The Use of Global Trade and Energy Volume Data for the Analysis of Global Energy-Environmental Issues – Some Illustrative Experiments.

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Abstract

The analysis of global energy and environmental issues have often been hampered by the lack of a comprehensive energy-economy wide-global data set. Recently the Center for Global Trade Analysis at Purdue University has produced a special version of the GTAP data base called GTAP 4-E together with an energy price and volume data set. This paper utilises these data set in some illustrative experiments. The experiments involve simulating the effects of the cutting back on the world CO_2 emission level by some 25 per cent in a comparative static framework. The results show that using the standard GTAP version 4 data base and the special purpose GTAP 4-E data base can produce significantly different results.

1. Introduction

Up to now, the analysis of global energy and environmental issues have been hampered by the lack of a comprehensive energy-economy wide-global data set, and a suitable model which can make use of this data set. The comprehensive data set needs to contain information on both the physical energy flows at the end-use sectoral level, as well as value flows at the economy-wide and global level. Quantity – or *volume* - information on energy flows is important for certain calculations such as the energy intensities or embodied carbon intensities of production and consumption activities[2]. These intensities are indispensable parameters in the calculation of the economic impact of certain energy-environmental policies such as the reduction of the world's CO_2 emission level. The suitable model needs to take account of important energy-economy interactions such as inter-fuel and inter-factor substitutions involving the energy variables.

Motivated by the need for a comprehensive energy-economy wide-global data set, a special project funded by the Department of Energy (DOE) was carried out jointly by researchers at Purdue university (the Center for Global Trade Analysis (CGTA)), the University of Colorado, Boulder, and the OECD Development Centre[3]. The objective of the Project was to construct a data base which contains the necessary combination of (a)

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[2] Babiker and Rutherford (1997).

[3] For more information on this Project, see the Web site of CGTA at: http://www.agecon.purdue.edu/gtap

comprehensive input-output data by region, (b) bilateral trade and protection data, and (c) energy price, quantity and tax data. The Project started with the collection of data on energy quantity flows, prices and taxes, from various sources[4]. Next, these independent information were then checked for accuracy and consistency with the energy data in the GTAP data base[5]. Where there are significant differences, the GTAP data set is then modified and re-balanced. The result is a 'special purpose' data base known as GTAP 4-E which is intended to be used, firstly, by researchers analyzing the energy-economy-trade-environment issues, but also in the future by regular users of the standard GTAP data base[6].

In this paper, we make use of this special purpose GTAP 4-E data base, the companion energy volume data set, and also the extended GTAP model which includes inter-fuel and inter-factor substitution in its structure[7], to carry out some illustrative experiments looking at energy-environmental issues. One of the experiments involves simulating the effects of a reduction of the world CO_2 emission level by 25 per cent, firstly, by all regions of the world, and then, by the Annex 1 regions[8] only (no participation of non-Annex 1 countries). The economic impact of this reduction in different regions, on different types of fuels, and among various sectors of the economy, are analyzed. To highlight the importance of the integrated data set, we first carry out the experiment using the GTAP 4 data base. We then repeat the experiment using the GTAP 4-E data base. In both cases, we use the volume data to calculate the CO_2 emission level for targeting. A comparison of the two different sets of results will reveal how important the use of the energy volume data set can be, and also the usefulness of 'integrating' this data set into the GTAP 4-E data base.

The outline of this paper is as follows. Section 2 describes the main elements of the theoretical framework for the experiments. Section 3 briefly describes main differences between the GTAP 4 and GTAP 4-E data sets. Section 4 describes the experiment set up and reports on the results. Section 4 concludes the paper.

2. Theoretical Framework

At the center of the experiment is the calculation of the (percentage change in the) volume of CO_2 emission across different regions and over the whole world. This calculation depends on the availability of energy *volume* (i.e. quantity) flows. In the

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4 Energy volume data were collected from the International Energy Agency (IEA). Energy prices and tax data were obtained from the IEA as well as the World Bank (Survey of Asia's Energy Prices), the Organizacion Latino Americana de Energia (OLADE), the Asian Development Bank (ADB), the US Department of Energy (DOE), China Energy Databook (CED), and the Tata Energy Research Institute (TERI).

5 GTAP stands for Global Trade Analysis Project. For information on this Project, see the CGTA web-site. For details about the latest version 4 of the GTAP data base, see McDougall *et al.* (1998).

6 GTAP 4-E is going to be integrated into the next release (version 5) of the GTAP data base. For information on the process of constructing the GTAP 4-E data base, see Malcolm and Truong (1999).

7 The model is called GTAP-E. For details on the construction of this model, see Truong (1999).

8 Annex 1 countries are those listed in the Annex 1 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change which consist mainly of Western industrialized countries.

absence of such information (for example, when we use the GTAP 4 or GTAP 4-E data bases on their 'stand alone' mode) the assumption often made by researchers is that the *value* flows of a basic input-output data base will also represent the relativity of the volume flows. This means different end-users (industries, household) face the same average price for their energy inputs[9]. Such an assumption is clearly unrealistic, since it implies that in practice, there is no price discrimination exercised by the energy suppliers with respect to the different types of users, and that the price charged to any user is constant with respect to the quantity supplied (uniform pricing). It also assumes that the margin costs (of distribution, transmission, retailing, government taxes and subsidies on these energy commodities) are all the same for all users[10]. Clearly, this does not reflect reality in the energy market. To overcome this deficiency, an alternative approach is to make use of the actual volume flow information (in the calculation of certain important parameters such as energy and CO_2 intensities of various economic activities), and use this information in conjunction with the value flow data contained in the standard input-output and trade data base (such as GTAP). In what follows, we illustrate how such calculations can be carried out, and compare these with so-called 'naïve' calculations, being based mainly on the value flows of the input-output data base.

2.1 Embodied CO_2 intensities using volume data

To calculate the CO_2 content embodied in the output of a particular production or consumption activity, we need both the information on energy volume flows (from the energy volume data base) and the information on the value of output or consumption activity (from GTAP 4 or GTAP 4-E).

Let $j \in$ U={set of users}
$i \in$ E={set of energy commodities}
$r \in$ R={set of regions}
Y(r) = value of output (in US95$million) in region *r* from the GTAP 4 data base.
Q(i,j,r) = quantity, or volume flow of energy commodity *i*[11] (in million of ton of oil equivalent – mtoe) to user *j* in region r, obtained from the energy volume data base.
$\kappa(i)$ = CO_2 coefficient for fuel *i* (in tons of CO_2 per toe).

The average CO_2 content embodied in fuel *i* for all economic activities in region *r* is given by:

$$A(i,r) = (1/Y(r)) * \kappa(i) * \sum_{j \in U} Q(i,j,r) \qquad (1)$$

[9] Note that these prices (in dollar per unit of energy such as ton of oil equivalent (toe)) can still vary between different types of fuels, to take account of their differences in qualities (such as ease of use, impurity content, etc), but the price of each fuel is assumed to be the same for all users.

[10] A standard input-output table can take account of different user margins and taxes, but often due to lack of information, the table often assumes uniform margin for all domestic users. This is the case with the GTAP data base (and GTAP model, see Hertel (1997)).

[11] In the actual model calculation, we distinguish between the quantity from domestic source and the quantity from imported source.

2.2 Embodied CO_2 intensities using mainly the input-output value flows

When the actual volume information is not available, we can infer these quantities from the input-output value flows together with some *aggregate* information on the total volume flow, as follow:

$$\hat{A}(i,r) = (1/Y(r)) * \kappa(i) * \sum_{j \in U} \hat{Q}(i,j,r) \quad (2)$$

where the symbol (^) is used to denote the estimated or *inferred* value, calculated from the value data base. The *inferred* quantity flow to each user *j* is calculated as:

$$\hat{Q}(i,j,r) = \frac{V(i,j,r)}{\sum_{j \in U} V(i,j,r)} * Q(i,r) \quad (3)$$

where $V(i,j,r)$ is the value flow of energy commodity *i* to user *j* in region *r* and Q(i,r) is the total usage of *i* in *r*.

2.3 Carbon tax imposition

We assume that a (carbon) tax is levied on all primary energy commodities[12] for its average CO_2 content. To calculate the carbon tax rate for each region, we assume that the tax rate is uniform for all users within the region[13], and therefore, we only need to calculate the average CO_2 content for all economic activities within a particular region. This is calculated as follows.

Let $\tau(r)$ be the carbon tax rate (\$/ton of CO_2) for each region *r*. The percentage increase in the power of the tax (i.e. one plus the tax rate) on energy commodity *i* in region *r* will then be related to the carbon tax and the average carbon content of the energy commodity as follows:

$$t(i,j,r) = \tau(r) * A(i,r) \quad (4)$$

[12] This includes coal (COL), natural and manufactured gas (GAS), and petroleum and coal products (P_C). In theory, crude oil (OIL) should be counted as primary energy rather than petroleum and coal products to avoid double counting of coal consumption. However, for the purpose of calculating CO_2 emission level, it is more accurate to calculate this from the consumption of petroleum products rather than from crude oil consumption. Furthermore, except for one region (FSU: former Soviet Union), where approximately 0.27% of the total coal usage is in the P_C sector, all other regions have zero consumption of coal in the P_C sector.

[13] Although in principle, we can levy different tax rates on different users, based on the CO_2 content level in their activities, for simplicity, however, we impose a uniform tax rate for all users within a region.

The tax on each energy commodity *i*, to user *j*, in region *r*, will have an effect on its total demand, i.e. on the volume flow *Q*(*i*,*r*). This will then have an impact on the total volume of CO_2 emission from energy usage region *r*, denoted by the variable *X*(*r*):

$$X(r) = \sum_{i \in E} \kappa(i) * Q(i,r) \qquad (5)$$

The percentage change form for this equation is given by[14]:

$$x(r) = \sum_{i \in E} S(i,r) * q(i,r) \qquad (6)$$

Here, *x*(*r*) and *q*(*i*,*r*) are the percentages in *X*(*r*) and *Q*(*i*,*r*) respectively, and are determined by the model[15]. *S*(*i*,*r*) is the share of CO_2 emission from fuel *i* over all fuels in region *r* and is derived from the volume data base as follows[16]:

$$S(i,r) = \kappa(i) * Q(i,r) / \sum_{i \in E} \kappa(i) * Q(i,r) \qquad (7)$$

q(*i*,*r*) is one of the existing variables in the standard GTAP model.

2.4 The issue of 'leakage'

In carrying out the experiment on CO_2 emission reduction, we make a distinction between Annex 1 and non Annex 1 regions. Let *A* denotes the former, and *N*, the latter set. We have $R = A \cup N$. The percentage change in the total amount of CO_2 emission from these two different sets of regions (x_A, x_N), and from the world as a whole (x_W), can then be calculated as follows

$$\begin{aligned} x_A &= \sum_{r \in A} S(r) * x(r) \\ x_N &= \sum_{r \in N} S(r) * x(r) \\ x_W &= \sum_{r \in R} S(r) * x(r) \\ &= x_A + x_N \end{aligned} \qquad (8)$$

where *S*(*r*) is the share of CO_2 emission from region *r* over all regions of the world, and is derived from the data base:

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14 A lower case letter is used to denote 'percentage change'.

15 In the standard GTAP model (see Chapter 2 of Hertel (1997)), *q*(*i*,*r*), and hence *x*(*r*), is also distinguished by sources: *qds*(*i*,*r*) to stand for the demand of commodity *i* in region *r* from domestic source, and *qim*(*i*,*r*) for the similar demand but from imported source.

16 Where volume data is not available, *Q*(*i*,*r*) is approximated by its 'inferred' value, as estimated from equation (3) of section 2.2.

$$S(r) = \sum_{i \in E} \kappa(i) * Q(i,r) / \sum_{r \in R} \sum_{i \in E} \kappa(i) * Q(i,r) \qquad (9)$$

To simulate an experiment where the world CO_2 emission level is reduced by *c* per cent, and the burden is shared equally among all regions, we impose the following conditions:

$$x(r) = -c; \text{ for all } r \in R \qquad \text{:“Experiment 1”} \qquad (10)$$

A different experiment is to assume that only Annex 1 regions are to share the burden of CO_2 reduction in equal percentages, while non-Annex 1 regions face with no such commitments. A set of conditions for this experiment is then given by:

$$\begin{aligned} x(r) &= -c; \text{ for all } r \in A \\ \tau(r) &= 0; \text{ for all } r \in N \end{aligned} \qquad \text{:“Experiment 2”} \qquad (11)$$

Here, non-Annex 1 regions are assumed to impose zero carbon tax on their energy consumption. As a result, the demand for energy commodities, and therefore the CO_2 emission levels, in these regions, may even increase. Such an increase is called ‘leakage’[17]: the reduction in CO_2 emission in Annex 1 regions are made ineffective by offsetting increases in CO_2 emissions in non-Annex 1 regions. The ‘leakage rate’ is defined as the ratio: $x_N /(-x_A)$. For example, if there is a 50% leakage rate, then x_N=-0.5 x_A, and x_W = 0.5 x_A, i.e the world CO_2 emission is reduced by only half of what is achieved by Annex 1 regions. If there is a 100% leakage rate, then x_N= -x_A, and x_W = 0, i.e the effect on the world as a whole is zero, irrespective if what is achieved by the Annex 1 regions.

Assume that the leakage rate is less than 100 per cent and if the Annex 1 regions are set out to achieve a fixed target for the reduction in the world CO_2 emissions level, then a third experiment can be defined as follows:

$$\begin{aligned} x_W &= -c \\ x(r) &= \bar{x}; \text{ for all } r \in A \\ \tau(r) &= 0; \text{ for all } r \in N \end{aligned} \qquad \text{: “Experiment 3”} \qquad (12)$$

In this case, the necessary reduction in the level of CO_2 emission for each of the Annex 1 regions (i.e. $\bar{x}$) will be determined endogenously by the model.

3 Data description

We use a 14 sectors by 14 regions aggregation, based on the GTAP version 4 data base. The list of the sectors and regions are given in the Appendix. To understand the differences of the results when we run the experiments with the different data bases, it is important to look at the detailed information contained in the data bases themselves.

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17 See Perroni and Rutherford (1993), and Felden and Rutherford (1993).

First, we look at the aggregate energy and CO_2 intensities. These are shown in Figures 1 and 2. In Figure 1, we divide the total energy usage (calculated from the volume data base) by the GDP value (from the GTAP 4 or GTAP 4-E data bases). In Figure 2, a similar procedure is carried out, but with the energy usage converted into CO_2 emission level[18]. From Figures 1 and 2, we can see that the results are very similar, and this is as expected because at the aggregate level of GDP calculation, GTAP 4 and GTAP 4-E give almost identical results. But if we look at the individual components of GDP, and in particular, if we look at the energy sector, then GTAP 4 and GTAP 4-E can produce different results. In Figure 3, for example, crude oil exports from the UK are seen to be higher with GTAP 4-E than with GTAP 4. The converse is true with petroleum and coal products imports into the USA (Figures 4). Non-energy commodities, however, show much more consistency when we move from GTAP 4 to GTAP 4-E, and this is as expected. In Figure 5, for example, the value of primary factor purchases by firms in the USA are seen to be almost identical for GTAP 4 and GTAP 4-E. Figure 6 also shows the same consistency with respect to the different data bases for non-margin exports of the USA at world prices.

When we move to a more disaggregated level, the differences between GTAP 4 and GTAP 4-E become more pronounced, especially with respect to the energy commodities. In Figures 7 and 8, the average energy intensities and CO_2 intensities at the industry level for the USA are seen to be significantly different, depending on whether we use the GTAP 4, or GTAP 4-E data base, and whether each data base on a *stand-alone* basis (i.e. using value shares to infer quantity shares and distribute the aggregate quantity according to the value shares – see section 2.2), or each *in conjunction with* the volume data base (i.e. using the volume information *directly* from the volume data base)[19]. For example, GTAP 4 gives a higher estimate of the energy and CO_2 intensities for the coal (COL), gas (GAS) industries in the USA, but a lower estimate for the electricity (ELY) industry. The results can be traced back to the fact that the share of energy inputs into the coal and gas industries are always higher for the GTAP 4 value data base, but much lower for the volume data base (see Figures 9-13). The converse can be true for other industries (such as ELY, in the case of COL and GAS inputs, or trade and transport (T_T), in the case of petroleum products (P_C) input). Therefore, while the aggregate intensities are very similar, when it comes down to the end-use (sectoral) level, the GTAP 4 value data base and the energy volume information diverge significantly.

When the GTAP 4 and the energy volume information are different, the approach taken in the GTAP 4-E data base construction process was to 'adjust' the GTAP 4 values towards the direction of the energy volume (and price) information. As a result, the estimates on the energy intensities and CO_2 intensities from the GTAP 4-E value data base (on its stand alone mode) are always much closer to the estimates from the energy volume data base, as compared to those from the GTAP 4 data base (also on its stand alone mode). This means that if we are to use the GTAP data bases to calculate certain

[18] We use the following coefficients for CO_2 emission: (3.8107, 1.8844, 2.7638) tons of CO_2 per ton of oil equivalent (toe), for (coal, gas, petroleum and coal products) respectively.

[19] There are thus four different combinations: GTAP 4 stand alone, GTAP 4-E stand alone, Volume data plus GTAP 4, and Volume data plus GTAP 4-E.

important energy and environmental variables (such as energy intensities and CO_2 intensities) then it is 'better'[20] to use the GTAP 4-E version rather than the standard GTAP 4 version.

4 Experiment set up and results

We use an extended version of the GTAP model called GTAP-E which allows for the possibility of inter-fuel and inter-factor substitution in the production structure of firms and in the consumption behavior of private households and government sector (Truong, 1999). We assume that there is a target reduction of the world CO_2 emission level by -25%. This may sound like a very large reduction. However, since the model is comparative static, the reduction is therefore to be interpreted as 'relative to the level which would have been arrived at in the target year if there is business-as-usual (BaU)'. According to the International Energy Agency, the world CO_2 emission is projected to increase (roughly linearly) by about 9723 million tons from 21401 tons in 1990 to about 31124 tons in 2010 in the BaU projection[21]. To meet the Kyoto commitments[22], there must be a massive reduction of CO_2 emissions of about 10793 tons, or 35% in the target year from the BaU projection. Thus, a 25% decrease is judged to be within the reasonable range relative to the objectives of the Kyoto Protocol.

In Experiment 1, we assume that *all* countries will agree to reduce their CO_2 emission levels by the same 25%, i.e. all share equally in the burden of CO_2 reduction. The instrument used for reducing CO_2 emission is a carbon tax, to be levied on energy consumption and based on their embodied CO_2 content. In Experiment 2, we assume that only Annex 1 countries[23] will agree to reduce their CO_2 emission levels by the same 25%. The non-Annex 1 countries will continue to maintain the existing level of taxes/subsidies on the energy commodities, and therefore their CO_2 emission level may not reduce significantly (or even increase), and the world CO_2 emission level as a whole will not therefore reduce by 25%. In Experiment 3, we assume that the Annex 1 countries will now set out to reduce the world CO_2 emission level by the fixed target of 25%, irrespective of the 'leakage' from non-Annex 1 countries. This will mean a larger commitment from each Annex 1 region, and the exact level for this commitment is going to be determined endogenously by the model.

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[20] The word 'better' is used here with some qualifications. Firstly, it is based on the assumption that the energy volume information at the end-use level in the energy volume data base is more reliable than the GTAP input-output information. Secondly, it is also based on the existing adopted structure of the GTAP data base (and model) which does not distinguish between domestic end-users with respect to the margins and average prices for their energy commodities (see the discussion in previous section 2). If such a structure is to be modified, then clearly the value shares should not always follow the quantity shares more closely in order to become 'better', and therefore, the comparison between GTAP 4 and GTAP 4-E should also be based on a different criterion.

[21] IEA (1998, Table 3).

[22] The Kyoto Protocol commits the developed countries to reduce their collective emissions of greenhouse gases by at least 5% compared to 1990 levels by the period 2008-2012.

[23] Corresponding to the following regions in our data set: {USA, FSU, JPN, DEU, GBR, REU, AUS, NZL, CAN}. The non-Annex 1 regions are thus: {CHN, IND, KOR, NEX, NEM}. For an explanation of these region codes, see the Appendix.

Table 1 reports on the carbon tax required in each of the three experiments. Firstly, using the standard GTAP 4 data base (in conjunction with the energy volume data to calculate the volume of energy consumption and hence CO_2 emission), experiment 1 reports a carbon tax ranging from 7 or 8 dollars per ton of CO_2 for China (CHN) and the Former Soviet Union (FSU), to 61 dollars per ton for the US, and a very high figure of 251 dollars per ton for Japan (JPN). When using the GTAP 4-E data base, however, the results are quite different: a much higher figure of 87$/ton for the US, but lower figures (relative to GTAP 4 results) of 215 and 88 $/ton respectively, for Japan and Germany (DEU). Clearly, we can see that the results are quite sensitive to the type of data base being used. This means that if we believe GTAP 4-E is more ‘accurate’ than GTAP 4 with respect to the energy volume information, then using the standard GTAP 4 would tend to *under*-estimate the carbon tax required for the cases of USA and Australia (AUS), but *over*-estimate it for the cases of Japan, Germany, and the rest of the European Union (REU) excepting the UK (GBR). A similar pattern is also observed in the results of experiments 2 and 3: underestimation for {USA, FSU, AUS, NZL, CAN}, and overestimation for {JPN, DEU, REU} if we are to use the standard GTAP 4 data base, as compared to the GTAP 4-E data base. Only the {GBR} results are quite robust with respect to the different data bases.

Comparing experiments 1 and 2, we observe that the magnitude of the carbon tax required to achieve the target reduction in CO_2 emission level in Annex 1 regions is smaller for experiment 2 than for experiment 1. This may seem strange at first, but if we recognize that because of the ‘leakage’ of carbon-intensive activities from Annex 1 to non-Annex 1 regions, the former will now have an easier task of reducing their CO_2 emission than before. This explains for the smaller magnitude of the carbon tax.

When it comes to experiment 3, because of the fixed target for the *world* as a whole, rather than just for the Annex 1 regions, the burden on the Annex 1 regions is now much heavier. The carbon tax required is now more than doubled for Japan and nearly doubled for the US, the European countries, Australia, New Zealand, and.

Table 2 reports on the overall reductions in CO_2 emission level by each region in each experiment in percentage terms, and Table 3 gives the corresponding absolute change in million tons of CO_2. Table 2 shows that the ‘leakage’ (i.e. percentage increase in CO_2 emission) for China ranges from 1 to 1.3% if we are to use the standard GTAP 4 data base, but much higher: 2.6 to 3.6% if we are to use the GTAP 4-E data base. The same pattern is observed for other non-Annex 1 regions. In fact, Table 3 shows that the leakage rate for all non-Annex 1 regions as a whole in both experiments 1 and 2 is more than doubled if we use the GTAP 4-E data base,. This can be related to the fact that using GTAP 4-E (which has a more detailed energy tax information than GTAP 4 – see Tables 10 and 11 and the discussion below) will result in the trade of energy-intensive commodities (such as I_S (ferrous metals), or CRP (chemical, rubber, and plastic products)) being more responsive to the imposition of carbon tax. As a result, the ‘leakage’ of energy-intensive production from Annex 1 regions to non-Annex 1 regions will become greater with GTAP 4-E than with GTAP 4 data base. Tables 4 and 5 confirm this: in both of these Tables, it is seen that, with the exception of USA, JPN, GBR, NZL, and CAN, the rest of the Annex 1 regions (FSU, DEU, REU, AUS) have their trade balance in energy-intensive commodities (I_S and CRP) worsened when we use GTAP 4-E as compared to the case of GTAP 4. This means that either their net imports have increased, or net exports decreased. The reverse is true for non-Annex 1 regions. From Table 4, we see that for all Annex 1 regions as a whole, moving from GTAP 4 to GTAP 4-E will increase their net imports of I_S by an additional $6310 million, while non-Annex 1 regions will increase their net exports of this commodity by an additional $6028 million (experiment 2). The 'leakage' of energy-intensive production from Annex 1 to non-Annex 1 regions thus has *increased* if we use the GTAP 4-E data base. This is also true for experiment 3. Note that in experiment 1 (Table 6), going from GTAP 4 to GTAP 4-E data base can change the *sign* of the trade balance (in I_S and CRP) of the Annex 1 regions from a positive to a negative figure, and the reverse is true for non-Annex 1 regions.

Next we consider the welfare effect of the imposition of the carbon tax. Table 7 shows that the change in welfare in all experiments are much more magnified if we use the GTAP 4-E rather than the GTAP 4 data base, especially for the USA, DEU, REU, and also to some lesser extent, JPN. In Tables 8 and 9, these welfare changes are decomposed into the 'allocative efficiency' effects and the terms of trade effects. It can be seen from Table 8 that the allocative effciency effect dominates the results on welfare change. This can be explained by the fact that the shock to the energy commodity prices (by the carbon tax) will cause distortions to the economy, reducing demand and output of the energy commodity (see Table 12). The loss is also seen to be much higher for GTAP 4-E than for GTAP 4 results. This can be traced back to the fact that GTAP 4-E shows higher levels of energy taxation than GTAP 4 (especially for some countries such as Germany: see Tables 10 and 11), and therefore, the distortion of the carbon tax is much greater because it is imposed on an already high existing tax.

Together with the magnified trade effects shown in Tables 4-6, the magnified welfare effect in Table 8 illustrates the importance of having a data base which contains adequate information on the existing (energy) taxes. When we impose some additional taxes (such as a carbon tax), these will added on to the existing ones. Without information on the latter, the results will tend to be more subdued, as has been shown to be the case with the GTAP 4 results when compared to the GTAP 4-E results.

5 Conclusion

In this paper, we have briefly described the main reasons for the construction and use of the energy volume information, and the 'energy-enhanced' GTAP 4-E data base. They are important for calculating certain energy and environmental parameters (such as energy and CO_2 intensities) which are of crucial importance in energy-environmental simulation studies. We then use the GTAP 4 and GTAP 4-E data bases (together with the energy volume information) in some illustrative simulations. The results indicate that using the GTAP 4-E data base and the energy volume information will produce results which can be greatly different from those produced by the GTAP 4 (and volume data base). In general, GTAP 4-E results will show greater effects on the economy when a carbon tax is imposed on the economy than does GTAP 4, and this should have important implications for policy analysts who may want to use the existing standard GTAP 4 data base to conduct studies into energy-environmental issues.

Figure 1

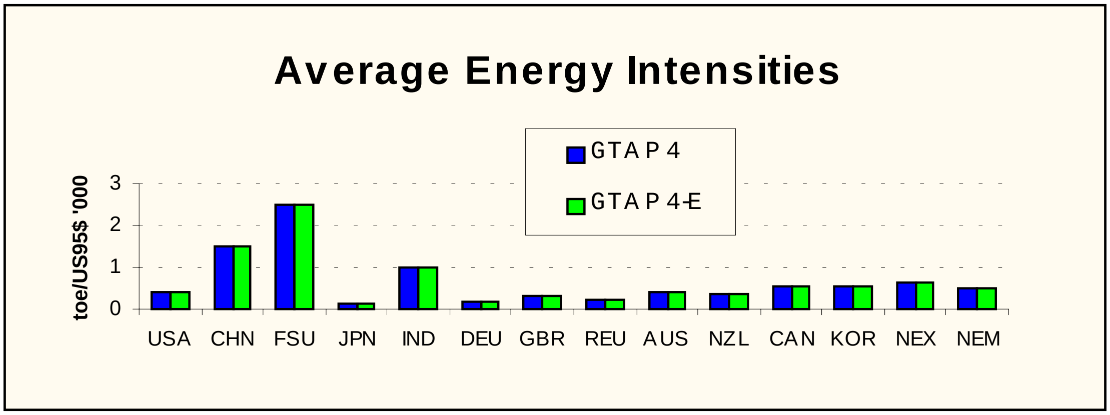


Figure 2

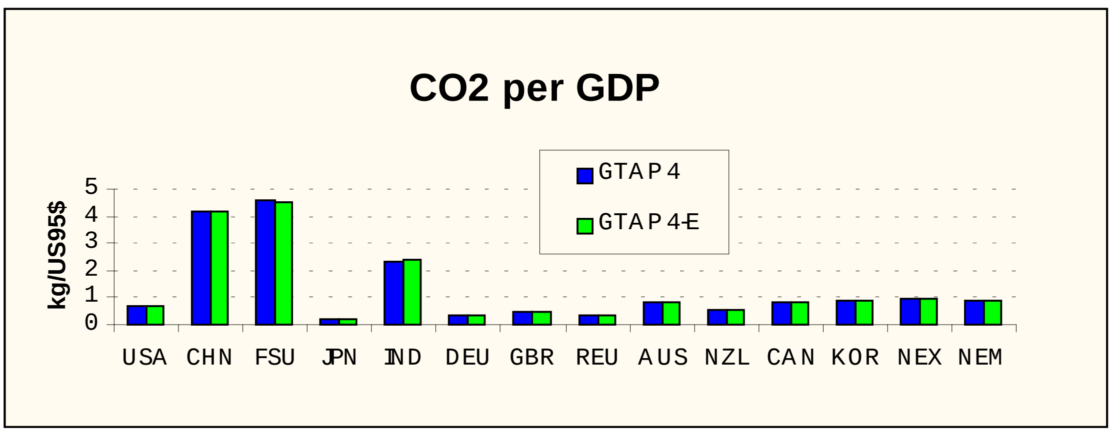


Figure 3

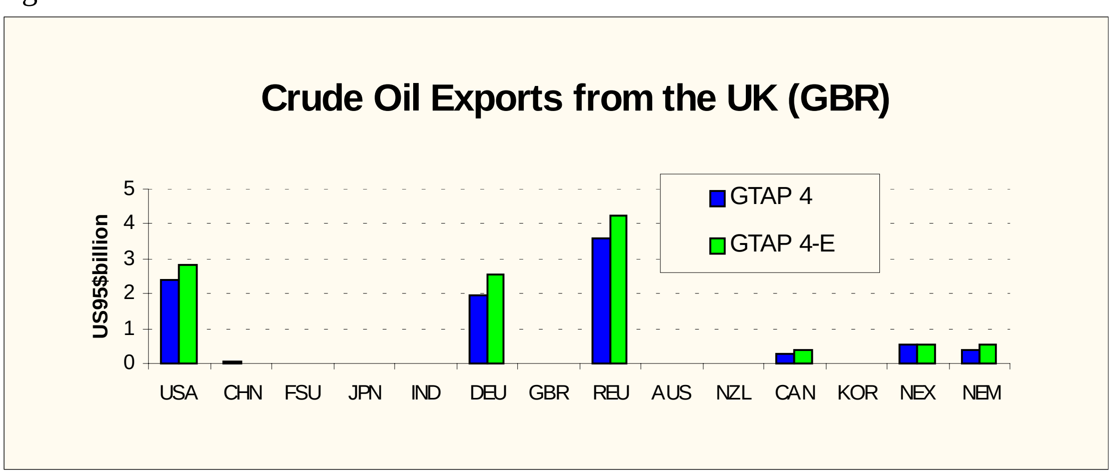


Figure 4

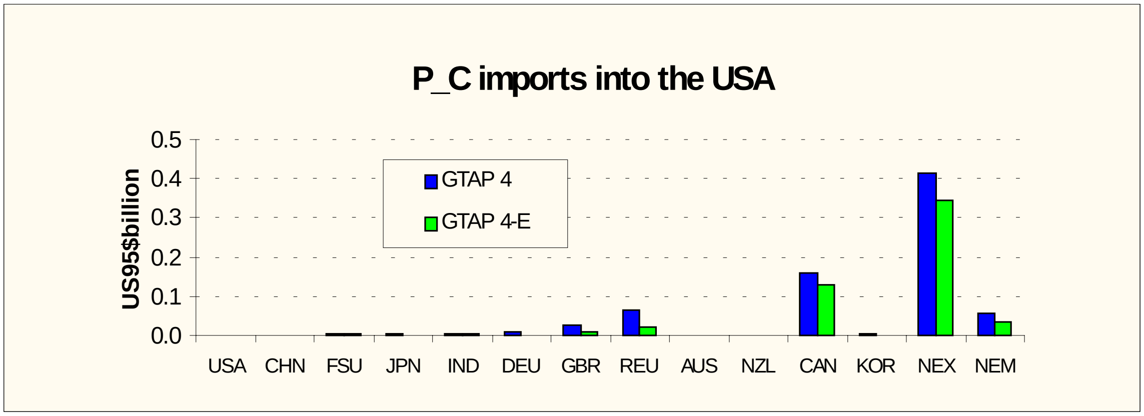
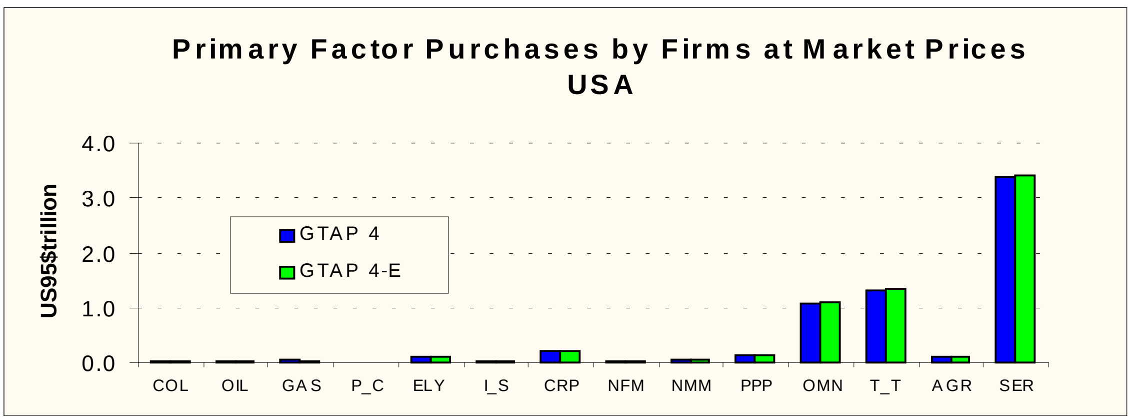


Figure 5



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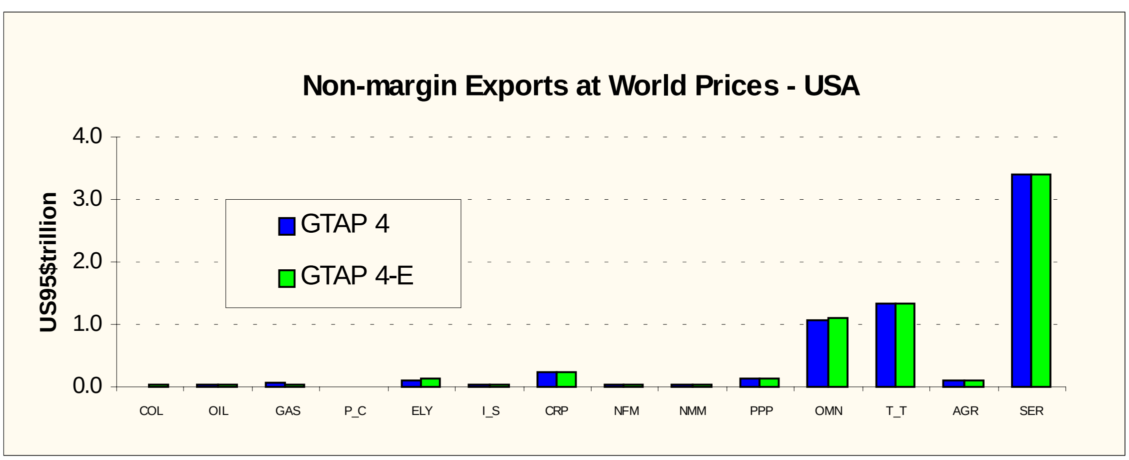

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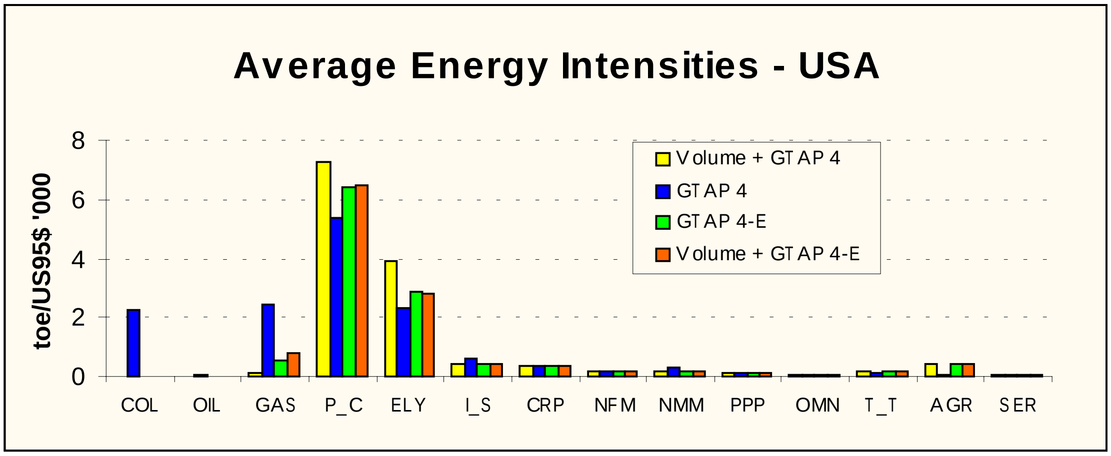

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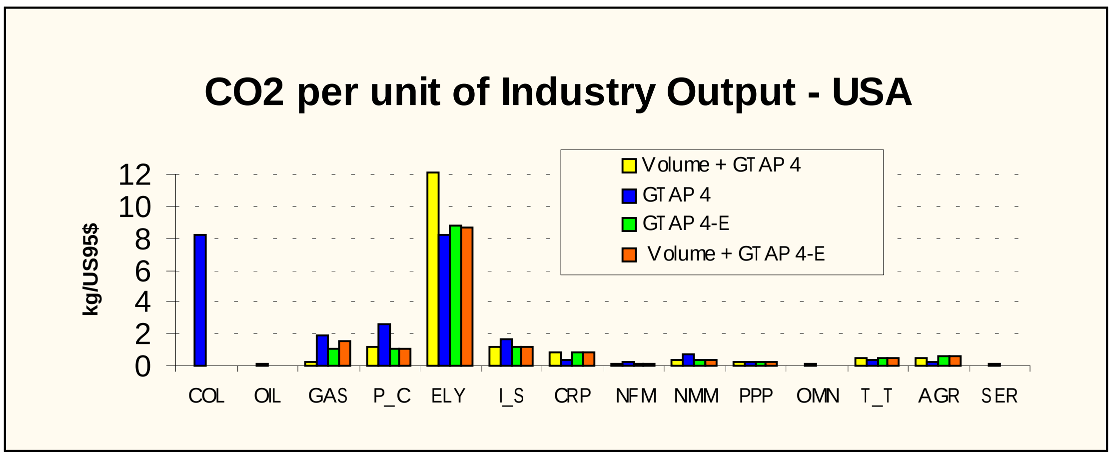

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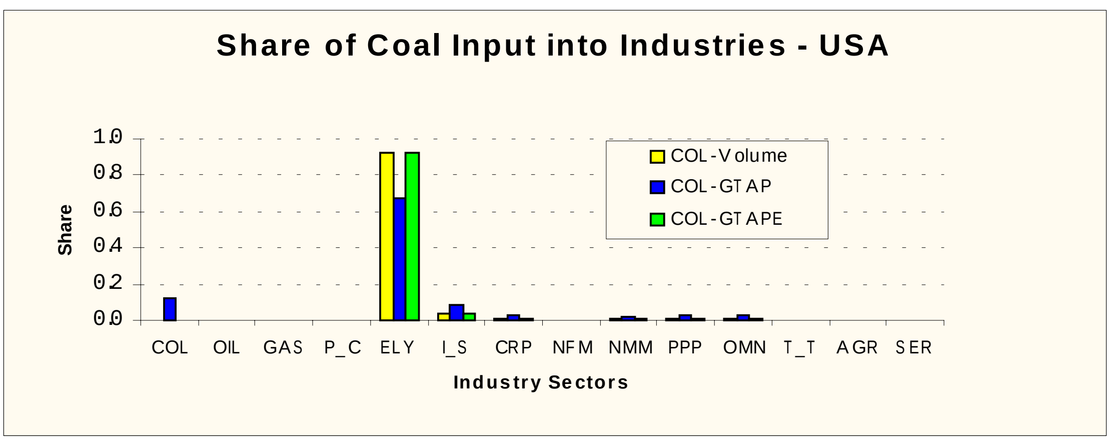

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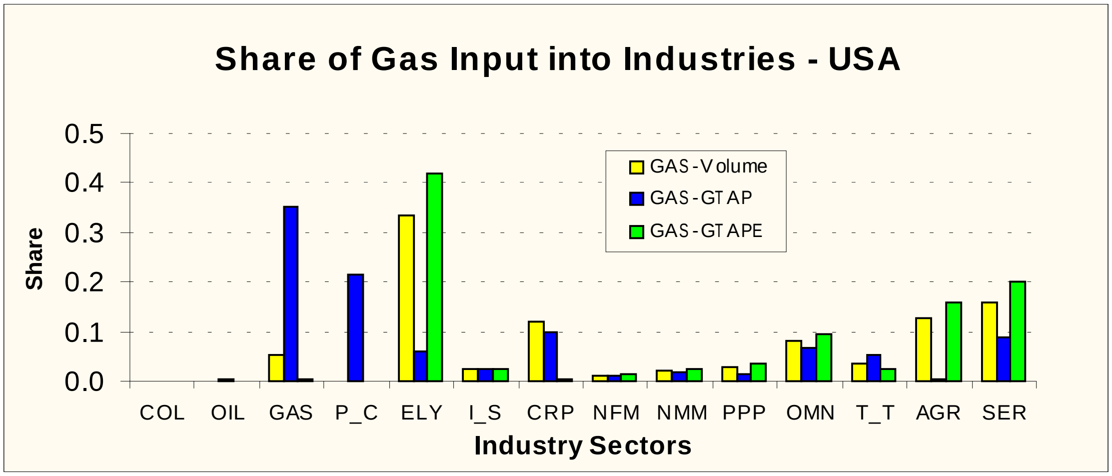

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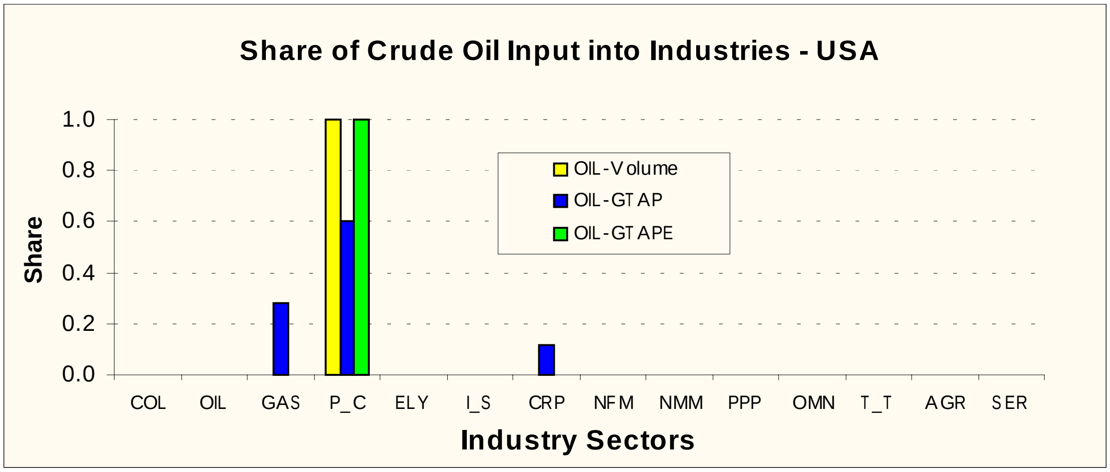

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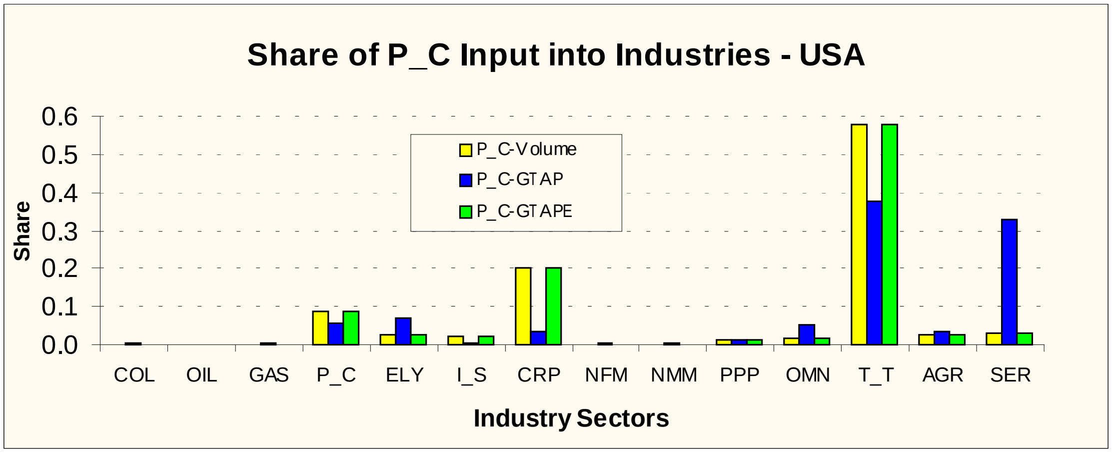

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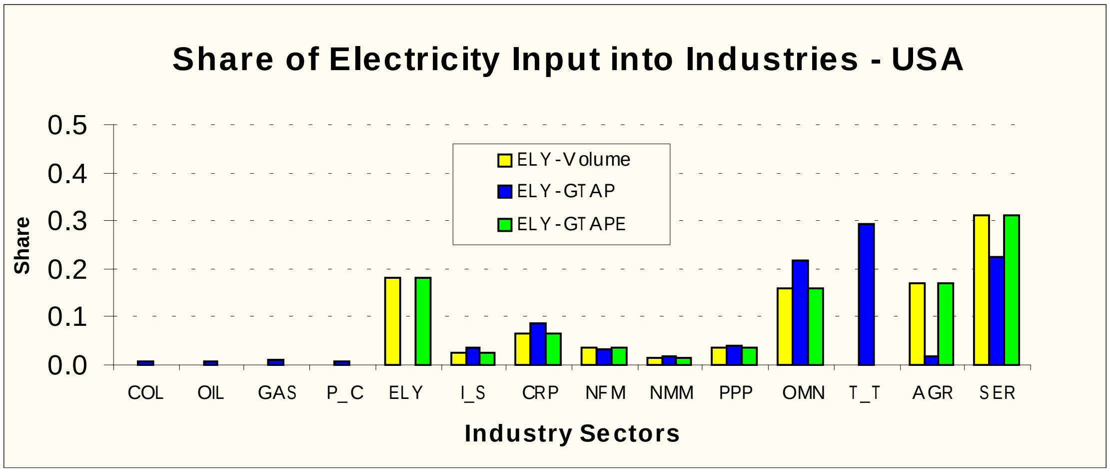

Table 1 - Carbon tax on domestic energy commodities (US95$/ton CO_2)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	61	87	57	81	115	176
CHN	7	10	0	0	0	0
FSU	8	11	7	10	12	18
JPN	251	215	238	181	725	482
IND	16	17	0	0	0	0
DEU	148	88	137	81	299	161
GBR	119	120	109	108	251	244
REU	98	76	90	67	200	136
AUS	56	70	50	61	100	127
NZL	65	70	59	67	121	144
CAN	61	59	57	54	115	103
KOR	53	52	0	0	0	0
NEX	44	41	0	0	0	0
NEM	56	67	0	0	0	0

Table 2 - Percentage change in the level of CO_2 emission

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	-25.0	-25.0	-25.0	-25.0	-40.3	-41.3
CHN	-25.0	-25.0	1.0	2.6	1.3	3.6
FSU	-25.0	-25.0	-25.0	-25.0	-39.8	-40.9
JPN	-25.0	-25.0	-25.0	-25.0	-38.1	-39.6
IND	-25.0	-25.0	0.2	1.9	0.2	2.5
DEU	-25.0	-25.0	-25.0	-25.0	-38.9	-40.2
GBR	-25.0	-25.0	-25.0	-25.0	-39.9	-40.9
REU	-25.0	-25.0	-25.0	-25.0	-38.2	-39.6
AUS	-25.0	-25.0	-25.0	-25.0	-40.4	-41.4
NZL	-25.0	-25.0	-25.0	-25.0	-40.1	-41.1
CAN	-25.0	-25.0	-25.0	-25.0	-40.0	-41.1
KOR	-25.0	-25.0	2.8	7.7	3.5	10.5
NEX	-25.0	-25.0	2.6	3.8	3.6	5.5
NEM	-25.0	-25.0	2.8	5.7	3.6	8.0

Table 3 - Absolute change in the level of the level of CO_2 emission (million tons)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	-1213	-1474	-1355	-1451	-2447	-2693
CHN	-809	-831	23	68	29	88
FSU	-503	-584	-655	-646	-1159	-1188
JPN	-374	-322	-357	-326	-604	-574
IND	-223	-228	3	16	3	22
DEU	-213	-205	-231	-223	-399	-399
GBR	-135	-146	-143	-150	-256	-275
REU	-443	-409	-490	-468	-826	-822
AUS	-58	-82	-82	-81	-147	-151
NZL	-9	-10	-9	-9	-16	-17
CAN	-129	-133	-126	-132	-226	-243
KOR	-131	-116	15	31	19	41
NEX	-690	-796	71	107	96	153
NEM	-526	-568	49	109	63	151
Annex 1	-3077	-3364	-3447	-3485	-6079	-6363
Non-Annex 1	-2380	-2539	160	330	210	455
Leakage (%)	0	0	4.6	9.5	3.5	7.1
World	-5457	-5903	-3288	-3155	-5869	-5909

Table 4 – Change in Trade Balance for ferrous metals (95US$million)

Region	Experiment 2			Experiment 3		
	GTAP 4	GTAP 4-E	Change	GTAP 4	GTAP 4-E	Change
USA	-1191	-866	325	-2184	-1829	355
CHN	294	663	369	528	1224	696
FSU	289	-726	-1015	189	-1575	-1764
JPN	-269	933	1202	-94	2003	2097
IND	100	175	75	176	336	160
DEU	-1145	-7246	-6101	-1880	-12608	-10728
GBR	-77	984	1061	-125	1789	1914
REU	-1172	-1974	-802	-2085	-4280	-2195
AUS	11	-48	-59	9	-131	-140
NZL	-1	20	21	-2	40	42
CAN	-46	355	401	-49	727	776
KOR	222	391	169	404	756	352
NEX	1831	3633	1802	2984	6462	3478
NEM	1037	3461	2424	1905	6517	4612
Annex 1	-3601	-8568	-4967	-6221	-15864	-9643
Non-Annex 1	3484	8323	4839	5997	15295	9298
World	-117	-245	-128	-224	-569	-345

Table 5 – Change in Trade Balance for Chemical, Rubber, and Plastics (95US$million)

Region	Experiment 2			Experiment 3		
	GTAP 4	GTAP 4-E	Change	GTAP 4	GTAP 4-E	Change
USA	461	-1798	-2259	1089	-3742	-4831
CHN	443	1210	767	813	2282	1469
FSU	-4368	-526	3842	-7132	-1028	6104
JPN	-1811	-260	1551	-4017	-209	3808
IND	154	347	193	278	616	338
DEU	238	-668	-906	939	-287	-1226
GBR	-252	-2006	-1754	-612	-4289	-3677
REU	-1233	-6723	-5490	-1776	-11432	-9656
AUS	110	-67	-177	213	-163	-376
NZL	-45	-183	-138	-78	-368	-290
CAN	-423	-1402	-979	-777	-2943	-2166
KOR	203	799	596	410	1464	1054
NEX	5008	7942	2934	7880	13745	5865
NEM	1453	2991	1538	2526	5586	3060
Annex 1	-7323	-13633	-6310	-12151	-24461	-12310
Non-Annex 1	7261	13289	6028	11907	23693	11786
World	-62	-344	-282	-244	-768	-524

Table 6 – Change in Trade Balance for I_S and CRP in Experiment 1 (95US$million)

Region	I_S			CRP		
	GTAP 4	GTAP 4-E	Change	GTAP 4	GTAP 4-E	Change
USA	3448	1561	-1887	-569	-280	289
CHN	16	291	275	-2400	11	2411
FSU	-4109	-102	4007	1470	145	-1325
JPN	-28	1633	1661	1941	2705	764
IND	-140	-178	-38	-302	-149	153
DEU	2199	1375	-824	-332	-6843	-6511
GBR	567	-1250	-1817	238	1401	1163
REU	1731	-3957	-5688	382	-326	-708
AUS	189	28	-161	184	91	-93
NZL	-38	-156	-118	12	32	20
CAN	-168	-1095	-927	103	527	424
KOR	-394	-1130	-736	-634	380	1014
NEX	-366	7234	7600	1244	2889	1645
NEM	-3304	-5138	-1834	-1689	-1072	617
Annex 1	3791	-1963	-5754	3429	-2548	-5977
Non-Annex 1	-4188	1079	5267	-3781	2059	5840
World	-397	-884	-487	-352	-489	-137

Table 7 Change in welfare (95US$billion)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	-16.2	-27.8	-18.0	-28.7	-59.9	-91.5
CHN	-8.1	-5.4	-0.5	-0.9	-1.0	-1.9
FSU	-13.8	-11.0	-12.7	-9.4	-30.4	-21.1
JPN	-4.0	-36.8	-6.6	-36.8	-26.5	-82.3
IND	-1.1	-3.3	0.6	1.7	0.8	2.1
DEU	-2.8	-100.0	-3.5	-100.0	-10.7	-200.0
GBR	-4.9	-24.0	-4.6	-23.3	-11.5	-47.6
REU	-16.5	-300.0	-19.6	-300.0	-54.1	-600.0
AUS	-3.9	-4.2	-3.3	-3.6	-6.8	-7.7
NZL	-0.2	-0.3	-0.2	-0.3	-0.6	-0.9
CAN	-5.4	-10.6	-4.9	-10.2	-10.8	-21.4
KOR	-0.3	-0.3	1.4	1.7	1.6	1.7
NEX	-77.5	-100.0	-30.1	-42.1	-41.2	-56.4
NEM	-11.3	-31.2	3.8	9.3	4.4	11.2

Table 8 Change in welfare due to allocative efficiency effect (95US$billion)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	-27.8	-41.0	-26.9	-40.0	-71.1	-105.1
CHN	-7.9	-4.4	0.1	-0.3	-0.1	-0.7
FSU	-12.3	-7.3	-12.0	-6.7	-29.7	-17.8
JPN	-14.2	-46.4	-14.0	-45.1	-37.3	-93.1
IND	-1.9	-4.1	0.2	0.9	0.2	1.1
DEU	-7.1	-140.3	-7.2	-135.9	-16.7	-251.6
GBR	-3.8	-21.5	-3.7	-21.6	-10.3	-45.1
REU	-26.6	-286.2	-26.4	-282.0	-61.8	-540.2
AUS	-2.7	-2.8	-2.6	-2.7	-5.9	-6.3
NZL	-0.3	-0.4	-0.2	-0.5	-0.7	-1.1
CAN	-3.5	-8.8	-3.3	-8.5	-8.8	-19.5
KOR	-3.7	-3.9	0.1	0.0	0.1	-0.2
NEX	-33.1	-84.6	-1.2	0.8	-1.8	0.8
NEM	-19.0	-41.0	0.5	4.4	0.6	5.8

Table 9 Change in welfare due to terms of trade effects (95US$billion)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	8.9	9.5	7.5	9.1	9.0	10.0
CHN	0.8	0.5	0.2	0.6	0.3	1.0
FSU	-1.5	-3.5	-0.8	-2.6	-0.5	-3.1
JPN	12.0	12.8	8.5	10.5	12.6	14.9
IND	0.9	0.9	0.4	0.7	0.6	0.8
DEU	3.2	5.7	2.4	5.2	3.2	6.6
GBR	-1.4	-2.5	-0.9	-1.6	-1.4	-2.1
REU	12.9	19.6	9.3	16.8	13.1	24.2
AUS	-1.2	-1.5	-0.7	-1.0	-0.9	-1.5
NZL	0.1	0.2	0.1	0.2	0.2	0.3
CAN	-1.5	-1.2	-1.4	-1.3	-1.6	-1.2
KOR	3.3	3.4	1.2	1.6	1.4	1.6
NEX	-43.2	-52.4	-28.4	-42.0	-38.6	-55.6
NEM	6.6	7.9	2.4	2.9	2.1	1.8

Table 10 –Purchase of domestic energy commodities by firms (US95$mill)

	GTAP 4			GTAP 4-E			Difference		
	Market Value	Tax	Agent's value	Market Value	Tax	Agent's value	Market Value	Tax	Agent's value
				DEU					
COL	604	0	604	682	0	682	78	0	78
OIL	0	0	0	0	0	0	0	0	0
GAS	975	0	975	15	4	19	-960	4	-956
P_C	1426	0	1426	4256	9409	13665	2830	9409	12238
ELY	1693	0	1693	991	138	1129	-702	138	-564
				USA					
COL	2201	200	2401	965	0	965	-1236	-200	-1435
OIL	11	0	12	0	0	0	-11	0	-12
GAS	2804	129	2933	654	0	654	-2150	-129	-2279
P_C	294	17	311	2036	0	2036	1742	-17	1725
ELY	2998	187	3184	5318	0	5318	2320	-187	2133
				JPN					
COL	90	0	90	6	0	7	-83	0	-83
OIL	1	0	1	0	0	0	-1	0	-1
GAS	7554	21	7575	105	14	119	-7449	-8	-7457
P_C	717	0	717	596	507	1103	-121	507	386
ELY	8841	-15	8826	16897	390	17287	8056	405	8460

Table 11 – Purchase of domestic energy commodities by firms (break up of market expenditure and tax into shares of total)

	GTAP 4		GTAP 4-E		Difference	
	Market Value	Tax	Market Value	Tax	Market Value	Tax
			DEU			
COL	1.00	0	1.00	0	0	0
OIL	1.00	0	1.00	0	0	0
GAS	1.00	0	0.78	0.22	-0.22	0.22
P_C	1.00	0	0.31	0.69	-0.69	0.69
ELY	1.00	0	0.88	0.12	-0.12	0.12
			USA			
COL	0.92	0.08	1.00	0	0.08	-0.08
OIL	0.97	0.03	1.00	0	0.03	-0.03
GAS	0.96	0.04	1.00	0	0.04	-0.04
P_C	0.95	0.05	1.00	0	0.05	-0.05
ELY	0.94	0.06	1.00	0	0.06	-0.06
			JPN			
COL	1.00	0	0.97	0.03	-0.03	0.03
OIL	1.00	0	1.00	-	-	-
GAS	1.00	0	0.88	0.12	-0.11	0.11
P_C	1.00	0	0.54	0.46	-0.46	0.46
ELY	1.00	0	0.98	0.02	-0.03	0.03

Table 12 Percentage change in industry output of petroleum and coal products (P_C)

Region	Experiment 1		Experiment 2		Experiment 3	
	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E	GTAP 4	GTAP 4-E
USA	-32.0	-31.5	-32.1	-32.1	-49.6	-52.0
CHN	-7.0	-2.8	2.2	3.7	3.0	5.3
FSU	-28.0	-28.9	-27.9	-29.0	-44.1	-46.1
JPN	-26.0	-25.5	-25.5	-25.4	-41.0	-42.0
IND	-14.3	-13.3	3.6	10.4	5.4	15.0
DEU	-24.1	-32.8	-25.7	-32.3	-39.2	-50.2
GBR	-34.3	-32.6	-34.6	-35.3	-52.8	-56.5
REU	-29.4	-28.9	-29.4	-29.5	-46.1	-47.8
AUS	-25.7	-21.5	-25.7	-22.9	-41.9	-39.2
NZL	-28.1	-28.3	-28.4	-30.0	-45.2	-48.7
CAN	-27.2	-29.5	-28.6	-32.2	-45.7	-53.5
KOR	-23.0	-19.9	6.2	14.1	9.4	20.9
NEX	-31.9	-38.7	3.5	0.7	5.7	2.8
NEM	-33.5	-28.9	0.8	10.0	1.8	15.4

References

Babiker, M. H., and T. F. Rutherford (1997) "Input-output and general equilibrium estimates of embodied carbon: A data set and static framework for assessment", Working Paper 97-2, University of Colorado, Boulder.

Felden, Stefan, and Thomas F. Rutherford (1993), "Unilateral CO_2 reductions and carbon leakage: the effect of international trade in oil and basic materials," *Journal of Environmental Economics and Management*, 25, 162-176.

International Energy Agency (IEA) (1998), *World Energy Prospects to 2020*, Paper prepared for the G8 Energy Ministers' Meeting, Moscow, 31 March – 1 April. http://www/iea.org/g8/world/index.htm.

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

Malcolm, G. and Truong, P Truong (1999), "The Process of Incorporating Energy Data into GTAP" Draft GTAP Technical Paper, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana University.

McDougall, R., Elbehri, A., and Truong, P. Truong (eds.) (1998), *Global Trade, Assistance, and Protection: the GTAP 4 Data Base*, Center for Global Trade Analysis, Purdue University.

Perroni, Carlo, and Thomas F. Rutherford (1993), "International trade in carbon emission rights and basic materials: general equilibrium calculation for 2020," *Scandinavian Journal of Economics*, 95(3), 257-278.

Truong, P. Truong (1999) "GTAP-E Incorporating Energy Substitution into GTAP Model" Draft GTAP Technical Paper, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana.

Appendix

Table 1: List of Sectors and Regions

Sector	Description
COL	Coal
OIL	Crude oil
GAS	Gas
P_C	Petroleum, coal products
ELY	Electricity
I_S	Ferrous metals
CRP	Chemical, rubber, plastic products
NFM	Metals nec
NMM	Mineral products nec
PPP	Paper products, publishing
OMN	Other Manufacturing
T_T	Trade, transport
AGR	Agriculture, forestry and fish
SER	Commercial/public services/Dwellings

Region	Description
USA	United States of America
CHN	China
FSU	Former Soviet Union
JPN	Japan
IND	India
DEU	Germany
GBR	United Kingdom
REU	Rest of European Union
AUS	Australia
NZL	New Zealand
CAN	Canada
KOR	Korea
NEX	Net Energy Exporters
NEM	Net Energy Importers