GTAP-E: An Energy-Environmental Version of the GTAP Model with Emission Trading

USER'S GUIDE

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1. Introduction

This document describes how the GTAP-E model is constructed. GTAP-E is an extension of the standard GTAP model, hence, for documentations on the standard GTAP model, see McDougall (2003a, b). The method used in constructing (this version of)[1] the GTAP-E model is very much a 'modular' approach. We first go through any latest version of the standard GTAP model and block out the parts which are going to be replaced by the GTAP-E modules. Then, at the end of the GTAP program, we insert the extra 'modules'. These modules are designed in such a way that they can be modified or extended independently of the GTAP model, i.e. mostly 'self-contained'. The approach is considered to be useful because often works carried out by different researchers on the standard GTAP have the potential to complement each other, and therefore, it is important that their works can be linked or brought together on a 'common platform' such as the GTAP model with a minimum level of efforts required at 'interfacing' and\or redesigning.

2. The GTAP-E Modules

Currently, there are three separate 'modules' which can be 'integrated' (or added on) to the standard GTAP model to become a "GTAP-E" model. These are:

(a) The basic "***E***-module". Here "E" stands for "***E***nergy substitution". This module replaces the original GTAP *production* as well as *consumption* structure with a different one, containing substitution between capital and energy and between different fuels. The substitution structures are as described in details in Truong (1999), Burniaux and Truong (2002), or Truong, Kemfert and Burniaux (2007)[2]. To ensure 'backward compatibility' or useful comparison with the standard GTAP model, the "E-module" is designed in such a way that it can be run in two different modes: the standard GTAP mode and the GTAP-E mode. To activate the standard GTAP mode, the two 'switch' parameters called "SW_F" (*SW*itching the *F*irm's production structure) and "SW_C" (*SW*itching the private household and government *C*onsumption structure) should be set to '0'. Then, to run the GTAP-E mode, we simply 'switch' one[3] or both of these parameters to the value of '1'.

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[1] This is to distinguish the version described in this document from another version written by Jean-Marc Burniaux and modified/extended by Alla Golub and R. McDougall.

[2] Of course, these structures can also be modified and\or extended in the future if so desired.

[3] Note that in comparison to another version of the GTAPE model written by Jean-Marc Burniaux (see Burniaux and Truong (2002)) which does not have an energy substitution structure for consumption activities, this version of the *E*-module can produce results which are comparable with those from the 'Burniaux version' if SW_F is set to '1', but SW_C remains at '0'.

(b) A "***C***-module" which stands for "***C***O$_2$ emissions module". This module can read in information on *quantities* of fossil fuel usage from an exogenous data base, and calculate CO_2 emissions based on these energy quantities – or, simply read in the CO_2 emissions information directly from an emissions data base (such as the GTAP emissions data base – see Lee (2002)). Given the availability of the emissions data base, the current version of the ***C***-module is written in the latter fashion, i.e. reading in CO_2 emissions directly without having to read in the energy volume information, and then 'link' these emissions directly to the levels of economic activities defined within the GTAP(E) model. Future works on the ***C***-module however, may want to read in the energy flow information instead of the emissions information, and estimates emissions from this energy information.. This is useful, for example, when users want to improve on the method of CO_2 emissions accounting, and\or supplement some part of the GTAP energy volume information with their own sources of these information..

(c) A "***T***-module" which stands for "emissions ***T***rading". The type of emissions trading behaviour can range from 'domestic' trading between selected sectors of an economy (including or excluding the household sector), and between different economies of the world.

3. Running the GTAP-E Model

To run the GTAP-E model, we assume that the user is familiar with the "RunGTAP" facility[4], since this will allow us to describe the setting up of the 'control' files to run the model in the simplest possible way. Essentially, the user is mainly concerned with the setting up of 4 different files: (1) BASEDATA.HAR file, which contains the basic data, (2) SETS.HAR file, which describes the sets of variables and coefficients required for running the model, (3) the ".PRM" files which contain parameters required for specific 'experiments', and finally (4) the ".EXP" files which describe these experiments. We will assume that the user starts with these four types of files for a typical standard GTAP model run, then describe the additional data that are required for the GTAP-E model.

<u>BASEDATA.HAR</u>: This standard GTAP data file for RunGTAP will need to be supplemented with the following additional 'header arrays' for running with the GTAP-E model:

"CODF" (type: RE, dimension TRAD_COMM*PROD_COMM*REG)[5]: this array describes the CO_2 emissions associated with the ***F***irm's usage of ***D***omestic commodity *i* in sector *j*, in region *r*, where $i \in$ TRAD_COMM, $j \in$ PROD_COMM, and $r \in$ REG. Note that

[4] https://www.gtap.agecon.purdue.edu/products/rungtap/default.asp.

[5] These are GTAP and GEMPACK terminology, hence the user is referred to the standard GTAP model for detailed explanation.

since only fossil fuels emit CO_2, the array contains non-zeros only for $i\in$EGY_COMM (energy commodities)[6].

“COIF” (type: RE, dimension TRAD_COMM**PROD_COMMREG: this array describes the CO_2 emissions associated with the ***F***irm’s usage of ***I***mported commodity *i* in sector *j*, in region *r*, where $i\in$TRAD_COMM, $j\in$PROD_COMM, and $r\in$REG (non-zero only for $i\in$EGY_COMM (energy commodities)).

Similarly, “CODP”, “COIP”, “CODG”, “COIG”, (all of type RE, dimension TRAD_COMM*REG), describing CO_2 emissions associated with ***P***rivate household and ***G***overnment consumption of commodity *i* in region *r* (non-zero only for $i\in$EGY_COMM (energy commodities)). The emissions arrays can be generated from the GTAP CO_2 emissions data base.

“TAXF” (type: RE, dimension PROD_COMM*REG): this array describes the initial CO_2 tax ($/tC) on ***F***irm’s emissions in sector $j\in$PROD_COMM and region $r\in$REG.

“TAXC” (type: RE, dimension REG): similarly, this describes the initial CO_2 tax on ***C***onsumption activities (private household and government) in region $r\in$REG. Often, these tax arrays contain only zero values initially. However, for dynamic simulation, subsequent-period values for these tax arrays in the (updated) data bases may contain non-zero values.

SETS.HAR: This standard GTAP set file will need to be supplemented with the following additional sets for GTAP-E runs:

“EGY5” (type: 1C, dimension 5 length 12): this set contains the five names of the energy commodities in alphanumeric characters, up to 12 in length. This set is essential because it has often been found that users may prefer to adopt different names to refer to the 5 basic energy commodities (for example, some may refer to coal as ‘col’, or ‘coa’’), hence it is convenient to allow for this definition of names to be ‘exogenous’ of the GTAP-E model. This same comment applies to the next set of arrays (described below).

“COL” type: 1C, dimension 1 length 12: name for coal commodity. (e.g. “coal”, or “col”)..

“OIL” type: 1C, dimension 1 length 12: name for oil commodity (e.g. “oil” or “crude oil”).

“GAS” type: 1C, dimension 1 length 12: name for gas commodity (e.g. “gas”).

“P_C” type: 1C, dimension 1 length 12: name for p_c commodity (e.g. “Oil_Pcts” or “p_c”)..

[6] and therefore, could be re-dimensioned appropriately. However, to maintain compatibility with other versions of the GTAP-E model, we keep the dimension as described.

“ELY” type: 1C, dimension 1 length 12: name for electricity commodity (e.g. “electricity” or “ely”).

“LAB” type: 1C, dimension 1 length 12: the name for labour endowment (e.g. “lab”, or “labour”)..

The Parameter (.PRM) Files: This standard parameter file in a GTAP model run is often called DEFAULT.PRM. Assuming that the user starts with this file. This file will then need to be supplemented with the following header arrays in order to be used with the GTAP-E model:

“SW_F” (type: 2I, dimension 1): This integer ‘dummy’ or ‘switch parameter’, is set equal to ‘0’ if the standard GTAP production mode is to be used, otherwise, it is set equal to ‘1’ if the GTAP-E production mode is to be chosen.

“SW_C” (type: 2I, dimension 1): This is the similar parameter switch for consumption structure: “0” if standard GTAP consumption structure is to be used, and ‘1’ if the GTAP-E consumption mode is to be chosen.

“TSEC” (type: RE, dimension PROD_COMM*REG): This real dummy parameter value is to define the emission trading sectors: ‘1’ if the sector *j* in region *r* is to be engaged in emissions trading; ‘0’ if otherwise, where $j \in$ PROD_COMM and $r \in$ REG.

“TCON” (type: RE, dimension REG): Similarly for the ‘*CON*sumption’ (i.e. private household and government consumption) sector: ‘1’ if included in emissions trading; ‘0’ if otherwise. $r \in$ REG.

“AREG” (type: RE, dimension REG): This is to define the set of Annex 1 regions for convenient printing out of the results; ‘1’ if Annex 1 region and ‘0’ if otherwise.

“TREG” (type: RE, dimension REG): This defines the emissions *T*rading *REG*ions: ‘1’ if trading – between regions – and ‘0’ if otherwise.

From the above description, we can now distinguish between different possible ‘scenarios’ or experiments:

(1) If all the elements of TREG are set equal to 0 (no regional trading in emissions) and if all the elements of TSEC and TCON are also set equal to 0 (no sectors or final consumers are engaged in emissions trading), then this can be referred to as the case of ‘NO TRADING”, and the parameter file can be given a name such as ‘NOTRADE.PRM’. This parameter file can then be used in experiments which seek to estimate the ‘marginal abatement cost’ curve for individual sectors in an economy in the absence of any trading in emissions (see descriptions of the ‘.EXP’ files below).

(2) If all elements of TREG are set equal to 0 (no regional trading in emissions) but some or all of the values of the arrays TSEC and/or TCON are set to 1, then this refers to a situation where there may be ‘domestic’ emissions trading between some sectors, even if

there are no regional emissions trading. We can refer to this as a case of ‘DOMESTIC TRADING’ and the file can be given a name such as ‘DOMTR.PRM’.

(3) If all the values of the array `TREG` are set equal to 1 (and therefore, all or at least some of the values of the arrays `TSEC` and `TCON` must also be set equal to 1), then this refers to the situation of ‘world emissions trading’, and the parameter file can be given a name such as ‘WORLDTR.PRM’.

(4) For some special cases, for example, when the values of the array `TREG` are set equal to 1 only for ANNEX 1 regions, this implies trading between Annex 1 regions, and hence the parameter file can be referred to by a name such as ‘ANNEXTR.PRM’.

<u>The Experiment (.EXP) Files:</u> Once the parameter files are set up, we can then set up the ‘experiment’ (.EXP) files. These files contains information on how each experiment is carried out. First, there is the issue of ‘closure’: for the GTAP-E program, the ‘standard’ closure may look like the following (which is also contained in the basic experiment file called GTAP-E.EXP):

```
! basic closure for GTAP-E
Exogenous
! --- standard GTAP closure --------------------
          pop pfactwld
          psaveslack profitslack incomeslack
          endwslack  cgdslack tradslack
          ams atm atf ats atd au
          aosec aoreg avasec avareg aoall
          afcom afsec afreg afall
          afecom afesec afereg afeall
          dppriv dpgov dpsave
          to tp tm tms tx txs
          qo(ENDW_COMM,REG)
!         tfd tfm tpd tpm tgm tgd : blocked for CO2TAX-module
! ---E-module-------------------------
          afLab afKE afNELY afNCOL afener
! ---C-module-------------------------
! non carbon tax on ENERGY commodities need to remain exogenous:
          tpd_nc tpm_nc tgd_nc tgm_nc tfd_nc tfm_nc
! tax on NON-ENERGY commodities need to remain exogenous:
          tpd(NEGY_COMM,REG) tpm(NEGY_COMM,REG)
          tgd(NEGY_COMM,REG) tgm(NEGY_COMM,REG)
          tfd(NEGY_COMM,PROD_COMM,REG)
          tfm(NEGY_COMM,PROD_COMM,REG)
! ---T-module-------------------------
          c_INT_MARKCTAX  c_DOM_MARKCTAX
          c_SEC_CTAX      c_CON_CTAX
          p_CO2SQ         p_CO2CQ;
Rest Endogenous ;
```

From this ‘basic’ closure, we then formulate the closure for various experiments. For example:

NOTRADE.EXP

When there are no emissions trade (either domestically or internationally), we can run the GTAP-E model to estimate, for example, the carbon tax which is required to reduce CO_2 emissions by a certain amount in certain sectors of an economy (including the household or consumption sector. This ‘carbon tax’ can also represent the ‘marginal abatement cost’ of reducing CO_2 emissions if the user chooses to do this unilaterally rather than paying the tax. In experiments such as this, *either* the ‘price’ of emissions (carbon tax) is fixed exogenously and shocked leaving the model to determines the level of emissions endogenously; *or* vice versa. In the former case, we can leave the standard closure as is, and then simply shock the relevant carbon tax. For example:

```
shock c_SEC_CTAX(“electricity”,”USA”) = 10;
```

This says: change the absolute amount (c_) of the sectoral carbon tax (SEC_CTAX) in the electricity sector in USA by 10 ($/tC). The model will then determine, among other things, the level of emissions reduction which will result from this tax, which is described by the variable p_CO2SR which stands for percentage change (p_) in CO_2 emissions by sector and region (SR). Alternatively, or in addition, we can also:

```
shock c_CON_CTAX(”USA”) = 5;
```

which means: change the absolute carbon tax on consumption activities (CON_CTAX) in the USA by 5 ($/tC). The model will then determine, among other things, the reduction of CO_2 emissions in the ‘consumption’ sector by a percentage which is described by the variable p_CO2CR which stands for percentage change (p_) in CO_2 emissions in the consumption sector in the region (CR).

Instead of shocking the carbon tax, we can shock the CO_2 emissions and let the model determine the required carbon tax endogenously. In this case, before we shock the CO_2 emissions variables (p_CO2SR and\or p_CO2CR), we need to ‘swap’ endogenous\exogenous status of the two variables by statements such as:

```
swap c_SEC_CTAX(“electricity”,”USA”) = p_CO2SR(“electricity”,”USA”);
swap c_CON_CTAX(”USA”) = p_CO2CR(”USA”);
```

Finally, we can also do this type of experiments with regions rather than sectors. For example:

```
shock c_DOM_MARKCTAX(”JPN”) = 25;
```

will change the domestic market price for carbon in Japan (“JPN”) by 25$/tC. This will result in changes in CO_2 emissions in the whole region by a percentage described by the variable p_CO2R. Alternatively, we can swap and then shock:

```
swap c_DOM_MARKCTAX(”JPN”) = p_CO2R(“JPN”);
shock p_CO2R(“JPN”)= -25;
```

This says: endogenise `c_DOM_MARKCTAX(”JPN”)` and exogenise `p_CO2R(“JPN”)` and then shock the latter by -25 (percent). The model will then determine the value of `c_DOM_MARKCTAX(”JPN”)` endogenously. An example of experiment of this kind is given by the following, so-called “Kyoto with No Trade” (KyoNOTR.EXP) experiment:

```
swap  p_CO2R("USA") = c_DOM_MARKCTAX("USA");
swap  p_CO2R("EU") = c_DOM_MARKCTAX("EU");
swap  p_CO2R("JPN") = c_DOM_MARKCTAX("JPN");
swap  p_CO2R("RoA1") = c_DOM_MARKCTAX("RoA1");
Shock p_CO2R("USA")   = -35.6;
Shock p_CO2R("EU")    = -22.4;
Shock p_CO2R("JPN")   = -31.8;
Shock p_CO2R("RoA1")  = -35.7;
```

Note that when we do experiments of this kind (shocking emissions or carbon taxes at the *regional* rather than at the sectoral level), the implicit assumption is that the tax is applied uniformly to all or to selected sectors as described by the header arrays TSEC and TCON contained in the parameter (.PRM) file. Hence it is important to specify these headers TSEC and TCON appropriately although we are not talking about emissions trading in these experiment[7].

DOMTR.EXP:

Here we assume that there are emissions trading at least between two sectors (and can include the final consumption sector)[8] in selected regions but there are no emissions trading between the regions. Trading occurs only when there are ‘quotas’ set for the emissions, hence, we will first deal with the issue of ‘quotas’. This is specified in the two variables `p_CO2SQ` and `p_CO2CQ` which are normally assumed to be exogenous and zero in the standard closure. When a particular industry sector (`S`) or the consumption sector (`S`) is given a quota (`Q`), these variables will then be shocked by an appropriate amount[9]. For example:

```
shock p_CO2SQ("Electricity","EU")=-30;
shock p_CO2SQ("En_Int_ind","EU")=-20;
shock p_CO2CQ("EU")=-10;
```

[7] Trading can only occur when sectors are given ‘quotas’. These quotas are represented by the variables `p_CO2SQ` and `p_CO2CQ` (where `‘Q’` stands for ‘Quota’, and `S` and `C` stand for (industry) *S*ector and *C*onsumption sector respectively) and these variables are left exogenous and not shocked (i.e. zero) in these ‘No Trade’ experiments, hence it is not appropriate to talk about ‘emissions trading’ in this case. The TSEC and TCON headers, however, are used to specify which sector is included/excluded in the targeting and imposition of the carbon tax.

[8] As specified in the arrays TSEC and TCON.

[9] These variables stand for percentage changes, hence the (absolute) quota levels need to be converted into percentage changes by using the base year emission level as the base.

Next, to allow for the carbon tax (price of emissions) in these sectors to become endogenous, we swap these taxes with their corresponding 'slack' variables:

```
      swap c_SECTAX_slack("Electricity","EU") =
c_SEC_CTAX("Electricity","EU");
      swap c_SECTAX_slack("En_Int_ind","EU") =
c_SEC_CTAX("En_Int_ind","EU");
      swap c_CONTAX_slack("EU") = c_CON_CTAX("EU");
```

Finally, if trading is to occur between these sectors, then these carbon taxes (emissions prices) must be the same across these sectors, which can be achieved by 'forcing' all these taxes to be equal to a "domestic market carbon tax' (`c_DOM_MARKCTAX`) which, in the standard closure, is assumed to be exogenous (i.e. zero). To allow this to be endogenous, we need to swap this (price) variable with a quantity variable, and this is provided by the variable defining the total emissions of all the trading sector, `p_CO2TS_T`. However, if we swap (`c_DOM_MARKCTAX`) with `p_CO2TS_T`, we will then need to shock the latter by an appropriate amount (which can be calculated but not known readily). A short cut is to say that this total amount must also be equal to the total *quota*, which is given by the variable `p_CO2SQ_T` calculated internally by the model from the shocked values of `p_CO2SQ`. Hence, a way to 'force' the equality between `p_CO2TS_T` and `p_CO2SQ_T` is to say that the 'slack' variable (`p_CO2TS_slack`) which defines the difference between these two variables, must be set exogenous. We thus end up with a short cut statement:

```
      swap p_CO2TS_slack("EU")  = c_DOM_MARKCTAX("EU");
```

The same procedure can of course be repeated for other sectors in other regions, and this can be carried out simultaneously within a single experiment. So we may end up with trading between the sectors "`Electricity`", `"En_Int_ind"` and the consumption sector in `"EU"` as defined by the above statements, and also trading between, say, sectors `"En_Int_ind"` and `"Oth_int_ser"` in `"JPN"` which is going to be defined by the following statements:

```
      swap c_SECTAX_slack("En_Int_ind","JPN") =
c_SEC_CTAX("En_Int_ind","JPN");
      swap c_SECTAX_slack("Oth_ind_ser","JPN") =
c_SEC_CTAX("Oth_ind_ser","JPN");
      swap p_CO2TS_slack("JPN")  = c_DOM_MARKCTAX("JPN");
```

All of this, of course, can be contained within a single experiment. In this case, the experiment called simply "DOMTR.EXP".

<u>**REGTR.EXP**</u>:

In this case, we assume that there are emissions trading between sectors as well as between different regions[10]. Before proceeding, we need to change one particular variable in the standard closure: if we assume that with emissions trading, countries will maintain their

[10] Note that in practice there would not be regional trading if there is no domestic trading as well.

trade balances *inclusive of emissions trading* rather than exclusive of emissions trading, then we need to replace the standard trade balance variable DTBAL in the closure with DTBALCTRA, the latter variable is trade balance inclusive of emissions trading. Next, following Burniaux and Truong (2002)) we assume that all regions except one (say "RoW") maintain their trade balances, hence we swap this variable with cgslack for that particular region:

```
swap cgdslack("RoW") = dtbalctra("RoW");
```

The stage is now set for specifying the regional emissions trading experiment. To do this, we first need to define the targets of emissions reduction for each region before trading (i.e. their emissions quotas). This is specified in the variable p_CO2RQ (where RQ stands for Regional Quota) and which is already specified as being exogenous in the standard closure. All we need to do therefore is simply to shock these quotas by appropriate values. For example in an experiment called "Kyoto with Annex Trading", we shock these quotas for the Annex 1 regions with the following values:

```
shock p_CO2RQ("USA")   = -35.6;
shock p_CO2RQ("EU")    = -22.4;
shock p_CO2RQ("JPN")   = -31.8;
shock p_CO2RQ("RoA1")  = -35.7;
shock p_CO2RQ("EEFSU") = 12.869;
```

Next, the 'slack' variable which defines the difference between the *actual* total emissions for these trading regions and their total *quota* – p_CO2TR_slack - is now set to zero, i.e declared 'exogenous' or swapped with the (exogenous) INTternational MARKet Carbon TAX which will now become endogenous:

```
swap gCO2TR_slack  = c_INT_MARKCTAX;
```

If trading occurs only between selected regions[11] - such as Annex 1 regions - then we can label this experiment appropriately by a name such as AnnexTR.EXP (or KyoTR.EXP). If trading is to occur between all regions of the world, then the experiment can be referred to as "world Trading" (WorldTR.EXP).

References

Burniaux JM, and Truong P. Truong. (2002) " GTAP-E :An Energy-Environmental Version of the GTAP Model", GTAP Technical Paper No. 16 (Revised), January. https://www.gtap.agecon.purdue.edu/resources/download/1203.pdf

[11] As defined by header array TREG in the parameter file

Lee, Huey-Lin (2002), "An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP", Draft GTAP Working Paper, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA
https://www.gtap.agecon.purdue.edu/resources/download/1218.pdf

McDougall, R. (2003a), "GTAP.TAB Release 6.2", GTAP Research Memoranda No. 3, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA.
https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1371

McDougall, R. (2003b), "Style Guidelines Observed in gtap.tab Release 6.2", GTAP Research Memorandum No. 4, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA
https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1372

Truong, T. P. (1999). "GTAP-E : Incorporating Energy Substitution into the GTAP Model", GTAP Technical Paper No. 16, December.

Truong, T. P., Kemfert, C., and Burniaunx, J-M. (2007) "GTAP-E :An Energy-Environmental Version of the GTAP Model with Emissions Trading", DIW (Deutsches Institut für Wirtschaftsforschung) Discussion Paper 668, February.
http://www.diw.de/deutsch/produkte/publikationen/diskussionspapiere/docs/papers/dp668.pdf.