**Response to Peer Reviews of**
**EPA's EMPAX Computable General Equilibrium Model**

**Reviewers:**
Dr. Charles Ballard – Michigan State University
Dr. Christoph Bohringer – Centre for European Economic Research (ZEW) Mannheim and University of Heidelberg
Dr. Hillard G. Huntington – Stanford Energy Modeling Forum

EPA would like to thank Drs. Ballard, Bohringer, and Huntington for their thoughtful review of the EMPAX Computable Equilibrium Model. A summary of the comments with EPA responses follows.

**Summary of Comments**
**Ballard General Comments –** EMPAX is an "impressive piece of work" and any suggestions are intended as possible improvements, not to convey an unfavorable impression of the model.
**Bohringer General Comments –** "Overall, the model documentation conveys the impression of solid competent work." He notes that the combination of static and dynamic versions is a reasonable way of analyzing different policies, and that the model incorporates the important issue of tax distortions in a "profound" way.
**Huntington General Comments –** He says that the model is "well crafted" and will be "very useful" for examining regional and industry impacts of policies, and that RTI did an "effective job in developing the CGE structure and merging data from available and credible sources into a framework that is economically consistent". His main suggestion is to include some policy analyses so that it would be easier to evaluate how the model acts.

As noted by the reviewers, we appreciate the difficult nature of attempting to review a model based solely on documentation, rather than model results for specific policies. A common theme across the reviewers' comments was the desire for sensitivity analyses, which were not discussed in the model documentation. We agree that this is an essential component of a CGE policy analysis and point out in our responses below the variables in the model we feel will be particularly important to investigate when examining impacts of environmental policies.

In the following memos, we address comments and suggestions made by reviewers in the following fashion (citing reviewer's comment in cases where comments were directed at specific text in the EMPAX-CGE documentation): first, we discuss general comments and suggestions for improving the model and analyses conducted with it; second, we note specific comments on particular topics/sections in the model documentation and describe how we have/will address the issues raised; and third, we respond to minor comments regarding changes and clarifications to the text of the documentation. Note: all page numbers cited by reviewers refer to position of text in the document as they reviewed it. While these cites have been included in the discussions below to provide an overall sense of their location in the document, the exact location may have changed as additional text has been added to address comments and suggestions.

**Peer Review of**
**EPA's EMPAX Computable General Equilibrium Model**

by
Reviewer:

**Dr. Charles L. Ballard**
**Department of Economics**
**Michigan State University**
**East Lansing, MI**

## I. General Comments and Suggestions Regarding EMPAX-CGE

This subsection includes general comments made by Dr. Ballard regarding EMPAX-CGE, sensitivity analyses, and suggestions for future model changes. The following two sections subsequently discuss specific comments by Dr. Ballard in more detail.

### A. Sensitivity Analyses

***Comment:***

In Section 3 of the Model Documentation, I learned that all consumption goods are combined using a Cobb-Douglas structure to form an aggregate consumption good. The Cobb-Douglas utility function imposes unitary income and own-price elasticities, which is highly restrictive. At a minimum, I think it would be straightforward to employ a C.E.S. structure. The additional computational cost would be very small. Even if the researchers' best guess of the elasticity of substitution is 1.0, at least a C.E.S. function would allow for sensitivity analysis.

In fact, I want to make the strongest possible case for sensitivity analysis, with respect to most or all of the parameters. The Model Documentation did not explicitly say a great deal about sensitivity analysis, one way or the other. However, there was a substantial amount of discussion of computational expense. I don't know how severe are the constraints on computation, but I do get the sense that there will be limits to the number of simulations that are run. I hope these limits are not made too severe. There is simply no way for us to know some of the parameters of the model with great certainty, so we owe it to the end users of the model to provide a sense of the degree of sensitivity. In a model of this size and complexity, it is possible that surprises may lurk beneath the surface. In fact, it could even be the case that sensitivity analysis could uncover an error. I remember at least one occasion where all of my consistency checks appeared to work properly, and yet sensitivity analysis revealed an implausibly large responsiveness of the results to changes in one of the parameters. As a result, I did further investigation, and found an error. In short, I'm making a pitch for lots of sensitivity analysis. Whenever the Cobb-Douglas form is imposed on any part of the model, it is impossible to perform any sensitivity analyses in that regard. So, at a minimum, I would argue for C.E.S.

However, there is another issue that is just as important, and maybe even more so. The C.E.S. allows us to vary the elasticity of substitution, but it still imposes homotheticity on

> the model. This has important implications, especially in the context of a model that is concerned with environmental issues. In a well-known paper from 1994, Bovenberg and de Mooij used a very simple model with homothetic preferences. In this context, they showed that the optimal environmental tax is less than the first-best Pigouvian tax. When Parry discusses this point, he says that the result turns on the good being an "average substitute for leisure". However, if we relax the assumption of homotheticity, this result can be reversed. Along with John Goddeeris and Sang-Kyum Kim, I have written a paper that explores the implications of homotheticity in greater depth. This paper is forthcoming in International Tax and Public Finance. I am sending along a copy of the paper with this report. I believe that the issue is especially important, since many of the goods that are associated with environmental externalities are goods for which the expenditure elasticity is less than one. Certainly, a case can be made that at least some of the energy products that are at center stage in the EMPAX model have expenditure elasticities of less than one. If so, then the imposition of homotheticity through the Cobb-Douglas function will prejudice the model in the direction of saying that environmental taxes are harmful, even in cases where they may actually be beneficial.
>
> I hope the EMPAX researchers will at least give consideration to the possibility of using a non-homothetic structure. My paper with Goddeeris and Kim gives one example of how this might be done, and provides illustrative calculations.

As noted by Dr. Ballard, sensitivity analyses are important to understanding both the model's policy findings and how the model is reacting to specific parameter assumptions. The ability of households to switch among consumption goods can influence model results, as can other key elasticities controlling the model's ability to improve energy efficiency and switch among fuels (discussed below). We can conduct sensitivity analyses on such assumptions (including CES functions, rather than Cobb-Douglas) when estimating policy impacts, without experiencing severe constraints on model run-time or having issues with generating an equilibrium solution in the model. Adopting a non-homothetic structure for households' preferences will be more difficult to implement (and collect data for), but we will examine this issue in the future.

***Comment:***

> In Section 7 of the Model Documentation, there is a discussion of the labor-supply elasticities. (See especially p. 7-14.) I have a concern about the calibration. It appears to me that the equations at the bottom of the page may not be correct. At the very least, I believe the modelers involved in this project should look into it further.
>
> There is a long history of models that specified the compensated labor-supply elasticity improperly. I have to confess that this is the case in some of my own work. In the original versions of the GEMTAP model, which I worked on along with Fullerton, Goulder, Shoven, Whalley, and others, the calibration of the uncompensated labor-supply elasticity was specified correctly. However, the income elasticity, and therefore the compensated elasticity, was not calibrated correctly. We were using a leisure endowment that was too large (i.e., a leisure endowment that actually implied compensated labor supply elasticities that were larger than we thought). I fixed this problem in 1986, or thereabouts. However, I continued to see other articles that were making the same kind of error. In some cases, researchers merely made an arbitrary assumption about the size of the leisure

endowment, and made no real attempt to achieve a proper specification of the compensated labor-supply elasticity.

Because I had seen this error so often, I finally wrote a paper on the subject. I am sending that paper along with this review. Unfortunately, the paper is, as yet, unpublished. (That's a long story, which I will share upon request.) In any event, the algebra shown in my paper "How Many Hours Are in a Simulated Day?" for the static labor-supply elasticities is considerably more involved than the equations on p. 14. This makes me believe that the EMPAX model may be incorrect in this regard.

"How Many Hours…" shows that the leisure endowment plays an important role in the specification of dynamic models, as well as static models. The precise channel through which this works is somewhat different in a dynamic model than in a static model, but the effects are no less important.

In experiments of the type that are proposed for the EMPAX model, both the uncompensated and compensated labor-supply elasticity play an important role. For a discussion of some aspects of this, see my paper in Journal of Public Economics, 1990.

***Response:***

We have altered the labor-supply elasticity calculations in EMPAX-CGE to reflect Dr. Ballard's work described in Ballard (2000). The original calculations were presented in a calibrated-share form (see Rutherford, 1995), which simplifies the algebra involved, but have been changed.

Ballard, C.L. 2000. "How Many Hours are in a Simulated Day? The Effects of Time Endowment on the Results of Tax-Policy Simulation Models." Michigan State University, June 28, 2000. This is a revised version of a paper presented at the Conference on Using OLG Models for Policy Analysis, Copenhagen, Denmark, August 13-14, 1999.

Rutherford, T.F. 1995. "Constant Elasticity of Substitution Functions: Some Hints and Useful Formulae." Notes prepared for GAMS General Equilibrium Workshop held December, 1995 in Boulder, Colorado. http://www.gams.com/solvers/mpsge/cesfun.htm

***Comment:***

Also in Section 7 of the Model Documentation, there is a discussion of the calculation of capital tax rates. In CGE simulation models, two basic approaches have been used for calculation of tax rates on capital. The first is exemplified by the work of Harberger (1962), or Shoven (1976), or Ballard, Fullerton, Shoven, and Whalley (1985). In this approach, the researcher calculates average tax rates. Then, it is assumed that marginal tax rates are equal to average tax rates (even though this may not be true).

The other approach is exemplified by the work of Jorgenson and several different co-authors, as well as Fullerton and Rogers (1993). In this approach, marginal effective capital tax rates are calculated, on the basis of some version of the cost-of-capital approach pioneered by Jorgenson (1963) and Hall and Jorgenson (1967). Then, it is assumed that average tax rates are equal to the marginal tax rates (even though this may not be true). The EMPAX model uses this second approach.

> I can't say unambiguously that one of these approaches is better than the other, because each has advantages and disadvantages. However, in this context, I do at least want to make the case for the EMPAX team to give serious consideration to the other approach…

***Response:***
We will examine this issue more closely in the future. The goal of the current formulation for representing capital taxes in EMPAX-CGE was to ensure that distortions caused by these taxes were appropriately included in the model (as measured by the welfare costs of these distortions). As Dr. Ballard notes, and many other researchers have pointed out (cited in Section 7 of the documentation), these distortions can have important implications for the total costs of environmental policies. Our approach has been to get these distortions in the range considered appropriate in the literature, and then adjust average tax rates through transfers after this goal has been achieved.

### B. Model Baseline Year

***Comment:***

> I did not fully understand why 2005 is being used as the baseline, since we don't yet have any data for 2005. Thus, the baseline is already based on some extrapolations. Why not use 2000 as the base year?

***Response:***
An initial baseline year of 2005 is used in the dynamic version of EMPAX-CGE for several reasons. First and most importantly, in a perfect-foresight model such as EMPAX-CGE, agents will adjust their behavior in all time periods as soon as a policy is announced so, if the model began in the year 2000, policies under consideration today would show effects in 2000. Attempting to "fix" the year 2000 results and only allow the model to change the economy starting in 2005 would also create difficulties since there are fixed resources in the model. Second, developing a baseline dataset, or SAM, for the year 2005 outside of EMPAX-CGE allows more opportunity to incorporate estimates of economic growth between the year of the IMPLAN economic data and the base year of 2005. If the model were solved for an initial year of 2000 and the 2005 solution was endogenous to the model, it would be more difficult to incorporate available historical estimates of growth between 2000 and 2005. Finally, the static version of EMPAX-CGE is designed to be run using data for either current or future years (e.g., 2015) and a consistent method of projecting baseline economic changes was desirable for generating all such baseline years in the model.

## II. <u>Comments and Suggestions by Section and Topic</u>

### A. Section 1 – Introduction

***Comment:***

> On p. 1-8, "Computational issues limit its size to fewer industries and regions than the static model, because it must solve for multiple time periods." I would like to see a little more discussion of this. Is the issue that it will just take a really

> long time to solve the dynamic model if the full set of industries and regions were used, or is it actually difficult or impossible to solve the model in its largest possible form?

***Response:***
Issues surrounding size involve the complexity of the model, rather than the length of time required to solve it (which is not extensive). Because the dynamic version of EMPAX-CGE uses a perfect-foresight, intertemporally-optimizing framework, all time periods are solved simultaneously, which increases the number of equations significantly over the static version of the model. Above a certain number of equations (i.e., between 10,000 and 20,000 equations), it becomes much more difficult for the model's solver to find an economic equilibria, necessitating limits on the number of regions and industries included.

## B. Section 2 – Overview of EMPAX-CGE

***Comment:***

> On pp. 2-3 and 2-4, there is discussion of the Armington assumption. Certainly the Armington assumption is extremely popular in CGE trade models. However, there are other ways to have cross-hauling. For instance, some models have imperfect competition. Drusilla K. Brown published a couple of papers in the 1980s, which raised questions about the validity of the Armington formulation. I am not saying that I think the EMPAX modelers should abandon the Armington function. I'm merely saying that they should be aware of its weaknesses.

***Response:***
The main motivation behind selecting the Armington formulation for controlling trade flows was the desire to maintain a theoretical structure similar to other CGE models used to examine environmental policies, in this case MIT's EPPA model upon which the trade elasticities are generally based. Our best option for addressing concerns about trade assumptions as they relate to model results is to conduct sensitivity analyses on the Armington elasticities. When adopting the current model structure, we were also concerned that adding a feature such as imperfect competition would have detrimental effects on the size of the model. While imperfect competition can be modeled, it generally increases the number of equations in a model, making it more difficult to solve.

***Comment:***

> On p. 2-5, "investment goods and government expenditures are…maintained at their current baseline levels…". Are those levels held constant in real terms, and if so, how?

***Response:***
In all versions of the model, government purchases (as measured in real terms using the cost of obtaining the desired bundle of goods) are maintained through non-distortionary lump-sum transfers between the government and households. In the dynamic version of EMPAX-CGE, it is not necessary to exogenously maintain investment-goods purchases since decisions on investment and capital stocks are a result of the model, rather than an exogenous input.

## C. Section 3 – EMPAX-CGE Modeling Framework

***Comment:***

On p. 3-2, in Table 3-1, we see a list of various elasticities. I have a question about two of them. First is the elasticity of substitution among material inputs, which is set to zero. Therefore, the Leontief structure is used. I have used this very same assumption in some of my own work, and I don't think it will necessarily have a huge effect on the results of the model. But it may have an important effect in some cases. It is easy to imagine that the elasticity could be positive, and maybe even large, at least for some combinations of inputs. Now that I have made a case for allowing some substitutability (although I'm not pushing it hard), let me just mention one piece of my own work that may be of interest to the EMPAX team. Along with Steven Medema, I published a piece on environmental taxes and subsidies in Journal of Public Economics, 1993. We did a variety of things that may be of interest. We had an abatement-cost function. And we had input-output coefficients that changed as a result of pollution. Thus, although we had Leontief coefficients, the precise values of those coefficients would change with every iteration of our computational algorithm. We had to add another layer of iteration, in which we used a Gauss-Seidel procedure to calculate the new input-output matrix. This turned out to be fairly expensive computationally, or so it seemed at the time. But computers are a lot faster now than they were a dozen years ago.

***Response:***

The Leontief structure for material inputs was chosen for EMPAX-CGE for a couple of reasons. It was our desire to follow the general structure of MIT's EPPA model (which uses this assumption) since EPPA is a well-established CGE model, and both it and EMPAX-CGE are intended to estimate how producers and consumers will respond to energy/environmental policies. Dr. Ballard's (1993) paper raises interesting points about the Leontief assumption, however, we believe it would be difficult to implement their approach in EMPAX-CGE. While such an approach might be practical in the static version of the model, in the dynamic version the process of iterating to a new input-output matrix for each time period simultaneously could be quite complex. In addition, when EMPAX-CGE is used to evaluate environmental policies (see Section 5.2), the input-output matrix is adjusted to account for any new expenditures on environmental protection equipment according to historical expenditure patterns, an approach that would not lend itself to allowing input-output coefficients to change in response to policies.

Ballard, C.L. and S.G. Medema. 1993. "The marginal efficiency effects of taxes and subsidies in the presence of externalities: A computational general equilibrium approach." *Journal of Public Economics* 52(2): pg. 199-216.

***Comment:***

My second question about the elasticities in Table 3-1 is that the elasticity of substitution between labor and capital is set to 1.0. I think an argument can be made for lower values in some industries. We used lower values in some sectors

> in Ballard, Fullerton, Shoven, and Whalley (1985). Regardless of the exact values chosen, however, I think the most important thing would be to allow the parameter to vary, so that sensitivity analysis could be performed.

**Response:**
The Cobb-Douglas elasticity of substitution between capital and labor is another parameter based on production functions in MIT's EPPA model. We agree with Dr. Ballard that this should be one of the assumptions explored during sensitivity analyses to evaluate its influence on model results.

***Comment:***

> In point #11, above, I argued against the Cobb-Douglas assumption. I want to do so again with respect to the Cobb-Douglas structure for the combination of natural gas with coal and oil. At least I hope some allowance is made for sensitivity analysis.

***Response:***
The Cobb-Douglas elasticity of substitution between energy types is also a parameter based on production functions in MIT's EPPA model. We again agree with Dr. Ballard that this should be one of the assumptions explored during sensitivity analyses to evaluate its influence on model results. The ability to switch among fuels can have significant implications for the effects of environmental policies. Such effects may be less relevant in the case of EMPAX-CGE than other CGE models, however, since EMPAX-CGE generally relies on EPA's IPM electricity model to evaluate responses of the electricity-generation industry to environmental policies (see Appendix B).

***Comment:***

> Also on p. 3-7, "EMPAX-CGE currently assumes that the amount of nuclear and renewable generation will not be affected by the policies being investigated." It would be nice to have a parameter from which you could find the critical value for renewable generation to increase. Under some scenario, by how much would fossil- fuel prices have to increase, in order for renewables to move in? How much renewable energy would be necessary to achieve a goal that could also be achieved by nonrenewables?

***Response:***
Characterizing how nuclear and/or renewable generation might respond to environmental policies using a CGE model is quite problematic. MIT is at the forefront of research on how to include renewable and advanced generation options in CGE models (see Jacoby et al., 2004). However, a number of uncertainties remain regarding how to incorporate these features in policy investigations. The capabilities of wind and solar power are sensitive to parameter assumptions about how these sources can substitute for other types of generation. Feasible penetration rates for new technologies have to be exogenously assumed by modelers, as do future costs for these technologies. In addition, capabilities of nonfossil generation frequently do not depend solely on economic factors, for example, the building of new nuclear generation depends more on political decisions than economics, and wind/solar generation depends on site-specific characteristics

(different classes of wind resources and days of sunshine) that are difficult to capture in a CGE model. Consequently, to avoid these difficulties, nuclear/renewable generation is fixed at levels given in the EIA's *Annual Energy Outlook* forecasts. To the extent that EMPAX-CGE relies on EPA's IPM model to evaluate policy responses in the electricity industry, effects of this approach on model results will be minimized/eliminated.

Jacoby, H.D., J.M. Reilly, J.R. McFarland, and S. Paltsev. 2004. "Technology and Technical Change in the MIT EPPA Model." MIT Joint Program on the Science and Policy of Global Change, Report No. 111. Cambridge, MA. http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt111.pdf

***Comment:***

On p. 3-12, "In the dynamic version, computational limitations reduce the number of households that can be incorporated." I wonder whether there is a theoretical reason to limit the number of households to one, in the dynamic version. Are there differences in savings propensities among the income classes? If so, then a dynamic sequence will find the capital stock more and more concentrated in the hands of the group with the highest incomes. This is an awkward feature, and it would create difficulties for the interpretation of any distributional results. By the way, the problem just described would be mitigated by using a life-cycle model. I'm not really suggesting that a life-cycle model should be incorporated. I have worked with life-cycle simulation models, and they cause a lot of headaches, not to mention a great deal of additional computational cost. Nevertheless, it might at least be good to say something about how you acknowledge that this model is not capable of addressing certain questions that can be addressed in a model with overlapping generations of life-cycle consumers.

***Response:***

As noted by Dr. Ballard, EMPAX-CGE defines household groups based on annual income, which will not capture how each generation borrows and saves over time, nor any bequest issues for future generations. A life-cycle model would be able to examine these issues, although at a potentially high computational cost and level of difficulty that is beyond the scope of what we would currently be comfortable including in an applied CGE model designed to focus on the next 10-20 years. We will note in the text, however, that the current approach is not able to address intra- and inter-generational income distribution issues.

***Comment:***

On p. 3-15, "It is also assumed that ownership of natural resources and the capital… are spread across the country, based on each region's share of total national income." I believe that data from the Bureau of Economic Analysis could probably be used to assess the extent to which that assumption deviates from reality.

***Response:***

Data from the Bureau of Economic Analysis are used by the Minnesota IMPLAN Group when developing the state-level economic databases used by EMPAX-CGE. While these data contain estimates of state personal income from labor and capital earnings, they do not focus on natural resources or on the physical location of capital stocks underlying any capital earnings. Given how capital markets and ownership of stock in companies will spread earnings (other than labor) across the country, this general assumption has been adopted in the absence of better data.

***Comment:***

> On p. 3-15, the sentence that ends with footnote 12 indicates that the United States is assumed in this model to be a small open economy. The footnote indicates that there may be plans to relax that assumption. I think this may be of particular importance for some of the policy scenarios that could be addressed by EMPAX-CGE. In the world market for petroleum, I think the U.S. accounts for more than 10% of production, and more than 20% of consumption. We don't sound like a small country there. In fact, I heard an economist argue in favor of high taxes on petroleum products in the United States, precisely because a large portion of the burden of the tax would be borne by the Saudis. Also, in this regard, you might take a look at the papers by Brown, mentioned … above. I believe she argues that the Armington formulation effectively takes us away from the small-open-economy assumption in certain cases.

***Response:***

We agree that the United States will not be well represented as a small open economy (SOE), although as Dr. Ballard notes Armington trade elasticities for imports remove some of the effects of this assumption. We are looking at changing the SOE assumption so that EMPAX-CGE can include international-trade elasticities.

***Comment:***

> Also on p. 3-16, it is said that there are regional differences in factor prices. That doesn't seem very problematic in the static version of the model. However, in a dynamic context, we would have to worry about how such differences could persist over time. Is there an equilibrating mechanism? It would be possible to build a model with migration, but where frictions prevent migration from achieving factor-price equalization immediately. This is one of several modeling questions that I want to raise, although I don't want to push too hard for a change of this type. Migration is not easy to model, and it could be costly to implement within the model. In view of those facts, it is reasonable to think that it might be best to leave it out, since this particular model is not primarily concerned with that type of issue.

***Response:***

Migration in response to environmental policies is not allowed in EMPAX-CGE, although forecasted trends in migration are captured in the baseline data/forecasts of the model. While it would be possible to add an equilibrating mechanism that allows labor to shift among regions as the result of a policy, calculation of the welfare effects on household(s) in each region would be impractical (or meaningless) as the size of the household(s) in each region would have changed at the same time that the incomes of individuals remaining in a region changed. To date, as EMPAX-CGE has been used to investigate policies resulting in very small changes in wage rates, precluding migration is unlikely to have a significant effect on results (this would be less true for some types of environmental policies such as strict caps on the amount of carbon-dioxide emissions, however, EMPAX-CGE is not used to look at such policies). One option to addressing these issues may be to remove the assumption of interregional differences in factor prices and allow wage rates and capital returns to equilibrate across regions as a sensitivity analysis.

### D. Section 6 – Dynamic Version of EMPAX-CGE

***Comment:***

> At the very beginning of this report, I emphasized that this model has an awful lot of really good stuff. As I read through Chapter 6, I found myself repeatedly noting decisions that seemed to be the right ones. I like the inclusion of AEEI. I think the aggregation decisions were generally made properly. And I like the inclusion of adjustment costs. Without them, dynamic models of this type can easily have very unrealistic intertemporal responses.

***Response:***

We are glad that Dr. Ballard likes these model assumptions. Determination of the AEEIs needed to match forecasts for energy consumption by industry and fuel is one of the major challenges of developing a baseline for EMPAX-CGE that reflects expected trends in energy use, without which policy analyses can not be adequately conducted. Also, as Dr. Ballard notes, without mechanisms for controlling the speed of economic adjustments, intertemporal responses in CGE models can be unrealistically fast.

***Comment:***

> On p. 6-9, "The model does not attempt to distinguish between these two sources of growth." That seems a little unfortunate. We can't say anything about the growth of income per capita, unless we know the rate of change in the number of people. Even an arbitrary division might be better. For instance, one could assume that half of the growth is due to population, while the other half is due to productivity.

***Response:***

This issue has not arisen so far in working with EMPAX-CGE, however, it can be addressed relatively easily if necessary. The model currently combines the effects of growth in population and growth in labor productivity to get an overall effective growth rate in labor inputs available for production in the economy. It would be possible to take the current results for labor and divide them by population-growth estimates from the U.S. Census Bureau to determine the implied growth in labor productivity per capita.

## III. <u>Additional Clarifications to Model Documentation</u>

### A. Section 1 – Introduction

***Comment:***

> On p. 1-3, there is a list of some papers that include CGE studies of trade liberalization. Tim Kehoe has a paper (in a forthcoming conference volume that was a Festschrift for Herbert Scarf) that reviews the CGE studies of NAFTA. Now that we are 10 years out from NAFTA, it is possible to get some idea of how the models have performed. I believe the answer is that they tended not to be terribly accurate in their predictions.

***Response:***

We have not seen this paper yet, but will examine it and update the EMPAX-CGE model documentation in the future.

***Comment:***

> At the end of the long paragraph in the middle of p. 1-5, "some have shown that a more complete accounting of environmental regulations, and benefits in particular, may have offsetting effects on social costs." I would like to see further discussion, with specific references.

***Response:***

This sentence was intended to refer to the subsequent paragraph on benefits and other issues, but has been removed from the text as the intention of the sentence was unclear.

***Comment:***

> On p. 1-7, "CES functions are used to describe these utility functions…". See my discussion of homotheticity, above. It is true that the CES form is by far the most popular one for CGE modelers. But that sentence is written as if only CES functions are used, which is not correct.

***Response:***

This sentence has been rewritten since, as Dr. Ballard notes, other types of functions (e.g., translog) can be used in CGE models.

## B. Section 2 – Overview of EMPAX-CGE

***Comment:***

> On p. 2-7, "It is assumed that energy intensities of these detailed manufacturing sectors are equivalent to those of the ones from which they have been disaggregated." This raises in my mind a question about whether the disaggregation actually buys us very much.

***Response:***

Unfortunately, energy consumption data do not exist with sufficient detail to provide information on many smaller industries, necessitating this assumption. The main intention of this disaggregation to smaller industries than covered in other versions of EMPAX-CGE is to allow investigation of policies affecting specific manufacturing groups, not to make generalizations about how a broad energy/environmental policy might have differential impacts on different subcomponents within a manufacturing sector.

### C. Section 3 – EMPAX-CGE Modeling Framework

***Comment:***

> On p. 3-1, in footnote 1, "A number of changes have been made to EPPA since publication of this document, but we do not have enough information to include these updates…". Is there a plan to incorporate these updates at some point in the future?

***Response:***

We can incorporate updates that are described in sufficient detail in future EPPA publications, although use of production functions similar to those in the EPPA model was intended to provide a starting point for EMPAX-CGE from a well-accepted model structure, rather than exactly duplicate the work at MIT (given differences in other areas between EMPAX-CGE and EPPA). To the best of our knowledge, many of the enhancements that have occurred in EPPA are focused on electricity generation. Such updates would be less essential for EMPAX-CGE since it generally relies on EPA's IPM model to determine policy responses in the electricity industry.

***Comment:***

> On p. 3-7, there is a discussion of the nesting structure of fossil fuels. I wonder whether the EMPAX team have given much thought to how the whole story might change if liquefied natural gas allows the creation of a fully integrated world market for natural gas.

**Response:**

To date, we have not focused a significant amount of attention on LNG's potential. Currently, net LNG imports represent only around three percent of domestic supply. This is expected to grow rapidly in the future. However, the extent of this growth appears to be highly uncertain. EIA's *AEO 2003* predicted net imports of LNG to equal around two trillion cubic feet (tcf) by 2025, out of a total domestic supply of over 34 tcf. By the publication two years later of the *AEO 2005*, this had changed to net imports of 6 tcf with domestic supply of around 30 tcf in 2025. If predictions remain at these levels (imports around 20 percent of total consumption), more attention will need to be directed towards LNG in future modeling.

***Comment:***

> On p. 3-14, in footnote 10, "Since EPPA is a recursive dynamic model, it assumes that savings provide utility to households in order to motivate savings for future time periods." I just want to mention that a recursive model could be constructed in a variety of ways. Putting savings in the utility function is one such way, but it is not the only one. The GEMTAP model of Fullerton, Shoven, Whalley, et al., has a structure in which savings are used to buy an annuity of future consumption. Thus, the actual arguments of the utility function are the current consumption composite and the discounted present value of a stream of future consumption. To my mind, that's not the same as putting savings in the utility function,

although the difference may be small as a practical matter.

***Response:***
The wording of this footnote has been changed so it does not appear to imply that the only way to motivate savings in a recursive dynamic model is through adding it to the utility function.

***Comment:***

> Also on p. 3-15, “Following standard conventions used in general equilibrium models,…trade in productive factors is not allowed among regions of the United States or with foreign agents.” I have two issues to raise with this sentence. First, I generally don’t like the part about “following standard conventions”. Our desire is to use the model that is best for our purposes, regardless of whether it is “standard”. In fact, there are certain conventions that are more common than others in the CGE literature, but we can find at least some examples of a very wide variety of conventions. My second point is that this formulation rules out foreign direct investment. I don’t want to push hard on this, but there might be some additional discussion of the issue. There are CGE papers with foreign ownership, including at least a few by Goulder and co-authors. I wrote a paper with Kiwon Kang, which was published last year in Journal of Policy Modeling. It might be of interest.

***Response:***
The text in the model documentation has been changed to remove the use of the phrase “standard conventions,” given the wide range of options available in CGE modeling. A footnote has also been added to clarify that, while EMPAX-CGE does not examine movements of physical capital between the United States and other nations, it is possible in the dynamic version of the model to borrow and lend financial capital over time from other countries through running current-account deficits and surpluses.

Ballard, C.L. and K. Kang. 2003. “International ramifications of US tax-policy changes.” *Journal of Policy Modeling* (25), pg. 825-835.

***Comment:***

> On p. 3-16, “The model solution occurs at a point where the marginal costs of production are equal to the marginal benefits from an additional unit of output…”. That’s true in a model, such as this one, in which all production is competitive. However, imperfect competition is not incompatible with CGE analysis.

***Response:***
We have clarified the text to indicate that this is a condition of perfect competition.

## D. Section 4 – Database and Calibration

***Comment:***

> On p. 4-3, “the value of government tax revenue equals the value of transfers.” That is only true if government does not make any exhaustive expenditures.

**Response:**
The text in the model documentation has been altered to reflect this point.

***Comment:***

> On p. 4-9, I'm not sure I understand the sentence that says "Other sectors in EMPAX-CGE like services are assumed to grow at AEO's GDP growth forecast…". Does this mean that the fraction of GDP in services is assumed to be constant? The percentage in services has actually been increasing for decades, and there is no reason to believe the trend will reverse any time soon.

This sentence in the model documentation was not clear and has been altered. EIA's AEO forecasts provide projections for energy-production and manufacturing growth, but not for services. Growth in services in EMPAX-CGE depends on the availability of future productive labor – based on AEO growth forecasts – after accounting for labor needs of manufacturing industries (for which growth forecasts are available).

## E. Section 5 – Model Calibration and Policy Evaluation

***Comment:***

> On p. 5-2, "adjustments must be made to 'calibrate' a baseline SAM…". This probably sounds like a small distinction of terminology, but, in my parlance, calibration is the process of imposing behavioral parameters on the model. This doesn't occur until after the consistency adjustments have occurred.

***Response:***
EPA chose this particular terminology after discussions about how people viewed the term, but realizes that there are alternative interpretations.

***Comment:***

> On pp. 5-3 to 5-5, there is a discussion of the study by Nestor and Pasurka, which uses data from 1982. I don't know the data sources in this area as well as the EMPAX folks do, so I guess if that is the most recent study available, then that is the best we can do. Still, it's unfortunate that nothing more recent is available. Is it known whether any new data will become available soon?

***Response:***
Unfortunately, we do not know of updates to this information.

## F. Section 6 – Dynamic Version of EMPAX-CGE

***Comment:***

> On p. 6-1, there is a discussion of the differences between recursive models and dynamic models. This model uses a fully dynamic set up. That's OK. I know from my own experience that, if one uses a recursive model, one leaves oneself open to attack from those in the profession who consider anything less than a fully

dynamic model to be terribly gauche. Nevertheless, I think I will at least raise the issue. A dynamic model involves considerably more computational expense, and I sometimes wonder about whether we really learn much. There are clearly situations in which a fully dynamic structure is necessary. But I'm not a purist on this score, partly because I believe that real people in the real world are often quite myopic.

***Response:***
Using intertemporal optimization with foresight certainly increases the size of the CGE model significantly. Whether or not this provides benefits in a policy analysis depends on if people anticipate and prepare for future policies. Given that the types of policies EMPAX-CGE will normally be used to investigate are policies announced today for implementation in the future, we chose to take the expenses and difficulties associated with a full dynamic model. This approach also assists in using results from the IPM model (that also assumes perfect foresight) in EMPAX-CGE.

***Comment:***

On p. 6-7, "The capital stock generated in the model is perfectly malleable across industries…". Thus, there is no industry-specific capital. This is probably an OK assumption. I would just point you to Fullerton's 1982 article in QJE, for a model in which such rigidities are included.

***Response:***
While there is no industry-specific capital, there are adjustment costs that control how fast investment as a whole can respond under a new policy (discussed above in Section II.F on Section 6 of the documentation).

## G. Section 7 – Taxation in EMPAX-CGE

***Comment:***

On p. 7-1, "the structure of a static model is unable to adequately represent all of the distortionary effects associated with taxes…". That's true, but it may be too strong a statement. Even in a static model, labor taxes can capture the distortion of the labor-supply decision, and capital taxes can capture the intersectoral misallocation of capital. In addition, even a dynamic model will not necessarily capture every single distortion. This model does not consider the distortions of organizational form, debt-equity choices, and dividend retention policy that are generated by the corporate tax. See also the discussion of the point made by Ballentine, on pp. 3-4 of this report.

***Response:***
We agree that the statement regarding static models was too strong and have altered the text, and gladly defer to Dr. Ballard on the other points as well.

**Peer Review of**
**EPA's EMPAX Computable General Equilibrium Model**

by
Reviewer:

**Dr. Christoph Böhringer**
**Centre for European Economic Research (ZEW) Mannheim**
**University of Heidelberg**

## I. General Comments and Suggestions Regarding EMPAX-CGE

This subsection includes general comments made by Dr. Böhringer regarding EMPAX-CGE, sensitivity analyses, and suggestions for future model changes. The following two sections subsequently discuss specific comments by Dr. Böhringer in more detail.

### A. Sensitivity Analyses

As noted by all reviewers, Dr. Böhringer suggests conducting sensitivity analyses on important model assumptions. Other modeling suggestions made by Dr. Böhringer may also be best addressed through sensitivity analyses – these cases are noted in the responses to comments below.

***Comment:***

> Functional forms (elasticities): The characterization of consumer preferences as a linear logarithmic function (Cobb-Douglas) is very restrictive and difficult to defend on empirical grounds (although it should be acknowledged that it may be hard to obtain household-specific data for own-price elasticities, cross-price elasticities, or income elasticities).

***Response:***
This component of EMPAX-CGE is probably best investigated through sensitivity analyses on the Cobb-Douglas elasticity assumption. As noted by Dr. Böhringer, obtaining data in this area can be difficult, however, it is feasible to move to a constant-elasticity-of-substitution formulation that is much less restrictive than the current Cobb-Douglas approach. Other alternative formulations such as a Stone-Geary consumption function (with minimum consumption requirements) would also be possible, but again it would be hard to find supporting data.

***Comment:***

> Baseline calibration: As is widely common in applied general equilibrium analysis, EMPAX-CGE adopts a deterministic calibration procedure to compute the free parameters of functional forms based on observed benchmark data and exogenous elasticities. Due to the reliance on exogenous elasticity values and a single base-year observation, comprehensive sensitivity analysis on key elasticities (and possibly

> alternative assumptions on economic incentives) should be performed before concrete policy recommendations are derived. In this context, extensions for systematic sensitivity analysis such as Monte Carlo procedures or Gaussian quadrature should be considered in future work. Another critical dimension is the use of the AEEI concept (referring to costless autonomous energy efficiency improvements) and the proper incorporation of different growth rates across regions for a steady-state calibration.

***Response:***
As noted by Dr. Böhringer, EMPAX-CGE is a calibrated (rather than econometrically estimated) CGE model that uses exogenous elasticities around the observed data. This places reliance on the elasticities when estimating results of policies. While Monte Carlo procedures for conducting sensitivity analyses may be impractical, there are several key elasticities that can be examined.

## B. Possible Model Enhancements

***Comment:***

> Market assumptions: EMPAX-CGE model is based on the competitive market paradigm. However, factor markets (e.g. labor markets) and in particular commodity markets for energy-intensive goods may be characterized by imperfect competition. As with initial tax distortions, the existence of market imperfections can substantially change the magnitude and distribution of adjustment costs to environmental regulation.

***Response:***
As noted by Dr. Böhringer, market imperfections can change estimated costs of environmental regulations. These model enhancements can be examined as a possible future extension to EMPAX-CGE. At this point, our model-development goal was to remain as close as possible to model structures used by other well-known applied CGE models (e.g., MIT's EPPA model) so that the model's results would be easier to interpret and place in the appropriate context.

***Comment:***

> Representation of environmental policies: EMPAX-CGE refers to detailed data for the composition of compliance costs to environmental regulation. However, it remains fairly unclear how the expenditure data is linked consistently to technical or behavioral changes (substitution processes) as provided by flexible cost functions or expenditure functions of agents (capturing e.g. fuel-switching or energy-savings). It must be laid how such adjustment processes can be isolated in a consistent way from disposal activities that might be directly incorporated based on expenditure cost. Another option to include bottom-up estimates on abatement costs is the reduced from integration of step-wise abatement costs functions as employed e.g. in the analysis of Non-CO2 greenhouse gases (see e.g. Hyman et al. 2003; Böhringer et al. 2004a).

***Response:***
Environmental-protection expenditures data are used in EMPAX-CGE to determine how bottom-up cost estimates from other detailed sector-specific models (i.e., IPM and AirControlNet) are incorporated in the EMPAX-CGE production-cost functions. When using cost data from other

models, EMPAX-CGE has to translate variables classified as “capital” and “operations & maintenance” costs into productive inputs used in the CGE model – e.g., manufactured goods, labor, and/or services. These expenditures data are used to handle such translations and the results are then used to adjust the technologies used in EMPAX-CGE to produce the relevant commodities. EMPAX-CGE does not look at non-CO2 gases and does not include these step-wise abatement cost functions.

***Comment:***

According to EPA, a primary field of EMPAX-CGE’s application is the economic impact assessment of National Ambient Quality Standards for particulate matters. From the documentation report, it is not clear how this objective will be achieved with the current model versions. First, there is no detailed information on which particulate matters are incorporated and how emissions are linked to economic activities. Second, there is no discussion of how transboundary air pollution can be dealt with – in essence, there is the need to link EMPAX-CGE to some reduced form dispersion model or to incorporate appropriate emission-imission matrices derived from such models.

***Response:***

EMPAX-CGE is designed to estimate macroeconomic impacts of regulations such as the National Ambient Air Quality Standards for particulate matter. It does not attempt to estimate air pollution emissions directly instead it relies on other models to provide this information and then extends the sector-specific cost estimates from these models to the rest of the economy.

***Comment:***

Linkage to bottom-up engineering information: There is a trade-off between the richness of economic features covered by CGE models and the level of technological detail that might be relevant for an appropriate assessment of energy policies. In fact, energy economy models have in general a very skimpy representation of the energy system: Fuel production and electricity generation is represented by smooth production functions which capture substitution (transformation) possibilities through constant elasticities of substitution (transformation). As a consequence, these models cannot readily incorporate different assumptions about how energy technologies and costs will evolve in the future, and can violate fundamental physical restrictions such as the conservation of matter and energy. Against this background, EMPAX-CGE features a soft-link with the Integrated Planning Model (IPM), a comprehensive model of electricity generation and transmission in the U.S. used by EPA. Although such a soft-link in principle enriches the macroeconomic CGE analysis with engineering bottom-up details, it typically stands out for substantial problems in achieving overall consistency and convergence of iterative solution approaches due to the heterogeneity in complexity and accounting methods across the different soft-linked models. The direct incorporation of bottom-up energy system information into a top-down CGE representation of the non-energy economy might be thus superior for preserving consistency. In fact, more recent developments in solution algorithms for mixed complementarity problems (Dirkse and Ferris 1995, Rutherford 1995) promote such a hard-link between bottom-up system models and large-scale general equilibrium models thereby allowing to exploit the advantages of each model type (Böhringer 1998; Böhringer et al. 2003a,b).

***Response:***
EMPAX-CGE can be linked to the IPM model in a variety of ways, depending on which IPM findings are expected to have the greatest impact on the economy outside of the electricity-generation industry. A "direct incorporation" of IPM's bottom-up energy system information is possible, but would require a wide range of data from IPM that are currently unavailable. A "hard-link" would involve enough simulation results from IPM for EMPAX-CGE to be able to independently arrive at the same conclusion regarding electricity-generation costs, prices, and technology mixes. While the current link with IPM captures features of the electricity industry relevant to extending IPM results to the rest of the economy (electricity generation costs, electricity prices, etc.), if it is feasible in the future we may wish to iterate further between IPM and EMPAX-CGE to ensure that the two models generate consistent information.

## II. <u>Comments and Suggestions by Section and Topic</u>

### A. Section 2 – Overview of EMPAX-CGE

***Comment:***
P.2-2, para.3: 'Households decide among various consumption goods according to a Cobb-Douglas specification.' The assumption of a linear logarithmic function is rather restrictive as this implies (i) unitary own-price elasticity (ii) zero cross-price elasticity (implying that different commodities are grossly independent), (iii) unitary income elasticities (exclusion of inferior goods). A follow-up version of EMPAX-CGE should consider extensions towards more flexible functional forms (nested CES, linear expenditure system) that incorporates empirical evidence on own-price, cross-price, and income elasticities due the extent of data availability. Perroni and Rutherford (1995) lay out non-separable nested CES (NNCES) functions as compromise between flexibility and regularity of functional forms: Empirical evidence of describing substitution possibilities can be increased without loosing regularity.

***Response:***
As noted by Dr. Böhringer, a Cobb-Douglas specification is quite restrictive in its assumptions. As a first step towards the more flexible functional forms mentioned, we suggest moving away from Cobb-Douglas to less restrictive CES formulations as a sensitivity analysis.

***Comment:***
P.2-5, para.3: 'Investment [in the static model] is maintained at current baseline levels.' To simulate the impacts of policy interference on investment activities, investment could be determined by savings decisions of private households following the approach by Ballard et al. (1985): The savings decision depends on the expected rate of return which - in a model with static expectations – is represented by the ratio of the quasi-rent on capital to the cost of a unit of new capital (both evaluated at equilibrium prices). Savings

> preferences should be specified to match a target benchmark (empirical) elasticity of savings with respect to the rate of return.

***Response:***
We will look into this approach. Our intention with the static version of EMPAX-CGE was to isolate the savings decision as much as possible, rather than rely on additional assumptions with regards to how it might shift in the model as a function of other parameter assumptions. To date, the dynamic version of EMPAX-CGE has been used in policy analyses since it provides the best link with other dynamic industry models used by EPA.

***Comment:***

> "The basic assumption in EMPAX-CGE is that all factor and commodity markets are perfectly competitive. Furthermore, capital is assumed to be immobile across regional borders." As the employment impacts of environmental regulation play a dominant role in the policy debate on many industrialized countries, real-world rigidities of the labor market could be represented in reduced form drawing on the concept of a wage curve (see e.g. Böhringer et al. 2003c). Recent modeling of trade policy emphasizes the importance of imperfect competition and economies of scale (see, e.g., Smith and Venables 1988; Willenbockel 1994; Harrison, Rutherford, and Tarr 1996). The standard imperfect competition framework involves fixed costs and an endogenous number of firms due to free entry/exit (N.B.: Free entry/exit joined with fixed costs is the natural assumption to be made in order to explain the number of firms, unless imperfect competition is the result of regulation.). In such a setting, the effect of policy measures works largely through their effect on the number and size of firms and the associated changes in economies of scale. Only recently, applied analysis of environmental taxation in open economies reflects imperfectly competitive good markets, hereby showing that in an open economy changes in economies of scale are also important when the effects of environmental taxation are to be examined (Böhringer et al. 2001). Given empirical evidence on imperfectly competitive market structures for various energy-intensive industries, future extensions of EMPAX-CGE could be directed at a model variant featuring imperfect competition.

***Response:***
Imperfect competition can be examined as a possible future extension to EMPAX-CGE. At this point, our model-development goal was to remain as close as possible to model structures used by other well-known applied CGE models (e.g., MIT's EPPA model) so that the model's results would be easier to interpret and place in the appropriate context.

***Comment:***

> The assumption of EMPAX-CGE on capital immobility (across regional borders) seems unnecessarily restrictive. The model should allow for cross-border capital flows. In a small open economy framework the rates of return on mobile capital would then be determined by the international capital markets (alternative one could include a large open economy setting with elastic foreign capital demand and supply functions). The treatment of capital mobility has important implications for the associated marginal excess burden of capital taxation.

***Response:***

EMPAX-CGE allows flows of financial capital to occur over time with the rest of the world, and we are examining possibilities for removing the small open economy framework. One option to addressing these issues may be to remove the assumption of interregional differences in factor prices and allow wage rates and capital returns to equilibrate across regions as a sensitivity analysis.

## B. Section 3 – EMPAX-CGE Modeling Framework

***Comment:***

> P.3-2, para.2: '… elasticity values and complete CES nesting structures … These features are large based on MIT's EPPA model.' The adoption of MIT's nesting structure and elasticities can not serve as an "excuse" to evade the cumbersome discussion of empirical foundation for key relationships, i.e. the choice of nesting and elasticities regarding empirical evidence on own-price, cross-price and income elasticities from the econometric literature (see also caveats on the simplistic and very restrictive treatment of the consumption side in the executive summary). There is a literature on elasticities and their incorporation in CGE models, for the U.S. most prominently featured by the models of Jorgenson and Wilcoxen (see e.g. Jorgenson and Wilcoxen 2003). In EMPAX-CGE, identical elasticities are assumed rather ad-hoc across all regions and most of the sectors (except electricity generation).

***Response:***

Basing the production functions and associated parameter assumptions in EMPAX-CGE on the EPPA model was intended to provide a well-established point of reference that modelers are familiar with and which can be used as a starting point for interpreting the model's results. Part of this basis involves utilizing the same elasticity assumptions for all regions and many industries in the model. Since the underlying economic data capture existing (and expected future) differences in technology across regions of the United States, we did not feel that it was appropriate to assume there would be significantly different options for technological improvement across the country (this might be more appropriate for an international CGE model). A policy analysis conducted jointly with EMPAX-CGE and Dale Jorgenson's IGEM CGE model is available that illustrates how the assumptions in EMPAX-CGE may, or may not, give different results than an econometrically-estimated CGE model, as referenced in this comment (Appendix E of *Regulatory Impact Analysis for the Final Clean Air Interstate Rule*, http://www.epa.gov/interstateairquality/pdfs/finaltech08.pdf).

***Comment:***

> Given the importance of electricity generation as a major polluting sector an elaborate treatment of power supply options by means of activity (or process) analysis is desirable to enhance the transparency and "credibility" of simulated technological responses in electricity generation triggered by specific regulatory policies. Recent developments in solution algorithms for mixed complementarity problems (Dirkse and Ferris 1995, Rutherford 1995) promote the incorporation of bottom-up system models into large-scale general equilibrium models thereby allowing to exploit the advantages of each model

type (Böhringer 1998). The direct integration of bottom-up energy system information and a top-down representation of the non-energy economy is sometimes referred to as hard-link: The production possibilities in the electricity sector are represented by the convex combinations of discrete technological options instead of top-down smooth constant-elasticity-of substitution (CES) production functions usually employed within the CGE approach (see e.g. Böhringer et al 2003 a,b for recent applications).

P.3-7, para.2: Nuclear/Renewable Electricity Generation -'EMPAX-CGE currently assumes that the amount of nuclear and renewable generation will not be affected by the policies being investigated.' The assumption of exogenously fixed power generation from nuclear and renewables seems rather critical. Environmental regulation – such as stringent climate policies - may substantially alter the relative profitability of alternative power generation options. Therefore, technology choice should be endogenized based on an activity analysis approach. As to baseline calibration of the electricity mix, the question arises what policies are assumed in order to match the EIA's Annual Energy Outlook forecasts. In principle, a sound economic framework calls for endogenous taxes or subsidies to achieve some exogenous target levels.

***Response:***
As mentioned previously, characterizing how nuclear and/or renewable generation might respond to environmental policies using a CGE model is quite problematic, even as a mixed complementarity problem. MIT is at the forefront of research on how to include renewable and advanced generation options in CGE models (see Jacoby et al., 2004). However, a number of uncertainties remain regarding how to incorporate these features in policy investigations. The capabilities of wind and solar power are sensitive to parameter assumptions about how these sources can substitute for other types of generation. Feasible penetration rates for new technologies have to be exogenously assumed by modelers, as do future costs for these technologies. In addition, capabilities of nonfossil generation frequently do not depend solely on economic factors, for example, the building of new nuclear generation depends more on political decisions than economics, and wind/solar generation depends on site-specific characteristics (different classes of wind resources and days of sunshine) that are difficult to capture in a CGE model. Consequently, to avoid these difficulties, nuclear/renewable generation is fixed at levels given in the EIA's *Annual Energy Outlook* forecasts. To the extent that EMPAX-CGE relies on EPA's IPM model to evaluate policy responses in the electricity industry, effects of this approach on model results will be minimized/eliminated.

Jacoby, H.D., J.M. Reilly, J.R. McFarland, and S. Paltsev. 2004. "Technology and Technical Change in the MIT EPPA Model." MIT Joint Program on the Science and Policy of Global Change, Report No. 111. Cambridge, MA. http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt111.pdf

***Comment:***
P.3-12, para.3: 'all consumption goods are combined using a Cobb-Douglas structure to form an aggregate consumption good' As laid out in the executive summary, the treatment of the demand side in EMPAX-CGE is very restrictive. Further work should be dedicated to employ more flexible functional forms to reflect empirical evidence on consumer preferences.

***Response:***
This is an area we feel can be addressed through sensitivity analyses. A Cobb-Douglas structure is not necessary to find a model solution so there is flexibility in choices of elasticity values.

***Comment:***

> P.3-13, "Table 3-4: Elasticities Related to Household Consumption and Trade" - The empirical background for the choice of Armington elasticities (of substitution and transformation) is missing. The GTAP project (http://www.gtap.agecon.purdue.edu/) may provide some guidance on the choice of trade elasticities – otherwise some literature research would be desirable.

***Response:***
The Armington elasticities in EMPAX-CGE are based on MIT's EPPA model. Sensitivity analyses can be conducted upon them to determine impacts of specific assumptions across a range of estimates. For small changes in goods prices, these trade elasticities will not significantly affect model results, but for larger changes they will increase in importance.

***Comment:***

> P.3-14, para.2: '... ownership of natural resources and the capital embodied in nuclear/renewable electricity generation are spread across the country, based on each region's share of total national income.' Given the rather detailed representation of households in the static model to accommodate incidence analysis it would be desirable to have a less ad-hoc mapping of assets in nuclear/renewable electricity generation.

***Response:***
It would be desirable to have a more detailed matching between households and ownership of various income streams. However, we are not aware of data sources that could improve this matching, given how capital markets and company stocks spread ownership across the country. To date, the focus of EMPAX-CGE analyses has not been on distributional issues.

***Comment:***

> P.3-15, para.2: 'Following standard conventions used in general equilibrium models, factors of production are intersectorally mobile within regions, but trade in productive factors is not allowed among regions of the United States or with foreign agents. This assumption is necessary to calculate welfare changes for representative households in each of the 10 regions in EMPAX-CGE. It is also currently assumed that policies investigated by EMPAX-CGE do not influence world prices of goods. (This assumption could be changed to incorporate foreign export demand and import supply elasticities.)' The assertion that capital immobility would be necessary for tracking down welfare changes is wrong. Instead the modeling of cross-region capital flows (investment) would provide policy relevant insights in particular with respect to long-term analysis of policy interference. Furthermore, it might be considered whether the small open economy assumption might be dropped for selected markets to accommodate terms-of-trade effects of domestic regulation (e.g. the U.S. may have some monoposony power on oil markets –

see Böhringer and Rutherford 2002 on the importance of indirect terms-of-trade effects in the context of unilateral climate policies).

***Response:***
The text of the model documentation was not clear regarding factor mobility and welfare estimation and has been altered to reflect the fact that assuming capital immobility is not necessary for calculating welfare changes. Although labor is assumed to be interregionally immobile in response to environmental policies, forecasted trends in migration are captured in the baseline data/forecasts of EMPAX-CGE. While it would be possible to add an equilibrating mechanism that allows physical labor to shift among regions as the result of a policy, calculation of the welfare effects on household(s) in each region would be impractical as the size of the household(s) in each region would have changed at the same time that the incomes of individuals remaining in a region changed. To date, as EMPAX-CGE has been used to investigate policies resulting in very small changes in wage rates, precluding migration is unlikely to have a significant effect on results (this would be less true for some types of environmental policies with more extreme impacts of policies). Sensitivity analyses may be an option for addressing capital mobility by removing the assumption of interregional differences in capital prices and allowing capital returns to equilibrate across regions.

***Comment:***

P.3-15- It should be clarified to what extent the current framework allows for equal-yield policy simulations. What are the equal-yield tax instruments to recycle additional revenues from environmental taxes in order to investigate the prospects of a double dividend from environmental taxation?

***Response:***
To date, policies with environmental taxes have not been addressed using EMPAX-CGE. In the future in cases where tax revenues are generated, they will be returned to households in a non-distortionary lump-sum fashion after the government retains enough revenues to hold its expenditures constant (assuming the particular policy does not specify another approach). If a policy specifies handling tax revenues in a manner that could potentially result in double dividends (i.e., using environmental taxes to lower capital or labor taxes), the existing constraint in the model holding the size of government expenditures constant through lump-sum taxes would be altered to hold it constant through adjusting capital or labor tax rates.

## C. Section 4 – Database and Calibration

***Comment:***

P. 4-9: ‘Combining the economic and energy data’ Reconciliation of monetary flows of the national input-output tables with physical flow energy in production sectors and final demand often reveals substantial price differences for the same fuel inputs across different sectors and countries. The differences can be explained in part by price differentiation on energy markets and by national or regional regulation (e. g., coal subsidies). In various cases the implicit prices may deviate significantly from official reports on market prices without a satisfactory explanation, and these discrepancies call for further study. In short, the problem of reconciling physical energy flow data with economic input-output data is vexing yet widely ignored by economic model-builders working on energy regulation issues. Within the GTAP-E project (http://www.gtap.agecon.purdue.edu/), partly supported by EPA, standard procedures for data reconciliation have been developed that are in use for EMPAX-CGE. However, the standard routines targeted at the sectoral and regional disaggregation level of GTAP can not account for specific national or regional circumstances such as market power or specific regulatory measures. Since the proper incorporation of energy market data is crucial for many issues that EMPAX-CGE aims to investigate a discussion to what extent the standard GTAP routines are appropriate would be desirable.

***Response:***
Procedures used in EMPAX-CGE to reconcile the economic data with energy data in physical units and monetary terms are similar to those used in the GTAP-E project. Our approach follows Rutherford and Paltsev (2000), which maintains the energy data and adjusts the economic data as necessary to balance the SAM used in the model. This is somewhat different that the approach used by GTAP, which adjusts both the energy data and the economic data to achieve the balance.

Rutherford, T.F., and S.V. Paltsev. 2000. "GTAP-Energy in GAMS: The Dataset and Static Model." University of Colorado at Boulder, Working Paper 00-2.

## D. Section 5 – Model Calibration and Policy Evaluation

***Comment:***
P. 5-1 In quantitative policy analyses, the effects of policy interference are measured with respect to a reference situation - usually termed business-as-usual (BaU) - where no policy changes apply. When the potential effects of some policy measure should be simulated, information on the future BaU development is required. Apparently, the BaU projections are a crucial determinant for the overall magnitude and distribution of adjustment costs For concreteness, exogenous climate policy constraints such as the Kyoto emission reduction targets will bind future economies the more, the higher projected BaU growth in GHG emissions. Substantial differences in model-based analysis can often be traced back to different assumptions about the reference case. Yet, the central role of baseline assumptions in general receives little attention in the literature. Regarding long-term energy or environmental policy analysis, the issue of baseline projections becomes very critical in view of the tremendous uncertainties regarding BaU developments over several decades. Not only is there the question why one baseline should be preferable over another, but often projections based on partial equilibrium analysis (or expert judgments) stand out for large internal inconsistencies. Therefore, a careful documentation of the baseline calibration is a conditio-sine-qua-non for the interpretation of results. Furthermore, some generic set-up to run sensitivity analysis on alternative future developments seems desirable. Against this background, Chapter 5 should be more explicit on the challenges of model calibration and how these challenges are handled.

***Response:***

The baseline, or BaU energy forecasts are very important when examining energy and environmental policies since initial energy consumption will have significant impacts on costs of policies leading to reductions in energy use. Energy consumption projections are taken from EIA's *Annual Energy Outlook*, discussed in Section 4. EMPAX-CGE does not look at GHG emissions and so does not focus on BaU emissions as would be necessary to examine climate-change mitigation policies such as the Kyoto Protocol.

***Comment:***

> P.5-1 - The procedure most commonly used to select parameter values is known as calibration (see Mansur and Whalley 1984). Calibration of the free parameters of functional forms requires a consistent one year's data (or a single observation represented as an average over a number of years), together with exogenous elasticities that are usually taken from literature surveys. The calibration is a deterministic procedure and does not allow for a statistical test of the model specification. The one consistency check that must necessarily hold before one can proceed with policy analysis is the replication of the initial benchmark: the calibrated model must be capable of generating the base-year (benchmark) equilibrium as a model solution without computational work. Due to the reliance on exogenous elasticity values and a single base-year observation, comprehensive sensitivity analysis on key elasticities (and possibly alternative assumptions on economic incentives) should be performed before concrete policy recommendations are derived. One approach to systematic sensitivity analysis is to conduct Monte Carlo simulations where values for key elasticities (e.g. trade elasticities, energy demand elasticities and fossil fuel supply elasticities) are drawn e.g. from uniform probability distributions around the model central values (see e.g. Böhringer and Vogt 2003). The sensitivity analysis may then include the core (central case) values together with the mean and the median as well as the 5 % quantile and 95 % quantile. Such statistics provide useful insights into the robustness of model results. An alternative to the Monte Carlo approach for systematic sensitivity analysis is Gaussian quadrature, especially if evaluations of large-scale models are time-consuming. Compared with Monte Carlo, Gaussian quadratures provide good approximations of means of model results and associated standard deviations while using substantially fewer model evaluations (see Arndt 1996). Hertel et al. (2003) apply this technique to the analysis of the Free Trade Agreement of the Americas (FTAA) based on the GTAP computable general equilibrium model of global trade.

***Response:***

After calibration, EMPAX-CGE replicates the base-year equilibrium as a model solution with computational work. We agree that sensitivity analyses will be important when interpreting model results regarding policies. A full Monte Carlo approach is probably not necessary for the types of policies investigated to date, which have small macroeconomic impacts compared to climate-change mitigation policies, but there are several key elasticities on fuel switching, etc. that can have important impacts on results.

***Comment:***

P.5-2 - The report stresses the strength of EMPAX-CGE to build on detailed data for the composition of compliance costs, i.e. a MAKE-matrix for sectoral environmental protection expenditures. However, it remains fairly unclear how the expenditure data is linked to the traditional CGE setup in a consistent way. Typically, environmental regulation involves technical or behavioral possibilities to reduce emissions per unit of activity that imply substitution processes in cost functions or expenditure functions of agents (capturing e.g. fuel-switching or energy-savings). It is conceptually not straightforward how to decompose such adjustment processes from disposal activities that might be directly incorporated based on expenditure cost data. Bottom-up cost data may be directly incorporated into multi-sector, multi-region CGE models through exogenous coefficients or estimated “meta”-functions. A prominent example is the representation of complex abatement options for non-$CO_2$ greenhouse gases which are not modeled in detail (see e.g. EPA bottom-up data in the EMF 21 exercise http://www.stanford.edu/group/EMF/research/). Instead, exogenous marginal abatement cost curves for emissions are based on sophisticated bottom-up analysis are employed (Hayhoe et al. 1999; Reilly et al. 1999; Böhringer et al. 2004). The approach adopted by EMPAX-CGE seems to resemble work by Fæhn and Holmøy (2003) who link consumption of material goods to solid waste generation for deposition, or Xie and Saltzman (2000), who use an environmentally extended social accounting matrix to identify three general types of pollution (waste water, smog dust, and solid waste) and include the respective pollution-abatement sectors. As a further useful reference, Strutt and Anderson (2000) employ a comprehensive environmental input-output data set complemented by case studies to project anticipated changes in technology in order to assemble a matrix of environmental coefficients over time. Based on these coefficients they estimate the environmental impact per unit of economic activity in each sector and project environmental outcomes for water use, water pollution and air pollution. Finally, this sections should clarify which particulate matters (emissions) are explicitly (and how) incorporated in the present version of EMPAX-CGE. How is the relationship for trans-boundary pollution problems accounted for?

***Response:***

EMPAX-CGE does not track emissions associated with manufacturing or electricity generation – it relies on other models such as IPM and AirControlNet to handle such issues. The environmental protection expenditures data are used to determine how costs from these other models are incorporated in the EMPAX-CGE production-cost functions. When using cost data from other models, EMPAX-CGE has to translate variables classified as “capital” and “operations & maintenance” costs into productive inputs used in the CGE model – e.g., manufactured goods, labor, and/or services. The MAKE-matrix is used to handle these translations and the results are then used to adjust the technologies used in EMPAX-CGE to produce the relevant commodities.

## E. Section 6 – Dynamic Version of EMPAX-CGE

***Comment:***

P.6-2 / p.6-9 - In applied policy analysis, growth rate projections typically differ across regions. In this situation, the baseline equilibrium must be computed. When regions grow at different rates, there may be a substantial induced change in the terms of trade, and this makes it difficult to calculate a baseline growth path that matches economic targets such as investment and consumption. A pragmatic means of dampening changes in terms of trade for differentiated baseline growth rates is to adjust Armington share parameters over time in proportion to potential GDP. As a country grows faster, it is assumed that this produces an autonomous (non-price induced) change in the demand for the country's goods both in the home country as well as for the rest of the world. Since there is no change in the efficiency as a result of these demand adjustment, at base year prices, the cost of a unit of the aggregate commodity remains unchanged, even though there may be a substantial difference in the relative growth rates across countries (see Böhringer et al. 2004 for a recent implementation of this approach). It would be desirable that the documentation of EMPAX-CGE is more explicit on how they handle projections of regional GDP and (even) sectoral outputs.

***Response:***

We will examine this issue when we update the EMPAX-CGE economic and energy data in the future. Unlike in cases where an international model has countries growing at substantially different rates, regions within the United States do not generally experience large enough differential growth rates for this to be an issue.

***Comment:***

P.6-4/ p. 6.9- AEEI factors represent energy efficiency improvements in addition to energy demand reductions caused by changes in energy prices. Reasons for AEEI may include research or changes in public standards as sources of efficiency improvements. A blunt application of AEEI scaling factors for energy demands overlooks potentially important "rebound" effects: If energy efficiency improvements were costless, energy-intensive goods become cheaper and thus general equilibrium feedbacks may lead in total to higher than lower energy use. Hence, AEEI should be used to re-scale the baseline cost shares in the production of the electric and non-electric energy aggregates. In order to preserve the initial total costs per unit of production, one should inversely adjust the capital cost shares, meaning that energy efficiency improvements are not costless but are linked to the increased use of capital services. Against this background, the EMPAX report should be more critical and elaborate on how the concept of AEEI is implemented (see suggestion above). Furthermore, it should be made explicit how baseline projections for nuclear and renewable sources are linked to potential policy constraints in the baseline such as nuclear phase-out policies or subsidy programs for renewables. Incorporation of the economic reasoning behind the baselines can crucially affect the costs of future environmental regulation (vis-à-vis blunt "blending" constraints as often employed in mathematical programming bottom-up models of the energy system). The current approach in EMPAX-CGE where exogenous fixed factors (see p.6-10, para.3) control the baseline for nuclear and renewable sources is relatively ad-hoc.

***Response:***
The text in the model documentation has been clarified to address this point. When calculating and applying the AEEI scaling factors needed to match energy-consumption projections, EMPAX-CGE re-scales industries' baseline cost shares for non-energy inputs to production to account for the fact that energy-efficiency improvements are not costless and can require use of additional non-energy inputs. In most cases this can be accomplished solely through adjusting capital-cost shares, in cases where initial capital shares are too small for this to be sufficient or provide a stable equilibrium, cost shares for other productive inputs and materials are also re-scaled. Given the complications arising when attempting to estimate responses of nuclear and renewable generation to policies (although as noted EMPAX-CGE is not designed to look at policies affecting carbon-dioxide emissions), we prefer to rely on EPA's IPM model to estimate these changes and simply apply them to EMPAX-CGE.

***Comment:***

> p. 6.9 'Generation of a Baseline Model Solution' The treatment of foreign and public closure in the intertemporal setting should be discussed as the specific design - e.g. periodic versus intertemporal balance-of-payment or equal-yield constraint) – has potentially non-negligible implications on scenario results.

***Response:***
Text has been added to Sections 2.6 and 3.3 to cover these points. In all versions of EMPAX-CGE, government purchases (as measured in real terms using the cost of obtaining the desired bundle of goods) are maintained through non-distortionary lump-sum transfers between the government and households. The dynamic version of the model also includes an intertemporal balance-of-payments constraint that allows financial capital flows through borrowing and lending over time, as reflected in current account deficits and surpluses.

## F. Section 7 – Taxation in EMPAX-CGE

***Comment:***

> P.7-3, para.3: '…EMPAX-CGE treats FICA as an ad-valorem tax on labor and Social Security benefits as lump-sum transfers to households.' This assumption seems critical in particular with respect to an intertemporal setting as there is no internal link between how much "taxes" are paid and what can be claimed as benefits. FICA might be better treated as part of savings or insurance mechanisms.

***Response:***
To adequately account for how FICA functions as a savings mechanism, an overlapping-generations model would probably be required, which tracks each generation's decisions regarding savings and dissavings. This type of structure is beyond the scope of the current model and so we have chosen to model FICA in a more straight-forward fashion that ensures we are accounting for the distortionary effects of these labor taxes and how they may interact with environmental policies.

***Comment:***

P.7-17, 'Table 7-12: MCPF and MEB Estimates in the Dynamic Version of EMPAX-CGE' The differences in marginal excess burden between taxes appear relatively small. A crosscomparison against published MEBs (or MCPFs) would be desirable. As noted before, the treatment of capital mobility is crucial for the simulated MEBs of taxes on capital. At least, in the dynamic mid-term perspective the assumption of regionally immobile capital is not very credible.

***Response:***

There is a footnote referring to the relevant literature in this section. Developing a cross-comparison of published estimates beyond those noted in the documentation and this cited literature would not be overly informative since these studies generally present a range of findings depending on labor-supply elasticities and other factors, as discussed in the text.

## III. <u>Additional Clarifications to Model Documentation</u>

### A. Section 1 – Introduction

***Comment:***

P.1-2, para.3: 'solution prices that conform to Walras' law (expenditure equal income for any set of prices)' More specifically, Walras' law – as a consequence of the assumption of non-satiation states that for any set of prices the value of the sum of excess demand over all markets is zero.

***Response:***

The text of the model documentation has been altered to reflect this comment.

***Comment:***

P.1-2: 'Description of the basic competitive Arrow-Debreu model' In the "History of CGE Modeling" it might be mentioned that meanwhile many large-scale CGE models extend the basic competitive Arrow-Debreu model by price and quantity constraints which reflect real world rigidities. The quoted advances in numerical simulation techniques also include solution techniques for mixed complementarity problems (MCP) which provide a general framework for stating economic market equilibrium problems (see Rutherford 1999; Dirkse and Ferris 1995). The MCP format accommodates constraints on decisions variables which are a typical on for many real-world markets: As to price constraints, one could consider price caps for regulated utilities or lower bounds on wages emerging from union-bargaining. As to quantity constraints, examples include administered bounds on the share of specific energy sources (e.g. renewables or nuclear power) or target levels for the provision of public goods. Associated with these constraints, are complementary (dual) variables. In the case of price constraints, a rationing variable applies as soon as the price constraint becomes binding (e.g. the unemployment rate in the case of minimum wages). In the case of quantity constraints, a complementary endogenous subsidy or tax is introduced (e.g. an equal-yield tax in order to warrant constant public good provision for revenue-neutral tax reforms). Furthermore the "History of CGE Modeling" should include a section dealing with the increasing number of model applications featuring imperfect competition with monopoly markups, monopoly with increasing returns to scale due to fixed costs, oligopoly (with/without free entry), or monopolistic competition with free entry (product differentiation).

***Response:***
EMPAX-CGE uses an MCP format and discusses these types of issues further on in the model documentation.

***Comment:***

P.1 - The description of the use of CGE models in environmental policy could be elaborated (to show the potential for future extensions of the EMPAX model) based on more recent survey articles including e.g. those of Conrad (1999, 2001).

***Response:***
The text of the model documentation has been altered to include these references.

***Comment:***

P.1-4, para.2: ‘To estimate the social costs of environmental programs, one must capture the sum of direct, indirect, and induced costs.’ The classification of economic effects induced by policy interference into “direct, indirect, and induced” is confusing. The common classification is restricted to direct effects (generally captured by partial equilibrium analysis) and indirect effects (including market interaction and income effects as generally captured by general equilibrium analysis)

***Response:***
This phrase refers to terminology normally used in input-output modeling. We have noted this in the text, but prefer to keep the terminology as input-output modeling has been used by EPA in the past.

***Comment:***

P.1-5, para.2: ‘Discussion of the role of initial tax distortions’ -The exposition should not only be restricted to the issue of tax-interaction effects but also discuss the importance of revenue-recycling effect. In other words, some concise representation of the double-/triple-dividend debate may be in place: : Concerns about adverse impacts of environmental taxes on employment motivate the recycling features of environmental tax schemes in various OECD countries: additional tax revenues are used to cut labor costs. Given persistently high unemployment rates in OECD countries, such a green tax reform is hoped to yield a "double dividend" in terms of both reduced emissions and increased employment (see e.g. Pearce 1991 or Repetto 1992). Moreover, as marginal tax rates on labor are high relative to other taxes in most OECD countries, the swap of green taxes for labor taxes suggests potential welfare gains from a more efficient tax system, sometimes referred to as the third (efficiency) dividend of a green tax reform (see Böhringer et al. 2003c for an interactive simulation model to study issues of multiple dividends).

***Response:***
While EMPAX-CGE is designed to maintain government purchasing power in a variety of ways, in analyses to date this has been accomplished through non-distortionary means, rather than adjusting tax rates and thus affecting tax distortions in the economy. Revenue recycling and the possibilities for double dividends are most likely to arise under GHG policies, which can raise substantial amounts of environmental-tax revenue. EMPAX-CGE however, is not currently intended to look at these types of policies.

***Comment:***

> P.1-6, para.1 (and at various other places in the model documentation): 'CGE models are able to estimate ...' Although it seems like a subtlety – the term "estimate" should be rather used with caution when referring to policy analysis based on calibrated models in order to avoid confusion or complaints on behalf of econometricians. It is recommended to replace the term "estimate" by the term "simulate".

***Response:***
We agree with this point regarding terminology, but prefer to use the word "estimate" to be consistent with past EPA work.

***Comment:***

> P.1-6, 'Figure 1-1: Circular Economic Flows within CGE Models' The exposition may revert the arrows for factor and good demands (purchases). In this way, it would become more transparent that supply and demand "constitute" the markets for goods and services as well as factors with prices equilibrating both market sides. See for illustration the Figure below which furthermore entails the price system and how markets/prices may be affected by governmental tax policy interference.

***Response:***
The figure provided by Dr. Böhringer is much more detailed and complete than the one in the model documentation. Our intention was to provide an overview of the economic system in a CGE model so we have chosen a less-detailed representation to simplify the discussion.

***Comment:***

> P.1-6, para.3: 'The "general equilibrium" component ....' The equilibrium paradigm should be phrased more general. Instead of 'The "general equilibrium" component of CGE modeling requires that all sectors in the economy must be in balance and all flows must be accounted for.' one may better state 'The "general equilibrium" approach typically implies comprehensive market coverage and balance.' followed by a footnote which points out that CGE model developments increasingly account for price rigidities that may lead to excess supply such as involuntary unemployment or unused capacities (see e.g. Böhringer et al. 2004b).

***Response:***
The text of the model documentation has been altered to reflect this comment.

***Comment:***

P.1-6, para.3: '... must be purchased by firms or consumers with the United States...' Skip 'within the United States'.

***Response:***

We have left this text in the document because the rest of the sentence refers to foreign trade and distinguishes between the United States and other countries.

***Comment:***

P.1-7, para.4: 'Because utility functions employed by CGE models are based on neoclassical economic theory...' Re-phrase 'Because of the explicit treatment of consumer preferences (in terms of utility or expenditure functions)..'

***Response:***

The text of the model documentation has been altered to reflect this comment.

***Comment:***

P.1-8, para.5: '...dynamic regional version to four households ...' Skip 'for a total of 20 households' in the last line.

***Response:***

The text of the model documentation has been altered to reflect this comment.

## B. Section 2 – Overview of EMPAX-CGE

***Comment:***

P.2-1, para.3: 'These data are contained in a social accounting matrix ...' The description of the contents of a social accounting matrix should be more comprehensive (see e.g. p.2-8 'SAM shows values of output, payments by firms for factors of production and intermediate inputs, household income and consumption, government purchases, investment, and trade flows. It characterizes existing production technologies available to industries in the economy by showing what inputs are used to produce output.'). A reference to the seminal paper by King (1985) might fit.

***Response:***

This reference has been added to the model documentation.

## C. Section 3 – EMPAX-CGE Modeling Framework

***Comment:***

P.3-1: 'Three components of a CGE model influence estimated policy effects: …' Worthy of mention with respect to the determinants of CGE results is the importance of behavioral and institutional assumptions that may imply market distortions and market imperfections (e.g. monopoly power, environmental externalities, knowledge externalities, etc.).

***Response:***
The text of the model documentation has been expanded to acknowledge these points.

***Comment:***

> P.3-11, para.1: ‘In the absence of other information, this transformation elasticity is assumed to be Cobb-Douglas, which is the typical default assumption in CGE model.’ The “default” assertion is rather arbitrary and should be skipped.

***Response:***
The text of the model documentation has been altered to reflect this comment.

***Comment:***

> P. 3-14, para.2: ‘(savings do not usually pay a role in static models)’ This assertion is misleading as there are several static models featuring endogenous savings decisions (e.g. Ballard 1985).

***Response:***
As noted by Dr. Böhringer, this assertion is too broad and has been removed from the text.

**D. Section 4 – Database and Calibration**

***Comment:***

> P.4-1, para.3: ‘I/O tables, which ignore income, ...’ This is not quite correct. I/O tables contain information on factor earnings (in the 2nd quadrant) but do not provide detailed information on income flows and transfers which are covered by the 4th quadrant of an extended I/O table (i.e. a SAM).

***Response:***
The text of the model documentation has been altered to reflect this comment.

**E. Section 5 – Model Calibration and Policy Evaluation**

***Comment:***

> P. 5-2, para 3: ‘Model development would not have been possible without the MPSGE software.’ This statement is misleading. MPSGE is nothing else than a meta-language under GAMS that relaxes the pain (and reduces potential errors) in writing down potentially complex forms of nested CES cost and expenditure functions. It provides a non-technical way of stating zero-profit conditions and income constraints, while market clearance conditions are automatically derived given the statement of preferences, technologies, and endowments. However, in principal, the whole MPSGE model could be written in plain algebra although this can be a rather tedious and error-prone process. Note that functional relationships that deviate form the standard simplistic Arrow-Debreu framework must be often written in plain algebra also under MPSGE in terms of so-called auxiliary constraints (a primer on the mixed complementarity problem approach to CGE modeling is given by Böhringer et al. 2003).

***Response:***
The text of the model documentation has been altered to reflect this comment. Model development would have been possible without the MPSGE software, but would have been substantially more difficult.

## F. Section 6 – Dynamic Version of EMPAX-CGE

***Comment:***

> P. 6-1, para 3: 'This is in contrast to other dynamic CGE models that assume savings and investment are based only on the current time period's characteristics and that households are not forward looking.' The phrasing should acknowledge that meanwhile a bulk of intertemporal CGE models (with perfect foresight) exist that are designed to investigate the adjustment path to environmental regulation (see e.g. the set of models employed in EMF-19, Weyant 1999).

***Response:***
The text of the model documentation has been altered to reflect this comment. The text only intended to draw a distinction between perfect foresight models and recursive dynamic models.

***Comment:***

> p. 6-4, paragraph 2: 'Not incorporating these changes would cause the model to estimate unrealistically large costs for energy/environmental policies because their initial energy use would be too high'. This assertion is not necessarily true. In fact, a major determinant of a country's adjustment costs to emission constraints is its baseline economic development. The reference (business-as-usual) scenario determines baseline emission growth, which in turn implies the effective cut-back requirement with respect to an exogenous emission target profile. A larger required reduction in emissions as a percentage of baseline emissions leads c.p. to higher abatement costs. The magnitude of the inframarginal welfare loss depends on a number of factors, such as the effective reduction requirement with respect to the baseline and the initial energy (emission) intensities. The ordering of inframarginal abatement costs may be reversed as compared to the ranking in marginal costs due to differences in energy intensities (see Böhringer and Welsch 2004).

***Response:***
The text of the model documentation has been altered to reflect this comment. The intention of the statement was to indicate that total costs of environmental policies could be too high if baseline energy consumption was incorrect, not to state that marginal costs of reducing emissions by one "unit" would be affected by total baseline energy use.

**Peer Review of**
**EPA's EMPAX Computable General Equilibrium Model**


by
Reviewer:

**Dr. Hillard G. Huntington**
**Energy Modeling Forum**
**Stanford University**
**Stanford, CA**


## I. General Comments and Suggestions Regarding EMPAX-CGE

### A. Types of Policy Analyses

This subsection includes general comments made by Dr. Huntington regarding CGE models, the types of policies that are suitable for CGE analyses, and expresses his desire to see results from EMPAX-CGE in order to better evaluate its capabilities and responses to policies. The following section subsequently discusses specific comments by Dr. Huntington in more detail.

***Comment:***

The CGE approach has many advantages for evaluating the economic effects of environmental policy. Consistency with economic theory allows for a straightforward application to determine how policies affect societal welfare (consumer and producers surpluses). Many economists prefer the CGE approach because they believe that policymakers should choose policies based upon the effects on the general population's welfare rather than upon the total goods and services produced by the economy, as measured by the Gross Domestic Product (GDP). However, the system can also report more standard economic impacts, such as the change in GDP, because the model is based upon standard economic data.

CGE models however also have some important limitations for policy analysis. First, detailed systems like EMPAX-CGE contain many parameters that can significantly affect how variables respond to changes in prices and policies. Many CGE models select these parameters, based upon what the researchers think are appropriate for the analysis. These systems are calibrated frameworks, as compared with estimated frameworks that seek to derive responses based upon historical experience. The main concern is that these parameters may be significantly different than the econometric literature. As an example, the parameters used in many models of international trade are often considerably larger than those estimated by econometricians. For example, see Shiells and Reinert, (1993) and Marquez (2002). This difference will be a significant problem for the policymaker who wants reliable estimates of the impacts.

A second problem is partly related to the issue of choosing parameters. Many economists do not use CGE frameworks for forecasting the national economy partly because they do not trust that these models capture some important problems and rigidities. Calibrated models may contain parameters that are not particularly well suited for forecasting. In addition, the CGE framework usually assumes that the economy is perfectly competitive and has considerable flexibility to reallocate factors and products to different sectors. Institutions that limit this flexibility, and sometimes contribute to problems like sticky prices and unemployment, are difficult (although not impossible) to represent adequately in CGE systems.

In general, however, the CGE approach is probably the appropriate framework for this particular set of policy issues. RTI International does a very effective job in developing the CGE structure and merging data from available and credible sources into a framework that is economically consistent. As argued below, however, it is extremely important to evaluate the calibration parameters and to understand the broad behavioral responses of the total system.

***Response:***
As discussed by Dr. Huntington, CGE modeling has many advantages for policy analyses, keeping in mind the types of issues and assumptions to which such models are sensitive. The overriding goal during the development of EMPAX-CGE was to base the model on accepted CGE modeling practices and parameter assumptions, along with energy data and forecasts from established government sources (EIA). Around this framework, additional information on the model's policy results (with sensitivity analyses) will be helpful when evaluating EMPAX-CGE. While the model documentation was under review, no policy analyses were available to provide to the peer reviewers. However, there is now an analysis of the Clean Air Interstate Rule available (http://www.epa.gov/interstateairquality/pdfs/finaltech08.pdf) that may address these types of concerns. This analysis presents results from EMPAX-CGE in conjunction with results for the same policy from the well-known IGEM model developed by Dale Jorgenson and others. We would refer interested parties to this information.

***Comment:***
The front section of the report should have spent more time in defining examples of the policy decisions that would be modeled. Since prices are so prominent in the CGE approach, it seems likely that emissions fees and other economic instruments that influence the cost of different fuels will be important candidates for review by the model. There are, however, many methods for implementing emissions fees, including the allocation of emissions rights and whether allocations can be traded within the economy. The U.S. Energy Information Administration (2001) provides a useful discussion of how these additional environmental markets are represented in their analyses of the impacts of incorporating limits on greenhouse gas emissions and other pollutants like sulfur dioxide, nitrogen oxides and mercury.

Noneconomic government mandates would undoubtedly be more difficult to represent than the economic instruments. Governments often adopt physical rather than economic limits in regulating pollutants. One example is a rule that requires that emissions in every power plant must be reduced by the same percent, regardless of how dirty the plant was. The documentation should discuss how different policies could be incorporated and whether the approach represents economic instruments better than mandatory physical limits without trading features. The choice of instruments may influence the costs of environmental regulations as much as the severity of the constraint.

***Response:***
The model documentation to date does not attempt to list the types of policies that EMPAX-CGE will be used to investigate because a wide range of feasible policies can be evaluated. For policies that might initially appear ill-suited for a CGE analysis, we believe that linkages between EMPAX-CGE and other detailed sector models can be developed that allow us to take industry-specific findings and use the CGE framework to extend these results to the rest of the economy (e.g., the current linkages with IPM and AirControlNet).

***Comment:***

> A standard approach useful for describing any model would include a front section that describes the input variables that drive the system (e.g., the growth rate in labor supply and productivity) and the key output variables that describe the impacts (e.g., energy prices and emissions levels). This information could be easily placed into a table, which also included such key elements as regions, time horizon, and principal applications. Although this is a presentation issue, it can be very important for communicating with potential model users.

***Response:***
At this point, we have not attempted to provide additional overview information in the model documentation as this paper is intended to provide the level of detail necessary for economists to evaluate policy findings of EMPAX-CGE. Each policy analysis conducted with the model contains an overview and summary description of the types of information mentioned in this comment.

### B. Sensitivity Analyses

Along with Dr. Huntington's comments regarding policy analyses, he also noted instances in which either model alterations or sensitivity analyses would be helpful in interpreting results from EMPAX-CGE. These comments, which are similar to those mentioned by other reviewers, are discussed in the comments below and include items such as choice of elasticities of substitution (especially in household consumption) and mobility of factors of production (capital and labor).

## II. Comments and Suggestions by Section and Topic

### A. Section 1 – Introduction

***Comment:***

> The documentation explains the advantages of the CGE approach and the basic methodology very well. Economists familiar with the approach will follow this discussion easily. Policymakers who are unfamiliar with the approach may have a more difficult time reading the documentation.

***Response:***
The goal and intended audience of the model documentation is to provide economists with enough details about EMPAX-CGE to allow them to evaluate policy results from the model in the future. As such, it is written in a style similar to documentation of other CGE models and, aside from the introductory section, assumes a certain degree of familiarity with economic modeling. Policy analyses conducted with EMPAX-CGE include a summary appendix with an overview of the model intended to address the types of questions more likely to be raised by policymakers.

## B. Section 2 – Overview of EMPAX-CGE

***Comment:***

> The elasticities of substitution between energy and value added (approximately 0.5) appear consistent with studies of energy demand (Dahl, 1993) and the analysis conducted by the Energy Modeling Forum (1980). The EMPAX-CGE elasticities occur at the wholesale level and would be higher if measured at the retail level, provided that energy taxes and markups do not change when wholesale costs are increased or decreased. Within a Constant- Elasticity-of-Substitution framework, energy price elasticities will equal the elasticity of substitution, divided by the value share of output that is not allocated to the energy factor. For energy value share equal to 5% or less (as is probably the case), the price elasticities should be pretty similar to the elasticities of substitution for aggregate energy and value-added inputs (labor and capital).

***Response:***
As alluded to in this comment, one of the reasons for relying on production equations from MIT's EPPA model was to ensure that EMPAX-CGE uses a structure suitable for examining energy and environmental policies.

***Comment:***

> Although the detailed information about elasticities in different sectors is useful, the documentation could contribute much more by developing a few summary measures of the aggregate response of the system to changes in a few variables. One example would be to implement a pre-specified change in one of the major fuel prices and report how much the major fuels used change in response. Elasticities provide part of the answer, but the full effect will also incorporate elasticities at different levels and for different clusters of inputs as well as the dynamic response of the energy system to price changes (through such effects as expectations and changes in adjustment costs). Policymakers should want to know how responsive the total system is to changes in key input variables, because this response will reveal a lot about the impacts of the system in more meaningful and realistic policy scenarios.

***Response:***
At the time the model documentation was under review, there were no publicly available policy analyses to provide to the peer reviewers, which makes it difficult to evaluate how a model will response in a policy analysis. There is now an analysis of the Clean Air Interstate Rule available that may address these types of concerns. Appendix E of *Regulatory Impact Analysis for the*

*Final Clean Air Interstate Rule* (http://www.epa.gov/interstateairquality/pdfs/finaltech08.pdf) presents results from EMPAX-CGE in conjunction with results for the same policy from the well-known IGEM model developed by Dale Jorgenson and others. We would refer interested parties to this information.

***Comment:***

> In EMPAX-CGE, agents can optimize over the full horizon and across many different commodities and factor markets at the national level. This same free- flow of commodities and resources, however, is not allowed across regions of the nation. Labor migration and capital mobility do not eliminate regional differences in the returns to either factor. This is a rather interesting constraint. The reasons for postulating open mobility between sectors but not across regions are not obvious. It may be particularly difficult for capital and labor in one sector to move to another sector and begin to produce output at no additional adjustment cost. Industry-specific capital stocks and labor-force skills may prevent the free flow of resources between different industries. On the other hand, there is considerable evidence of labor migration between U.S. regions and interregional capital mobility is widely acknowledged. The approach in EMPAX-CGE is reasonably standard for a CGE system. Allow flexibility first between sectors and then over time. If a CGE model has multiple regions, these separate areas often represent different countries rather than regions within a country. Under those conditions, restricted factor mobility may appear more reasonable. This assumption, however, may be quite different from other regional models of the US, where labor migration and capital mobility often form the essence of regional economic growth.

***Response:***

Migration in response to environmental policies is not allowed in EMPAX-CGE, although forecasted trends in migration are captured in the baseline data/forecasts of the model. While it would be possible to add an equilibrating mechanism that allows physical labor and capital to shift among regions as the result of a policy, calculation of the welfare effects on household(s) in each region would be impractical (or meaningless) as the size of the household(s) in each region would have changed at the same time that the incomes of individuals remaining in a region changed. To date, as EMPAX-CGE has been used to investigate policies resulting in very small changes in wage rates, precluding migration is unlikely to have a significant effect on results (this would be less true for some types of environmental policies with more extreme impacts of policies). One option to addressing these issues may be to remove the assumption of interregional differences in factor prices and allow wage rates and capital returns to equilibrate across regions as a sensitivity analysis.

***Comment:***

> In any CGE system, there will be some sectors where market participants can bid away differences in profits or factor returns and other parts of the economy where constraints disallow such behavior. To allow full arbitrage across all markets can be very burdensome, especially if the model is large.

***Response:***
As noted above, we may wish to consider allowing these interregional differences in factor returns to be "bid away" as a sensitivity analysis.

***Comment:***

> The model uses a Cobb-Douglas specification for final goods (p. 2-2), which means that the share of total expenditures for each commodity remains fixed. Is this assumption made for tractability or for economic accuracy?

***Response:***
The Cobb-Douglas specification for consumption goods was made for simplicity and is not essential for tractability. We would suggest considering including this parameter when conducting sensitivity analyses on policy findings.

***Comment:***

> One crude type is used to produce three different refined petroleum products. In some applications where residual fuel is strongly displaced, there may be reasons to consider several different types of crude oil where one source is heavier than the other.

***Response:***
This point is something we need to bear in mind if examining policies with extreme implications for petroleum refining. Currently, we do not have enough data to make these distinctions among types of crude oils. Our preference for examining policies in which these distinctions could have important effects on model results would be to rely on a petroleum-refining model, similar to our approach with IPM for some types of electricity policies. An aggregated modeling framework such as CGE may not be sufficient to capture all refinery options for producing different types of petroleum products from crude oil.

***Comment:***

> The documentation did not discuss opportunities for technical change in any sector of the economy. Presumably, the calibration of the model with the EIA forecasts may implicitly incorporate technical change in the use of energy. In this respect, some technical change is allowed in defining the reference path of the energy system and the economy, but these trends are not changed in any policy case. This assumption may be perfectly reasonable for many policy interventions that change fuel and capital costs without inducing new processes and techniques. There exists, however, a significant research effort to understand how policies may induce shifts in technology frontiers. Mandated limits may be "technology forcing" in that firms are convinced that they must change their practices from past experiences. Higher carbon prices may induce innovators to find new ways to meet growing demand while limiting carbon emissions. This issue appears particularly important for a model with a horizon that extends through the year 2050.

***Response:***
Calibration to EIA forecasts incorporates the technology changes and energy-efficiency improvements expected to occur in the future in the absence of new policies. Under a new policy, the structure of EMPAX-CGE allows additional technological changes and

improvements, resulting in additional energy-efficiency improvements, to occur. Beyond these improvements, however, the model does not consider potential effects of "induced technological change" (ITC) or "technology forcing" – improvements in technology brought about through the presence of a policy encouraging additional research on cost-effective technologies. Goulder (2004) has examined the implications of ITC and finds that, in climate-change mitigation analyses, its presence can lower the costs of achieving emissions reductions by stimulating additional technological change. However, since EMPAX-CGE already allows for technology and energy-efficiency improvements, this analysis does not allow additional ITC, based in part on concerns expressed in Jacoby et al. (2004) about possible double-counting of potential technology improvements. In general, issues regarding ITC are generally raised in a climate-change mitigation context, where policies can cause significant alterations in technologies, but EMPAX-CGE is not intended to look at these types of policies and instead focuses on policies with substantially smaller economic adjustments.

Goulder, L.H. 2004. "Induced Technological Change and Climate Policy." Pew Center on Global Climate Change Report. http://www.pewclimate.org/press_room/sub_press_room/itc.cfm.

Jacoby, H.D., J.M. Reilly, J.R. McFarland, and S. Paltsev. 2004. "Technology and Technical Change in the MIT EPPA Model." MIT Joint Program on the Science and Policy of Global Change Report #111. http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt111.pdf.

## C. Section 3 – EMPAX-CGE Modeling Framework

***Comment:***

There is a very useful discussion of the production function for electric power and why its specification requires considerable care if the model is to be consistent with heat rates and other constraints in that sector (p. 3-5).

***Response:***

We are glad that this point is clear in the documentation. While EMPAX-CGE is not designed to investigate climate-change mitigation policies that can have significant implications for electricity generation, it is still essential to appropriately characterize this industry for other types of electricity-related policies.

***Comment:***

It is assumed that policies will not influence nuclear & renewable generation (p. 3-7). That may seem appropriate for some environmental controls like sulfur dioxide, but it seems too stringent for situations where significantly higher carbon prices will make both non-carbon sources of electric power much more attractive.

***Response:***

As noted in the responses to Drs. Ballard and Böhringer comments above, characterizing how nuclear and/or renewable generation might respond to environmental policies using a CGE model is quite problematic. To the extent that EMPAX-CGE relies on EPA's IPM model to evaluate policy responses in the electricity industry, effects on model results of assuming fixed nuclear and renewable generation will be minimized/eliminated. Also, as EMPAX-CGE is not designed to examine climate-change mitigation policies with restrictions on carbon dioxide emissions, the types of policies generally investigated do not focus on those likely to cause significant new investment in non-fossil generation.

## D. Section 4 – Database and Calibration

***Comment:***

> The model will need to be calibrated with EIA forecasts from 2004 rather than earlier ones. The 2004 forecast extends through 2025 rather than 2020 and also incorporates significantly lower natural gas consumption than in previous outlooks. Although it is interesting that the model can be calibrated with IPM as well, this procedure may create some conflicts because IPM forecasts may be quite different from EIA's forecast. Another procedure for obtaining more electricity plant detail would be to allow calibration with POEMS (Policy Office Electricity Modeling System), maintained by the Department of Energy's Office of Policy.

***Response:***

As noted by Dr. Huntington, EIA forecasts can exhibit fairly significant volatility from one publication year to the next, and have generally tended towards higher energy prices over the last several annual publications. We anticipate that the AEO 2006 forecast, available in early 2006, will show substantial increases in oil and gas prices over forecasts from previous years as well. Updating the energy data in EMPAX-CGE, including consumption, production and prices, involves a significant amount of effort as all economic and energy data in the model, along with its forecasts, have to be adjusted. The currently-incorporated AEO 2003 forecast, however, is closer to those used by EPA's IPM electricity model than are the AEO 2004 or AEO 2005 forecasts. Consequently, we have not yet adjusted the EMPAX-CGE data and forecasts as doing so will move the model farther away from IPM, which has been used to estimate electricity-industry responses to environmental policies for EMPAX-CGE.

***Comment:***

> The assumption that the services sector will grow at the same rate as GDP (p. 4-9) will understate its growth, because GDP will include the slower growing industrial sector as well as the service sector.

***Response:***

This sentence in the model documentation was not clear and has been altered. EIA's AEO forecasts provide projections for energy-production and manufacturing growth, but not for services. Growth in services in EMPAX-CGE depends on the availability of future productive labor – based on AEO growth forecasts – after accounting for labor needs of manufacturing industries (for which growth forecasts are available).

***Comment:***

> The calibration procedure adjusts for expected economic growth and changes in energy markets between the base year for data inputs (2000) and the starting year of the model.

> The latter start date is not identified, but it would be useful to know what year the simulations begin.

***Response:***
The initial simulation year of EMPAX-CGE is currently 2005.

**E. Section 5 – Model Calibration and Policy Evaluation**

***Comment:***

> The model will be very useful for deriving regional and sectoral impacts of environmental policies that use economic instruments that directly affect the costs of using different energy types. Included in these policies would be "cap and trade" approaches, where total emissions constraints are imposed but participants have the option to trade emissions permits among themselves. It is uncertain how useful the model will be to address the impacts of policies that mandate physical constraints that do not have market-oriented instruments associated with them.

***Response:***
In general, EMPAX-CGE and other similar CGE models are designed to evaluate broad environmental and energy policies. For policies without market-oriented instruments or policies that affect relatively small portions of industries or specific firms, we prefer to rely on more detailed sector-specific models (e.g., EPA's IPM model) to estimate reactions within an industry and subsequently use EMPAX-CGE to extend these reactions to the rest of the economy.

**F. Section 6 – Dynamic Version of EMPAX-CGE**

***Comment:***

> Although the model bases many of its substitution elasticities on MIT's EPPA model, it uses very different assumptions about linking the time periods. EMPAX-CGE allows agents to optimize their decisions over the full horizon under the assumption that they have perfect foresight, while EPPA solves each time in a recursive dynamic fashion. Moreover, capital is malleable in EMPAX-CGE whereas EPPA maintains some rigidities on substituting different capital types. These assumptions about investment and capital can significantly influence the long-run impacts to changes in prices and policies on the energy system and the economy. As a result, the long-run responses of the models may be quite different. On the effect of capital malleability, see Jacoby and Wing (1999).

***Response:***
As noted by Dr. Huntington, the dynamic structure of EMPAX-CGE, which is significantly different than MIT's EPPA model, will provide somewhat different insights than EPPA (the foresight in EMPAX-CGE, however, allows more consistency between the CGE model and other models used by EPA such as IPM). In EMPAX-CGE, agents will prepare in advance for a policy to be instituted in the future, rather than waiting until the policy takes effect. There is also more capital mobility in EMPAX-CGE than EPPA, although capital movements and investment changes will not be as large as in the IGEM CGE model, which does not use features like the capital adjustment costs that are in EMPAX-CGE. Anticipation of policies will tend to reduce

policy costs as people prepare ahead of time in order to minimize costs. Similarly, additional capital mobility will also tend to lower estimated policy costs.

***Comment:***

These aggregate responses may also be compared with responses reported by the US Energy Information Administration for their NEMS system. One issue that is not addressed in the EMPAX-CGE documentation is whether the model responds similarly to the NEMS system upon which it is based and calibrated, when key variables such as economic growth and energy prices are changed.

***Response:***

We would not characterize EMPAX-CGE as based on or calibrated to EIA's NEMS model. EMPAX-CGE uses the AEO energy forecasts generated by the NEMS model to establish a baseline for EMPAX-CGE, but there are essentially no similarities between the models themselves. EMPAX-CGE is a general equilibrium model based on neoclassical economic theory, while NEMS is a collection of many sector-specific models tied to an econometrically-based macroeconomic model.

***Comment:***

The documentation discusses the role of the fixed factor in producing natural resources (e.g., oil, natural gas and coal) but does not report any summary measures of the associated price elasticity of supply for any of these fuels. (p. 6-6) These responses could play a significant role in some policy cases.

***Response:***

Section 6 in the documentation did not discuss these elasticities, however, natural resource supply elasticities are presented in Table 3-3.

***Comment:***

Although the same elasticities are used for most industrial sectors (aside from producing electricity), a significant amount of industrial energy use is for feedstock use. Much of this occurs within the chemical industry (Table 6-4 on p. 6-14). Chemicals account for 95% of total manufacturing oil use. Where energy is used as a feedstock, its substitution possibilities may be more like materials than direct fuel use for heating and other purposes.

***Response:***

This is an interesting point we have not seen fully addressed by CGE models. Across all types of energy, around 55 percent of energy use in the chemicals industry is for feedstocks. While we can not address this point currently because developing the balanced dataset needed by EMPAX-CGE is a significant effort, we will revisit this issue when we update the energy data and forecasts used by the model.

## G. Appendices

***Comment:***

> Other approaches exist for evaluating the regional and sectoral impacts of US environmental policy. The documentation compares EMPAX-CGE with two others energy-environmental systems (AMIGA and IGEM) in a short appendix, but it never states clearly why they are developing EMPAX-CGE rather than using one of these other systems. In addition, it does not compare the model with the econometric approach used by Regional Economic Models, Inc. in their framework, REMI Policy Insight. These comparisons need not be long, but policymakers do have other models that could be applicable to the problem.

***Response:***

There are a wide range of models that could potentially be used to evaluate policies, including REMI as mentioned by Dr. Huntington. Our model comparison, however, was only intended to focus on the two models that were under consideration at the time by EPA's Science Advisory Board (http://www.epa.gov/science1/index.html).