

**U.S. Environmental Protection Agency  
Science Advisory Board**

**DRAFT ADVISORY  
on the  
SECOND GENERATION MODEL**

**By the  
Second Generation Model Advisory Panel**

**5-04-05**

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DRAFT

## **A. Improve the 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 need significant improvement. An interested reader will not find many important details of the SGM model in the Overview. On the other hand, the Documentation is written in a confusing manner and can be greatly improved.

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

(8) 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.

(9) 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:**

Brenkert A., R. Sands, S. Kim, H. Pitcher (2004). *Model Documentation. The Second Generation Model*, Pacific Northwest National Laboratory (PNNL-14256), Joint Global Research Institute, College Park, MD.

Edmonds J., H. Pitcher, R. Sands (2004). *Second Generation Model: An Overview*, Pacific Northwest National Laboratory (PNNL-14916), Joint Global Research Institute, College Park, MD.

Hertel, Thomas W. (1997). *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, Cambridge, UK, 1997.

**B. Improve documentation of values for all of model's parameters; improve empirical basis for choice of parameters.**

In our commentary we inventory the documentation of the sources of the data and parameters, suggest ways to improve the documentation, and suggest ways to improve the empirical basis of the parameters.

**1. Documentation Inventory**

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.

Model Overview. 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. The IEA is cited as the source for the energy balances.

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), Bohi

(1981), and Edmonds and Reilly (1985), along with "numerous unspecified studies." The document also indicates that the elasticities are in the process of being updated.

Model Documentation. This also contains very limited information on parameter sources.

page 10, indicates that historical investment data are used but gives no references.

page 10, indicates that local data by regions is used.

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 110, indicates that the model is calibrated to 1990 to match actual energy consumption, carbon emissions, and economic activity but does not give a reference for the variables.

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.

### Our Summary

1. Our reading of the documentation suggests is that we know roughly where the input-output tables and energy balances come from, where the emission information comes from, and where the population projections come from.
2. We know the model is calibrated to historical information on income and other variables, and historical information is needed to compute capital stock. However, it is less clear where such historical data come from.
3. Behavioral parameters are more ambiguous. Elasticities of substitution and income and price elasticities for the production sectors have a loose empirical basis in general.
4. For land and labor supply parameters, technical coefficients, and adjustments for capital by vintage, the picture gets foggier still. Here, if no parameters are available, some indication of the reasoning behind the parameter choices would be helpful.
5. We have not had time to check whether all input parameters were reported in the Appendix.

## **2. Ways to Improve the Documentation**

1. Provide a master list of parameter names, symbols, benchmark year, updating frequency, and data source (author, date). Provide full bibliographical information for the citations in a separate “Data References” section.
2. Annotate the data presentation in the “Model Documentation” or “Appendix” for those parameters and data sets that required further refinement or where further explanation is needed for the general reader (cross-reference this between “Documentation” and “Appendices”).
3. Include benchmark year and dollar index (where applicable) for all data tables following table title (e.g., in current 1990 dollars).
4. We realize many of 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.”

## **3. Ways to Improve the Empirical Basis of the Model**

We offer several illustrative suggestions below. Suggestions from other aspects of this model review should be added after consensus is reached on them and on our examples by the entire review team.

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.?

App Table 18, the elasticities of the non-nested production function reveal the weakness of that approach in comparison with a nested CES.

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.

### **C. Undertake systematic sensitivity of model simulations and appropriate “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 uses 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 were brilliantly accurate for the near term, the model is not likely to be able to forecast decades in the future when the structural model 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.

## References

- DeVuyst, Eric A., and Preckel, Paul V., "Sensitivity Analysis Revisited: A Quadrature-Based Approach," *Journal of Policy Modelling*, 19(2), 1997, 175-185.
- Harrison, Glenn W.; Jones, Richard; Kimbell, Larry J., and Wigle, Randall, "How Robust Is Applied General Equilibrium Analysis?" *Journal of Policy Modelling*, 15(1), 1993, 99-115.
- Harrison, Glenn W., and Kimbell, Larry J., "Economic Interdependence in the Pacific Basin: A General Equilibrium Approach," in J. Piggott and J. Whalley (eds.), *New Developments in Applied General Equilibrium Analysis* (New York: Cambridge University Press, 1985).
- Harrison, Glenn W., and H.D. Vinod, "The Sensitivity Analysis of Applied General Equilibrium Models: Completely Randomized Factorial Sampling Designs," *The Review of Economics & Statistics*, 74, May 1992, 357-362.
- Pagan, Adrian R., and Shannon, John H., "How Reliable are ORANI Conclusions?" *Economic Record*, 1987, 33-45

#### **D. Clarify treatment of the “Everything Else” sector.**

We have two steps indicating how to clarify the everything else (ETE) sector. Step 1 is to inventory the discussion of the ETE sector in the three parts of the model documentation: the overview, the model documentation and the appendices A-D. Our inventory contains a list of where the ETE is mentioned, our general interpretation of the documentation for each time ETE is listed, and questions we have about the documentation each time ETE is listed. Step 2 is to sum up the results of our inventory after each of the three pieces of the documentation.

##### **Overview Document**

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”<sup>45</sup> 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  
<sup>45</sup>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.

It would be helpful to clearly document 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.

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.

You might want to compare choices about sectoral detail to other IAMs. Does the current grouping, especially ETE, make sense?

### **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. (Although not relating to ETE we have the question is carbon also a production sector?)
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." (Although not relating to ETE we have the question is carbon also a production sector?)  
(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,  $\alpha_{i=ETE,j,j,v}$  is used to create the scale coefficient for the capital stock. (Again is this only for the base year? But doesn't  $\alpha_{i=ETE,j,j,v}$  always equal 1 from equation 22 on page 38?)

9. Page 41,  $\alpha_{i=ETE,j,j,v}$  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 ( $P_{i=ETE,j,j,t}$ ) 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  $P_{i=ETE,j,j,t} = P_{ETE,t}$  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  $P$ ,  $P_i$ ,  $P_r$ .)

12. Page 60, The price paid by the producer for the everything else sector ( $P_{i=ETE,j,j,t}$ ) 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 than just service and that parts of transportation are not included in production sector 18 but are included in ETE.

13. Page 79,  $P_{i=ETE,j,j,t}$  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 ( $P_{i=ETE,j=27,t}$ ) 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  $l_{bs}$  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,  $P_{i=ETE,j=27,t}$  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,  $P_{i=ETE,j=27,jj,t}$  is again called price of the numeraire. (Other places the subscript 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  $P_{i=ETE,j=26=g, jj,t}$ . (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.)

Overall comments for Model Documentation.

1. We believe that some of the confusion is related to overall documentation. It would be helpful in this regard to have a table clarifying all inputs and endogenous variables. Include more discussion for most equations explaining what the equation is doing and why. Checking all notation including subscripting for consistency. Taking out empty sector so summation notation is not ambiguous. Consider eliminating subsector notation and treating subsectors as sectors.
2. Clarify the relationship between  $P$ ,  $P_i$ , and  $P_r$ .  $P_{iETE}$  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?
3. 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?

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  $\rho_{inv}$  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  $r_{inv}$  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 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.

We have no additional overall comments for the appendix but only the more specific questions noted in the inventory.

DRAFT

### **E. Improve the treatment of international trade in the SGM model.**

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.<sup>1</sup>

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. One is to “close” the single-open economy model 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 other is to extend SGM to be a truly global model, by explicitly including other regions and trade between regions. Both approaches have long traditions in the broader general equilibrium modeling literature, and the strengths and weaknesses of each are well known.

The latter 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.

Therefore, our major recommendation is that the SGM team take the path of least resistance by incorporating trade using the first approach, which is to treat the United States as a small open economy.<sup>2</sup> 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.

<sup>1</sup> 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.

<sup>2</sup> 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.

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.<sup>3</sup>

The one concern with adding 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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<sup>3</sup> 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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DRAFT

**F. Derive household behavior from utility maximization; consider changes in welfare in policy assessments.**

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 income classes.

The challenge faced in extending to multiple representative consumers is to identify data adequate to specify a demand function for a representative consumer in each sub-aggregate (e.g., low income vs. medium income individuals). 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 an 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, Kirman 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 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  $x_i(\cdot)$  is demand for consumer  $i$ ,  $P$  is a vector of market prices,  $a_i(\cdot)$  is a function of prices that can vary over consumers,  $b(\cdot)$  is a coefficient that is a function of prices but is the same for all consumers, and  $m_i$  is income for consumer  $i$ .<sup>4</sup> 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 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:

$$X^j(P, M) = A^j(P) + b^j(P) M^j$$

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

---

<sup>4</sup> 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.

$$x^j(P, m^j) = a^j(P) + b^j(P) m^j$$

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 income classes. 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 income class, allows one to calculate aggregate welfare measures, as well as welfare measures disaggregated across income classes, 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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**G. Replace flat CES production specification with more flexible specification, e.g., nested CES.**

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 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.

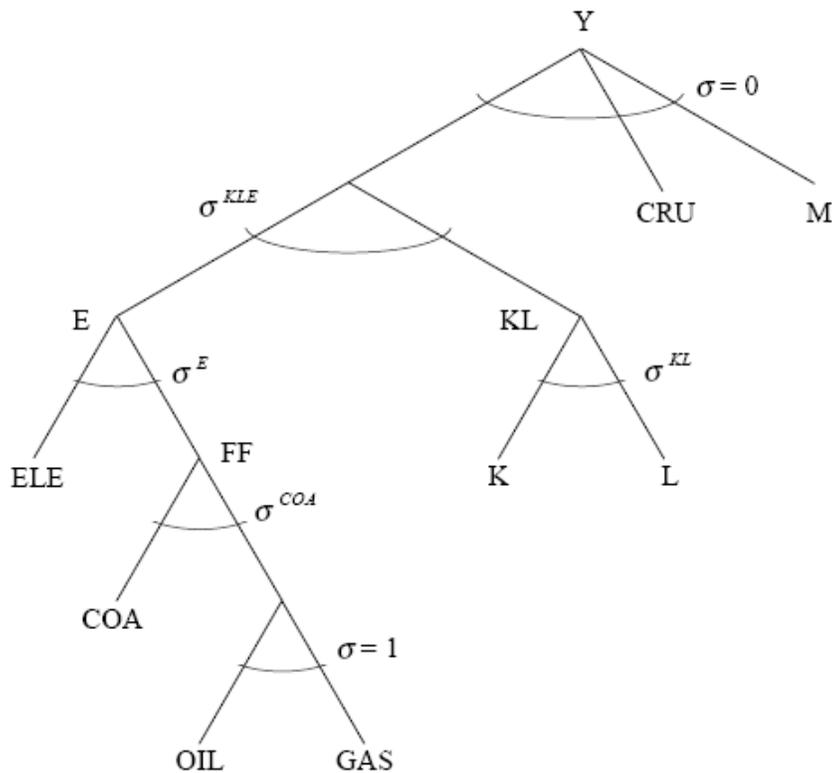
More common approaches in the CGE modeling literature focus on more structured, less flexible production models, in part because of the difficulty in parameterizing a fully flexible model (which will have  $n \times (n - 1) / 2$  parameters, where  $n$  is the number of inputs). These models typically 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).

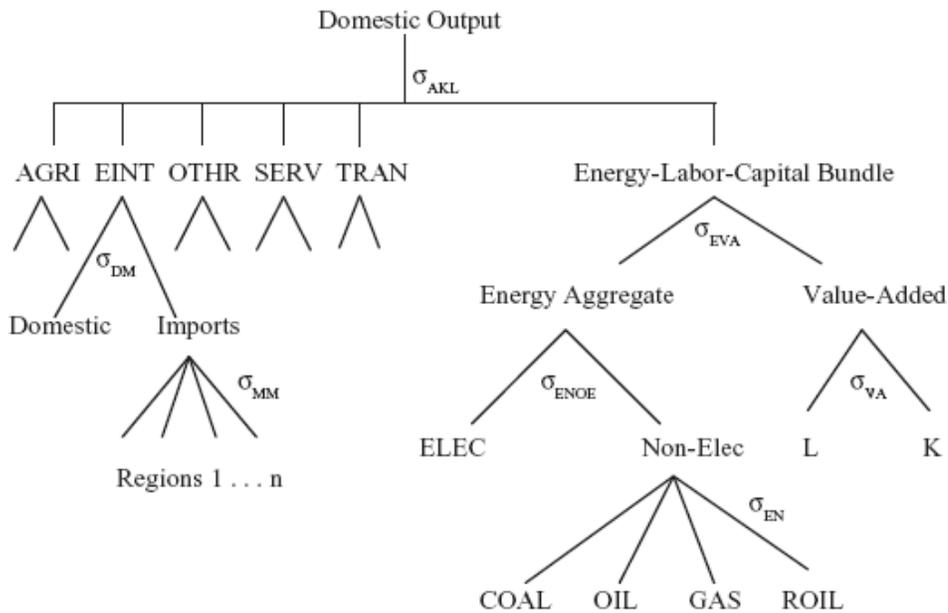
**Recommendation**

Employ a nested CES production structure more in line with existing CGE models and parameterized based on empirical data.

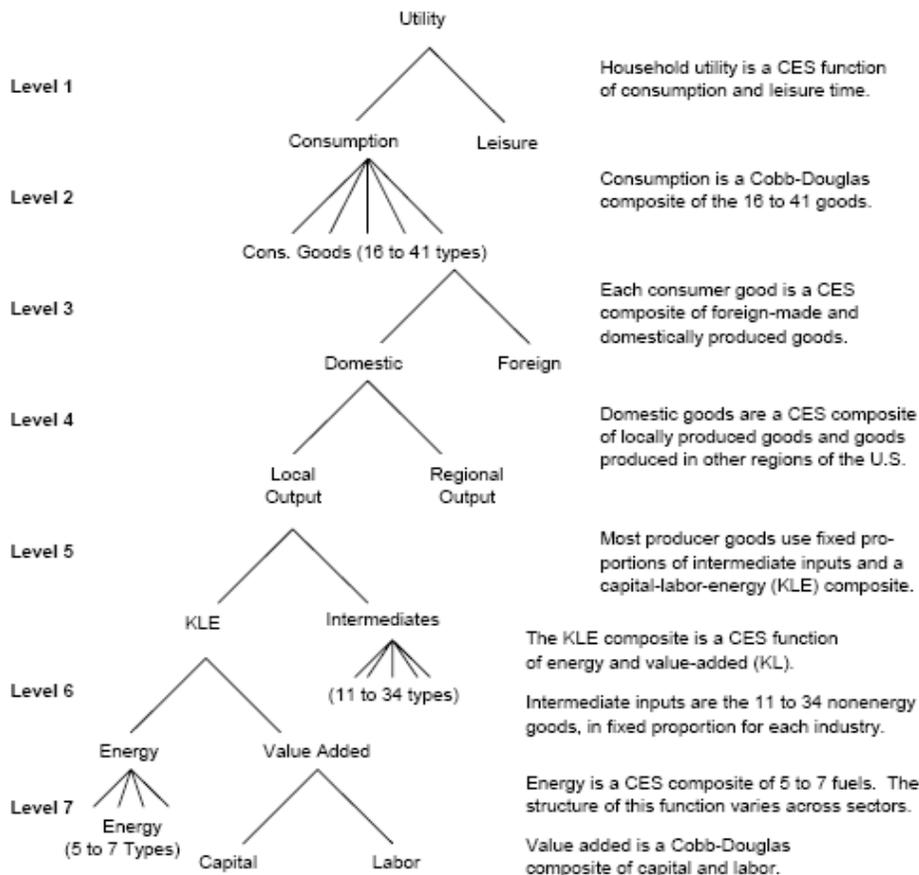
**Appendix: Examples of Nesting Structures**



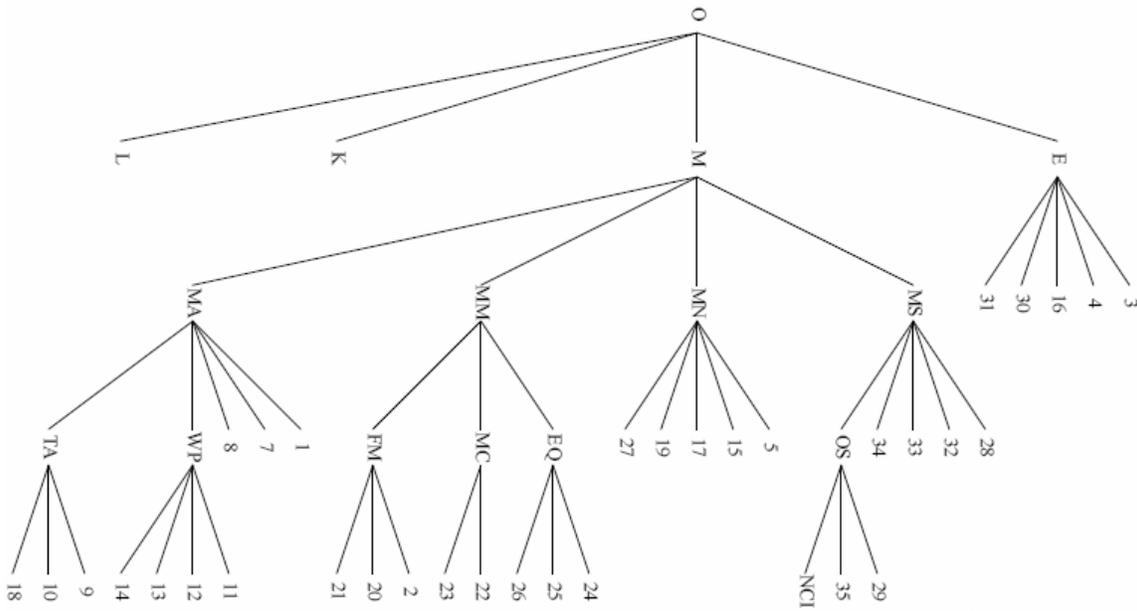
(Böhringer and Löschel 2004)



(Jacoby et al. 2004)

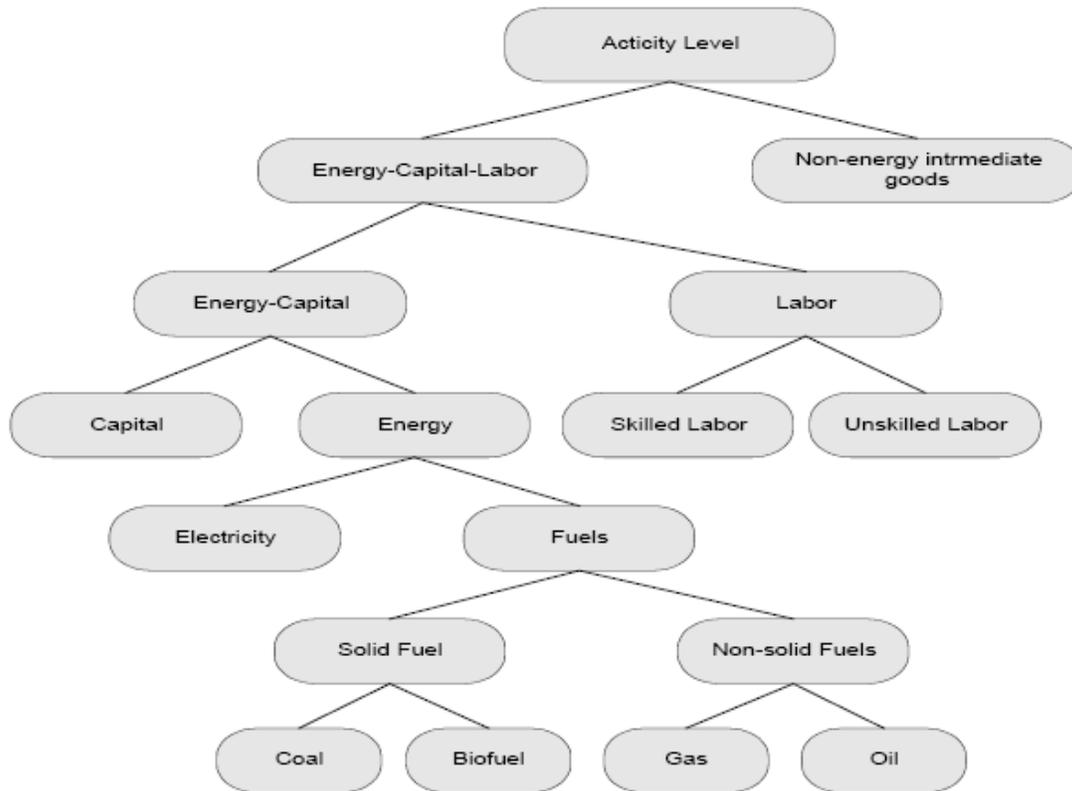


(RTI International 2004)



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

(Wilcoxon 1988)



(Hill and Kirström 2002)

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## **H. Update the data set.**

The SGM data set should be updated to a more recent year than 1990, to reflect changes in economics conditions, technology in critical sectors, and to 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.

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, Champenowne 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, there are two feasible scenarios for updating the SGM data set. First, the SGM developers can 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. Second, the SGM developers can use the GTAP data with additional disaggregation of electricity sector. We recommend the latter, but would minimally require the former.

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## **I. Endogenize the emissions of other (non-CO2) 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. Other models of a similar type have done so. One possible way to implement endogenous mitigation options is as follows:

- a) incorporate non-CO2 emissions mitigation into 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 GWP sources (Table 26 of Appendix A). However, 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 “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 for a stringent climate policy the approach of using GWPs to express non-CO2 emissions in terms of equivalent amounts of CO2 has significant weakness (see, for example, Eckaus (1992), Reilly and Richards (1993), Schmalensee (1993), Reilly et al. (1999)).

Eckaus R. (1992). Comparing the effects of greenhouse gas emissions on global warming. *Energy Journal*, 13, 25-34.

Reilly J. and K. Richards (1993). Climate change damage and the trace gas index issue. *Journal of Environmental and Resource Economics*, 3, 41-61.

Schmalensee R. (1993). Comparing greenhouse gases for policy purposes. *Energy Journal*, 14, 245-255.

Reilly J., R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov, and C. Wang (1999). Multi-gas assessment of the Kyoto Protocol, *Nature*, 401, 549-555.

DRAFT

## **J. Improve the model's treatment of sector-specific policies.**

### **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. Moreover, one manifestation of this is increased availability and generation from existing capital investment (especially nuclear and coal).

### **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.

### **Agriculture/forestry**

The agricultural/forestry sector is an important component of the SGM model as a source of GHGs, and as 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.

Some policies may increase GHGs (e.g., developing country policies that encourage conversion of forests or other land covers to agriculture), while others reduce emissions. An example receiving much current attention in the US is the Conservation Reserve Program (CRP). The CRP is a voluntary program in which farmers contract to place cultivated land in permanent plant cover, which can lead to increases in soil carbon. Some estimates suggest that land in CRP program can offset 25 to 40% of agriculture's CO<sub>2</sub> emissions. A similar program is offered in Canada.

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.