon of long-lived capital in the electricity sector.

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.

Other policies

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.

ii. Agriculture/forestry

The current SGM model is without agricultural policies. More importantly, the current specification does not facilitate modeling agricultural policies that are of importance to GHGs.

This is problematical because the agricultural/forestry sector is an important component of the SGM model as a source of GHGs, and as a potential carbon sink. Agriculture in both developing and developed countries is subject to extensive government intervention with a substantial impact on land in agriculture, the agricultural produce mix, and production practices, all of which have implications for GHG emissions and the marginal costs of sequestration.

Appendix A: List of ETE Clarifications

The everything else sector is mentioned in 6 places in the Overview document.

1. In footnote 15 on page 7 it is stated that the everything else sector '(approximates services)'

2. In footnote 17 on page 8, it is implied that the "everything else sector is the service sector"

3. On page 19, "With the exception of the “everything else” sector, each separate sector in the SGM represents production of a distinct product.

4. On page 22, "One produced good is selected as the numeraire. This is the “everything else”[45] good and it is tradable. The price of the numeraire good is set to 1 during each time period."

5. In footnote 45, page 23
"[45]In regions which have been updated to include energy intensive sectors, transport and buildings,“everything else” approximates the services sector. In less elaborate sectoral breakdowns it includes everything not explicitly modeled."

6. Table 3.2 on page 25. A number of activities and their emissions are attributed to the "everything else" sector.

From the introduction. We conclude that the "everything else" sector is approximately the service sector except in regions where the model has not as many sectors as in the U.S. case and then it is the residual. It is chosen as the numeraire with a price of 1 in each period.

Model Documentation

The "everything else" sector or ETE is mentioned over 80 times in the Model Documentation file. Most often it is included as ETE in a subscript. We note below where it is included and questions we have about how it is treated. Some of the comments relate to the treatment of all sectors including ETE where it would be helpful to clarify overall model documentation.

1. It first appears as a production sector and product market ETE in Figure 1 on page 13, which is clarified when it is written out as Everything Else (ETE) in Figure 3, page 14 and in Table 2, page 15.

2. Table 2 indicated that ETE is Sector/Market number 2.

3. At the bottom of page 15 top of page 16, it is stated that " In the reference case, production sectors with markets are implemented for the so-called “Everything Else”

sector or ETE, three energy production sectors, four energy transformation sectors, five agriculture sectors, six industrial sectors, a passenger transport sector, a freight transport sector, and a carbon sector (see Table 2)." This suggests that ETE is a production sector and a market like the others.

4. On page 28, market prices are set to one in the base year. ETE is described as the numeraire good with price of 1 in all projections.

5. At the top of page 29, "In the base year market prices equal one ($P_{i,t}=1$), with the exception of labor; market prices in the projections result from the market solution processing but can be set exogenously. The prices for crude oil, land rental and the Everything Else sector are set exogenously in the reference case; . . . When market prices are set exogenously they retain their exogenously set value in the market solution process." (Here all market prices but labor are 1 in base year. Is labor not considered a market? ETE is said to be set exogenously in the reference case. We presume that is 1 in all periods. Is it then allowed to vary from 1 in non-reference cases?)

6. On the bottom of page 38 and top of page 39, base year technical scale coefficients are extracted from the CES production functions for all produced factors for produced good and each variable factor are computed using the base year price and quantities for ETE and base year price and quantity for the specific factor. In the base year there is only one vintage.
(Do these formulas hold for non-base years? If not, since all prices are 1 in the base year it could be simplified considerably) When i = 1-22 is that sectors 1-6, 8-22 and labor? Is carbon an input, an output or both?)

7. On the bottom of page 38 base year technical scale coefficients for each sector j are computed using the base year price and quantities for ETE, total inputs into product j including the indirect business tax, and total inputs into product j excluding the business tax.
(How does this relate to Eq. 22? Again is this only for the base year. We did not understand this computation. We couldn't get q to equal q when eq 22 and 23 were plugged into Eq. 3 on page 24. What are the sectors = 1: 27. Since sector 7 is missing shouldn't it be 1:26?)

8. Page 40, $\alpha_{i=ETE,j,jj,v}$ is used to create the scale coefficient for the capital stock. (Again is this only for the base year? But doesn't $\alpha_{i=ETE,j,jj,v}$ always equal 1 from equation 22 on page 38?)

9. Page 41, $\alpha_{i=ETE,j,jj,v}$ is normalized in Eq. 27. (Equation 27 doesn't work unless the denominator is 1, in which case it is not a very interesting normalization.)

10. Page 50, Eq. 55. The expected profit rate for output i is normalized by the expected price if ETE which is stated to be one over time. (Why does v = t, can't an older vintage operate at time t?)

11. Page 59, The price paid by the producer for the everything else sector ($Pi_{ETE,j,jj,t}$) is used in computing distribution and markup factors for each of the 25 supply sectors i = 1-25 also denoted as variable factor inputs. (On page 39 there were 22 variable inputs. Now there are 25? On page 29 there were 23 variable inputs. It might be helpful to eliminate the empty sector 7. Would it be clearer to treat each electricity subsector as a sector to eliminate the jj subscripting. It is claimed that $P_{i,t}$ is one only in the base year and is computed by supply and demand after that but does not specifically exclude the ETE sector. Elsewhere it seems $P_{ETE,\ t}$ was designated as 1 for all periods in the reference case. The price paid by the producer for the ETE is $Pi_{ETE,j,jj,t} = P_{ETE,\ t}$ plus taxes, markups and intra-regional transport costs from equation 9 page 29. At this point we are still not totally clear on the differences between P, Pi, Pr.)

12. Page 60, The price paid by the producer for the everything else sector ($Pi_{ETE,j,jj,t}$) is used in computing transport costs for imports and exports. (How do these transport costs relate to your transport sectors?)

13. Page 76, Figure 10 includes a graph with investments in ETE and other sector for the reference case. (The reference case is mentioned frequently but we are not sure what is the reference case?)

14. Page 78, The transportation and distribution costs are added to the ETE suggesting that it is more then just service and that parts of transportation are not included in production sector 18 but are included in ETE.

13. Page 79, $Pi_{ETE,j,jj,t}$ is used again to compute markups and transport costs for sales to households. (Could these parallel computations be combined?)

14. Page 81, Eq. 144. The price paid by households for the everything else sector ($Pi_{ETE,j=27,t}$) is used to normalize the wage rate in the labor supply for household consumption equation Eq. 144. (Have we interpreted equation 144 correctly. Is it price for the quantity of labor used by households? We did not see lbs defined in this equation but presume it is both male and female supply. Should ED have a t subscript. Sometimes ED is a demand and sometimes a supply, which is confusing. Does the phrase "or read in " 7 lines below Eq. 144 mean it could be exogenously entered? It would be helpful to explain the initial price of labor. It would be helpful to have a Table listing the demand sectors similar to Table 2 for the production sectors. It is shown in the appendix in the IO table but we didn't see it in the model documentation.)

15. Page 83, $Pi_{ETE,j=27,t}$ is used to compute the demand for supply of land in similar fashion to demand for supply of labor. Could these parallel computations be combined? Might want to explain demand for supply of a factor. Is it the quantity of land used by households? Should ED have a t subscript. It would be helpful to explain the initial price of land.

16. On page 89, equation 170, the market price of everything else is multiplied times government transfers. (It is not clear why we need to make these price adjustments if the price of ETE is always 1.)

17. Page 91. The sales price to consumers of the price of everything else is used to normalize personal income and the price of the good in the household demand equations. (It would be good to clarify personal income. Eq. 180 suggests it might be expenditures but other places it is called personal income. In 188 it is personal income minus expenditures on labor and land.)

18. Page 92, $Pi_{i=ETE, j=27, jj, t}$ is again called price of the numeraire. (Other places the substrict is j rather than j = 27. Is the price paid by household sector for ETE different than the price paid by other sectors for ETE.)

19. Page 93-94. Markups and transport costs are computed for Households by normalizing $ED_{i,j=27=hh}$ by the producer price of ETE. (Should ED be EDV in Eq. 193 as in earlier equations for other sectors on page 79 and as in definitions below Eq. 193? Should WHSL and TRNP have a time subscript.)

20. Page 97, Eq. 211 – Government deficit is multiplied by $Pi_{i=ETE, j=26=gv, jj,t}$. (Again called price of numeraire but now j=26. Why do we start at 0 in Eq. 212?))

21. Page 99, Eq. 223, Government expenditure appears to be equal to the amount of variable goods purchased times their price plus the expenditure on capital times the price of everything else to the government. It is not clear what the letter l is at this point. Is it the number of government subsectors?)

22. Page 100, Eq. 227. Government demand for ETE is updated. (This equation is internally inconsistent. It implies that the summation on the right side = 0.)

Page 106, Defines the demand for everything else good by the investment sector and gives equation where it is defined.

Page 109 Table 4, (What happened to ETE sector?)

Page 114, Table 5, Gives activity, emission sources, drivers and mitigation options ETE and other sectors. (As mentioned about it would be good to clarifying relationship between activity, emissions and everything else. How does MAC fit into overall model? Sometimes abbreviated MACC and sometimes MAC.)

Appendix A-D

ETE is a row and column in the hybrid input output matrix Table 1

ETE is a row in Table 2 which shows the summation of each sector by model regions and by implication the sectors included in ETE. (Is region 3 China or Germany? Is region 8 Mexico or Brazil? This table implies there are 15 regions but Table Title and other documents claim there are 14 regions.)

ETE is a row and column in:

the hybrid input output matrix with gross production as diagonal in Table 3 and in
the hybrid input output matrix with demand minus gross production as diagonal with a carbon equivalent emission limit in Table 4. (What is t = 7?)

ETE and prices for all factors 1 to 23 are shown as 1 in Table 6 for all periods.

Table 5 appears to contain a model run for a $100 carbon tax. (Why is ETE not included in Table 5 as a variable and oil and gas price are set to 1? Are oil and gas now the numeraire? Why is land now included when it is not included earlier?)

Table 7 shows that ETE, Crude Oil and Natural Gas prices can be set exogenously

Table 8 shows IBT for ETE and all other sectors.

Table 9 shows transport costs equal to 20 for ETE and all other sectors.

Table 10 contains additive taxes, proportional taxes and transport export-import cost multipliers for inputs 1-26.

Table 11 contains adjustments to prices for ETE and all other supply sectors 1-22, capital and IBT.

Table 15 contains the technical change parameters for inputs for K, L, Energy, (not clear what this includes), manufacturing, oil refining, Ref Gas (not sure what this includes), land, coal, and electricity into ETE for the 12 periods. (Would be useful to add sector numbers to clarify what some of these inputs are.)

Table 18 contains the elasticity of substitution (eos) for ETE and all other sectors 1-22. ETE has the largest eos at 0.4.

Table 20 contains example output for capital stock technical coefficient transformations. The included equations are helpful in placing the outputs in the model.

Table 22 contains the prior capital stock by vintage for ETE and the other 21 production sectors.

Table 23 contains technology characteristics for the 22 producing sectors and subsectors. It includes life of technology, time from investment to operation, maximum time periods, how long a renovation lasts, time to initial investment and last time period investment is allowed.

Table 25 contains emission coefficients for ETE and other sectors. (It is not clear what gas toggle and type are. Should the zero's in the last column be –1?)

Table 26 contains the cost curves for emissions for ETE and other emissions activity. (What are the levels in this table?)

Table 31 contains investment and expected profits in period 0 and period –1 for ETE and the other production sectors. (It is not clear why expect profits are either 0 or 1 for all sectors. Is this a toggle?)

Table 34 contains an expected profit rate exponential rhoinv that determines investment in Eq. 104 for ETE and other production sectors but we don't understand what is going on in the equation. Why is rinv is assumed 1 in the reference case.

Table 40 includes the capital demands for ETE as well as other sectors and subsectors for vintage 0 in year 0.

Table 41 contains contains investment shares for ETE and all input sectors. It is not clear what year this is for but we presume it is exogenous shares in year 0. The comment above it refers to Table 39 but seems to be referring to Table 40. If so these are the fixed coefficients for Leontief production functions for capital.

Table 60 contains income and price elasticities for ETE and all other production sectors for the U.S.

Table 63 contains trade data for period 1 and 2 for ETE and all other production sectors and factors of production.

<u>Appendix B: Details on Existing Model Documentation</u>

<u>SGM Model Overview</u>. This contains some documentation about parameter sources but clearly states on page 3 "nor does it provide a complete documentation of all of the data employed in SGM 2004." Documentation is limited to:

page 21, footnote 39 indicates that population data come from projections of UN, World Bank or US Census.

page 25, indicates the same four sources for emission drivers and control options as in the Appendix and cites McCarl as the source of information on the soil and forest carbon sequestration functions.

page 26-27, notes that input-output tables have been obtained for 7 of the countries but does not offer an exact reference. These tables are computed by interpolation and other non-specified data if 1990 versions are not available. Supplemental information is said to come from national accounts. The IEA is cited as the source for the energy balances. No source is given for fossil fuel resources.

page 30, the documentation indicates that historical data for investment are used, but no sources are indicated.

page 33, Table 4.3 contains typical elasticities of substitution and own- and cross-price elasticities of demand. The documents indicate these elasticities " were set using expert judgment after surveying the open literature." It cites surveys by Edmonds (1978), updates and summarized by Edmonds and Reilly (1985), and Bohi (1981), along with "numerous individual studies." The document footnote 51 also indicates that the elasticities are in the process of being updated.

<u>SGM Model Documentation</u>. This also contains very limited information on parameter sources.

page 12, indicates that local data by regions is used.

page 20, indicates that historical investment data are used but gives no references.

page 51, notes that no elasticity of substitution has a value less than 0.05 but provides no reason; elsewhere in the documentation this is attributed to limitations of the solution algorithm .

page 72-72, footnote 40 gives the Bureau of Mines as the source for mineral reserves and the World Energy Council as the source for energy reserves including uranium.

page 110, indicates that the model is calibrated to1990 to match actual energy consumption, carbon emissions, and economic activity but does not give a reference for the variables.

page 114, Parameters for MAC curves are not given. It is unclear to what documentation Mark Jacobsen references refer. Are they expected profits in gas production sector? Are they personal communications? Does the natural gas in "methane and natural gas" refer to natural gas liquids. Offsets are attributed to personal communication with McCarl but values for them are not given.

page 128, the documentation notes that the model is calibrated against historical data back to 1985, but no sources are given for the historical data.

pages 133-34, at most, 8 of the 22 references are possible original sources of parameters and data.

SGM Appendix A. An impressive array of model parameters and inputs are included in Appendix A, Tables 1-63. However, source documentation is extremely sparse, with only two sets of sources indicated:

page 27, footnote 2 provides four references for mitigation cost curves in Table 25 relating to nitrogen and high global warming potential GHGs (a common curve is used for each of these two categories regardless of the source of emissions). The references are cited as forthcoming in the *Energy Journal* in 2004, but have to date not been published there.

page 37, the World Bank or United Nations are cited as the sources for population projections presumably given in Tables 42-44.