GTAP-E: A Revised Energy-Environmental Version of the GTAP Model

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GTAP Research Memorandum No. 15

October 2007

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1   Introduction

The purpose of this memorandum is to document recent revisions to the energy environmental extension of the GTAP Model (GTAP-E) described in GTAP Technical Paper No.16 by Burniaux and Truong (2002). We revise the solution program, data, stored input and command files, and welfare decomposition program. The revisions are undertaken to improve the model's user friendliness, adapt it to a wider range of energy-environmental policy scenarios, and correct errors. A technical paper documenting the theoretical structure of GTAP-E is forthcoming.

Associated with this memorandum is a RunGTAP zip archive containing four experiments:

- price homogeneity test: gtap
- Kyoto without emission trading: kyonotr
- Kyoto with Annex 1 trading: kyotr
- Kyoto with worldwide trading: kyowtr

2   Theoretical structure

2.1   Emission accounting

We add to the data file new arrays showing carbon dioxide emissions by region, commodity, and use. We read these into coefficients CO2DF, emissions from firms' usage of domestic product, CO2IF, emissions from firms' usage of imports, CO2DP, emissions from private consumption of domestic product, and so on. We define corresponding variables, gco2fd for emissions from firms' usage of domestic product, gco2fm for emissions from firms' usage of imports, gco2pd for emissions from private consumption of domestic product, and so on. We assume that emissions are proportional to usage, for instance,

$$gco2fd(i,j,r) = qfd(i,j,r)$$

We calculate emissions gco2 by region and commodity by summing over uses:

$$\begin{aligned}
CO2(r,i) * gco2(r,i) = sum(j,\ & PROD\_COMM,\ CO2IF(i,j,r) * gco2fm(i,j,r) \\
& + CO2DF(i,j,r) * gco2fd(i,j,r)) \\
& + CO2DG(i,r) * gco2gd(i,r) + CO2IG(i,r) * gco2gm(i,r) \\
& + CO2DP(i,r) * gco2pd(i,r) + CO2IP(i,r) * gco2pm(i,r)
\end{aligned}$$

Similarly we calculate emissions by region, gco2t, by summing over commodities, and world emissions, gco2tw, by summing over regions.

2.2 Emission permits and emission trading

To represent emission trading, we divide the world into *blocs* of regions trading emission permits amongst themselves; a non-trading region is just a one-region bloc. With no trading, the set BLOC of blocs is just the set of regions; with Annex 1 trading, the Annex 1 regions form one bloc together, and the non-Annex-1 regions form blocs individually. A mapping REGTOBLOC shows which regions belong to which blocs. One might expect to find the set of blocs and the region-to-bloc mapping in the sets file. RunGTAP, however, allows only one sets file per version, so, to allow different trading scenarios in the same RunGTAP version, we store them counterintuitively in the parameters file.

With emission trading, regions' actual emissions gco2t and emission quota gco2q may diverge, but bloc-level actual emissions gco2tb and emission quota gco2qb must agree. Since emission trading equalizes the carbon tax rate within blocs, the carbon tax rate NCTAXB is a bloc-level variable.

To enable users to impose or relax emission constraints, we define a bloc-level power-of-purchases variable pempb, with

$$pempb(b) = gco2tb(b) - gco2qb(b)$$

Then we can impose emission constraints by making pempb exogenous and NCTAXB endogenous, and relax them by making pempb endogenous and NCTAXB exogenous.

With constraints in force, region-level quota gco2q is exogenous, and determines bloc-level quota gco2qb through an adding-up equation. Without constraints, the quota variables are not meaningful, yet to solve the model we must still somehow determine them. To that end we introduce an equation

$$pemp(r) = gco2t(r) - gco2q(r)$$

relating region-level quota to actual emissions through a region-level power-of-purchases variable pemp. When constraints are in force, we make gco2q exogenous, and pemp endogenous, so that region-level emissions and emission quota are decoupled; when not in force, we make gco2q endogenous, and pemp exogenous, so that region-level "quota" tracks emissions. In either case, bloc-level quota is determined by summing over regions.

2.3 Carbon taxation

As noted above, we can simulate an economic environment without emission constraints by making the bloc-level power of emissions purchases pempb endogenous and the carbon tax rate NCTAXB exogenous. But NCTAXB is a nominal tax rate, so, if it is exogenous, and if the initial carbon tax rate is non-zero, the model is not homogeneous in prices. To provide a price-homogeneous unconstrained emissions closure, therefore, we define a real carbon rate variable RCTAXB, also at the bloc level, and, for information only, a real region-level variable RCTAX.

We define the real tax rate as the nominal tax rate deflated by the income disposition price index, represented in levels by PIND and in percentage changes by p. We have the equation

$$RCTAX(r) = [1.0 / PIND(r)] * [NCTAXB(REGTOBLOC(r)) - 0.01 * NCTAXLEV(r) * p(r)]$$

for the region-level variable, and a similar equation for the bloc-level variable. The price-homogeneous unconstrained emissions closure then has RCTAXB exogenous, and NCTAXB and RCTAX endogenous.

Between market and agents' prices we now have two wedges, the *old ad valorem* tax and the new carbon tax. To distinguish them we introduce a new level of valuation, inclusive of non-carbon tax but exclusive of carbon tax. We define coefficients at this level, VDFANC for firms' usage of domestic product, VIFANC for firms' usage of imports, VDPANC for private consumption of domestic product, and so forth, reading them from new arrays in the data file. We elaborate the price linking equations to take account of the carbon tax; for the price to firms of domestic product, for instance, we have

$$pfd(i,j,r) = SHVDFANC(i,j,r) * [pm(i,r) + tfd(i,j,r)]$$
$$+ 100.0 * CO2DFVDFA(i,j,r) * NCTAXB(REGTOBLOC(r))$$

where SHVDFANC represents the share of the carbon-tax-free value in the carbon-taxpaid value, VDFANC(i,j,r) / VDFA(i,j,r), and CO2DFVDFA represents carbon intensity, CO2DF(i,j,r) / VDFA(i,j,r). Note that this reduces to the standard gtap equation

$$pfd(i,j,r) = pm(i,r) + tfd(i,j,r)$$

when both the initial level of carbon tax revenue is zero, so SHVDFANC is equal to one, and change NCTAXB in the carbon tax rate is zero.

We exclude carbon tax revenue from the region-level tax revenue variables, del_taxriu for tax on intermediate usage, del_taxrpc for tax on private consumption, and so on. Instead, we define a levels variable VCTAX representing carbon tax revenue by region from all sources. This treatment is under review, and may change in later versions.

2.4   Net revenue from emission trading; regional income

The variable gco2q represents percentage change in the emission quota. The variable DVCO2TRA represents change in net emission trading revenue:

$$DVCO2TRA(r) = CO2Q(r) * NCTAXLEV(r) * 0.01 * gco2q(r)$$
$$- CO2T(r) * NCTAXLEV(r) * 0.01 * gco2t(r)$$
$$+ [CO2Q(r) - CO2T(r)] * NCTAXB(REGTOBLOC(r))$$

The variable DTBALCTRA represents the balance of trade, including net emission trading revenue:

$$DTBALCTRA(r) = DTBAL(r) + DVCO2TRA(r)$$

Emission trading also enters into regional income:

INCOME(r) * y(r) = FY(r) * fincome(r)
$\qquad$ + 100.0 * INCOME(r) * del_indtaxr(r)
$\qquad$ + INDTAX(r) * y(r)
$\qquad$ + 100.0 * DVCO2TRA(r)
$\qquad$ + 100.0 * sum{i,CTAX_COMM, c_VCTAX(r,i)}
$\qquad$ + INCOME(r) * incomeslack(r)

Since the region-wide indirect tax revenue variable del_indtaxr excludes carbon tax, we bring that separately to account through the linear variable c_VCTAX associated with the levels variable VCTAX.

2.5   Production

As described in TP-16, we introduce a new production system, with many more intermediate levels of nesting, and combining capital not with other endowments but with energy. To implement this system, we define a new set SUBPR_COMM of subproducts, corresponding to the various composites of TP-16, the value-added-energy composite, the capital-energy composite, and so on (we call them "subproducts" not "composites" to avoid confusion with the domestic-import and import-import composites). We include subproducts with endowments and tradables in a set FIRM_COMM of commodities demanded by firms. The old variables qf and pf, ranging over tradables, we rename qft and pft, and reuse the old names qf and pf for variables ranging over FIRM_COMM. The old variable af representing tradable-input-saving technological change, along with afe for endowment-saving and ava for value-added-saving technological change, is replaced by a new af variable ranging over all FIRM_COMM, enabling us to simulate technological change at every point in the production system.

$\qquad$ For each nest in the production system, we define a set of inputs and a substitution elasticity. For non-electricity energy, for example, we define the set NELY_COMM, comprising the tradable commodity coal and the subproduct ncoal (non-coal). We define also the substitution elasticity ELNEL, reading its values from a new array ELNE in the parameters file. With these we write the demand equation for inputs into non-electricity energy subproduction,

qf(i,j,r) = -af(i,j,r) + qf("nely",j,r) - ELNEL(j,r) * [pf(i,j,r) - af(i,j,r) - pf("nely",j,r)]

where the input index i ranges over all elements of NELY_COMM. The same form of equation works too for all the other nests in the production system, whether the inputs are tradables, endowments, subproducts, or any combination thereof.

2.6   Welfare decomposition

Arising from the previous changes are two changes in the welfare decomposition. First, net emission trading revenue DVCO2TRA contributes to welfare. We represent this contribution through a new variable CNTco2trd in the model, and a new column co2trd in array A in the welfare decomposition. Second, the welfare contributions of all forms of input-saving technological change are reported in a single variable CNTtech_afijr in the model, and a single array C12 in the welfare decomposition.

3   Closure

The experiment gtap uses a price-homogenous closure generally similar to the standard gtap closure.

Table 1: Closure swaps

Endogenous to exogenous	Exogenous to endogenous
DTBAL	cgdslack
cgdslack("ROW")	DTBAL("ROW")
NCTAXB	RCTAXB
pempb(CONSTR_BLOC)[a]	NCTAXB(CONSTR_BLOC)[a]
gco2q(CONSTR_REG)[a]	pemp(CONSTR_REG)[a]

[a] CONSTR_BLOC denotes the set of trading blocs subject to emission constraints, CONSTR_REG the corresponding set of regions.

All three TP-16 experiments treat the capital account according to the WALRAS/-GREEN modeling tradition, with investment adjusting to preserve a fixed trade balance. To implement this, we exogenize DTBAL and endogenize cgdslack; the latter switches off the international investment allocation equation RORDELTA. But we cannot keep this swap for all regions. On the one hand, we cannot make DTBAL exogenous for all regions: because the trade balances necessarily sum to zero, that would create a linear dependence amongst the equations of the model, and a singularity in the solution matrix. And on the other hand, the model cannot determine the general level but only the relativities of the various components of cgdslack (given any solution to the model, we can construct another solution by applying a uniform change to all components of cgdslack, applying an equal and opposite change to the "global rate of return" rorg, and keeping all other variables unchanged). So for one region, which we arbitrarily choose to be the "rest of the world", RoW, we swap DTBAL and cgdslack back again.

For our price-homogeneous closure, which like the standard GTAP closure involves no emission constraint, we necessarily take the real carbon tax rate variable RCTAXB for our exogenous carbon tax rate variable. But in the TP-16 experiments, we find it more natural to think in terms of the nominal tax rate, so we exogenize NCTAXB and endogenize RCTAXB. But then, for each bloc in which we impose an emission constraint, we endogenize NCTAXB again and exogenize the power of emission purchases pempb. At the same time, for all regions in such blocs, we exogenize emission quota gco2q and endogenize the region-level power of purchases pemp, as discussed above under the heading "emission accounting".

Table 1 summarizes the closure changes in the TP-16 experiments. For convenience, the table uses CONSTR_BLOC to denote the set of emission-constrained blocs, and CONSTR_REG to denote the corresponding regions; the experiment files in your RunGTAP version use individual bloc and region names, though it would be possible to use set names, if suitable xset and xsubset statements were added to the cmfstart file.

Table 2: Marginal costs of achieving the Kyoto targets

	With no use of the flexibility mechanisms		With emission trading among Annex 1 countries		With worldwide emission trading	
	% reduction in emissions	1997 USD per tonne of carbon	% reduction in emissions	1997 USD per tonne of carbon	% reduction in emissions	1997 USD per tonne of carbon
USA	-36	126	-27	77	-12	29
EU	-22	139	-14	77	-6	29
EEFSU	5	0	-27	75	-13	29
Jpn	-32	222	-16	77	-6	29
RoA1	-36	171	-21	0	-9	29
EEx	4	0	3	0	-7	29
ChInd	1	0	1	0	-33	28
RoW	4	0	4		-8	29
Annex 1	-24		-22		-10	
Non-Annex 1	3		2		-19	
Leakage rate (incl. EEFSU)	11		na		na	
Leakage rate (excl. EEFSU)	7		6		na	

[a] Marginal costs are expressed in real terms, that is, deflated by the income disposition price index for each region. Slightly different marginal costs within trading blocs are therefore consistent with a common nominal trading price.

Table 3: Macroeconomic effects of implementing the Kyoto Protocol (percentage changes)

	With no use of the flexibility mechanisms		With emission trading among Annex 1 countries		With worldwide emission trading	
	Welfare	TOT	Welfare	TOT	Welfare	TOT
USA	-0.24	0.97	-0.26	0.53	-0.15	0.17
EU	-0.39	0.33	-0.23	0.21	-0.03	0.12
EEFSU	-0.41	-0.86	2.73	0.89	0.64	0.04
Jpn	-0.53	1.36	-0.23	0.68	-0.06	0.44
RoA1	-1.2	-0.64	-0.81	-0.55	-0.4	-0.38
EEx	-1.01	-3.04	-0.74	-2.21	-0.53	-1.47
ChInd	0.08	0.02	0.05	-0.01	0.49	0.78
RoW	0.16	0.26	0.14	0.23	0.1	0.32

4   Simulation Results

The new implementation of the model corrects some errors in the older TP-16 implementation; this leads to slight but noticeable changes in some results. Table 2 replaces table 14 of TP-16, table 3 the old table 15.

Modeling the energy-economyenvironment-trade linkages is an important objective in applied economic policy analysis. Previously, however, the modeling of these linkages in GTAP has been incomplete. The approach is implemented as an extended version of the GTAP model called GTAP-E. In addition, GTAP-E incorporates carbon emissions from the combustion of fossil fuels and this revised version of GTAP-E provides for a mechanism to trade these emissions internationally as well as domestically. The policy relevance of GTAP-E in the context of the existing debate about climate change is illustrated by some illustrative simulations of the implementation the European emissions trading scheme in 2005. Literature on energy-economy-environment-trade linkage, an important objective in applied economic policy analysis, is growing. Burniaux and Truong (2002) implemented an extended version of the GTAP model called GTAP-E, which includes the standard GTAP model as a special case. GTAP-E incorporates carbon emissions from the combustion of fossil fuels and provides a mechanism to trade these emissions internationally. This analysis provides useful environmental policy GTAP literature is focusing on trade liberalization and its impact on environment is not large. The GTAP model simulates the impact of the import tariff reductions in the two scenarios. The model will estimate how trade flows will change as different scenarios reduce import tariff restrictions. GTAP Resource #2959. "GTAP-E: A Revised Energy-Environmental Version of the GTAP Model" by McDougall, Robert and Alla Golub. Abstract The purpose of this memorandum is to document recent revisions to the energy environmental extension of the GTAP Model (GTAP-E) described in GTAP Technical Paper No.16 by Burniaux and Truong (2002). We revise the solution program, data, stored input and command files, and welfare decomposition program. The revisions are undertaken to improve the model's user friendliness, adapt it to a wider range of energy-environmental policy scenarios, and correct errors. A technical paper documenting the theoretical structure of GTAP-E is forthcoming. [Close]. APA format copy and paste this citation. The standard GTAP model (named after the Global Trade Analysis Project at Purdue University) is a multiregion, multisector computable general equilibrium model. GTAP-E incorporates energy substitution and carbon emissions into the standard model, and allows international emission trading. This tool is included in the Development Impacts Assessment (DIA) Toolkit from the LEDS Global Partnership.