

Energy Application: Notes for Small Group

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This is a simple climate change application, examining various climate change policy options within the framework of the *Kyoto Protocol*:

- Action is taken to reduce emission of *carbon dioxide*.
- Responsibility for abatement is assumed by the *Annex 1 countries*.
- The favoured instrument is the *carbon tax*.
- Under some scenarios, there is international trade in *emissions permits*.

The application is conducted with a modified version of the GTAP model, incorporating:

- carbon dioxide accounting,
- carbon taxation,
- an emission trading facility, and
- a modified treatment of energy demand, incorporating:
 - energy-capital substitution, and
 - inter-fuel substitution.

Some standard results are verified, including:

- Emission trading reduces the cost of abatement.
- The larger the trading group, the greater the reduction in the cost of abatement.

Task

- Read this note.
- Skim *Technical Paper 16*, read section 4.
- Replicate the results, as reported at the end of this note.

- Review the modifications to the standard GTAP closure.
- Review the modifications to the standard GTAP model.
- Review the simulation analysis in *Technical Paper 16*.
- Design an extension of the application.

Extensions

Some rules apply:

- An extension is usually done by a mini group of two participants, occasionally by one or three.
- Everyone presents.
- One mini group should explain the base application.
- An extension usually involves some modification to one of the original simulations; it is however perfectly acceptable to present new analysis of an old simulation.
- You don't have time to make extensive changes to the data base, much less to the theoretical structure.
- The object is an original piece of simulation analysis.

One approach to inventing an extension is to identify a point of interest in the original simulation analysis, construct an hypothesis about it, and develop a plan to test it.

Mini groups

Division into mini groups is determined by participants and instructors jointly. A common procedure is:

- List ideas for extensions.
- Match extensions and participants.

Old experiments

In your RunGTAP folder, there are two versions of the application. The newer, preferred version is GTAP-E (the older version is TP16).

- price homogeneity test: `gtap`
- no emission trading: `kyonotr`
- Annex 1 trading: `kyotr`

- worldwide trading: `kyowtr`

Some special features of the original experiment design deserve investigation:

- In the no-trade scenario, why are emissions from Eastern Europe and the Former Soviet Union (EEFSU) not exogenous?
- In the Annex-1-trading scenario, why are they no longer endogenous?
- In the world trading scenario, why are emissions from non-Annex-1 countries exogenous?

Theoretical structure

Emission accounting

We add to the data file new arrays showing carbon dioxide emissions by region, commodity, and use. We read these into coefficients `C02DF`, emissions from firms' usage of domestic product, `C02IF`, emissions from firms' usage of imports, `C02DP`, 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:

$$\begin{aligned} C02(r,i) * gco2(r,i) = & \text{sum}(j, PROD_COMM, C02IF(i,j,r) * gco2fm(i,j,r) \\ & + C02DF(i,j,r) * gco2fd(i,j,r)) \\ & + C02DG(i,r) * gco2gd(i,r) + C02IG(i,r) * gco2gm(i,r) \\ & + C02DP(i,r) * gco2pd(i,r) + C02IP(i,r) * gco2pm(i,r) \end{aligned}$$

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

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

$$\text{pempb}(b) = \text{gco2tb}(b) - \text{gco2qb}(b)$$

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

$$\text{pemp}(r) = \text{gco2t}(r) - \text{gco2q}(r)$$

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.

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` endogenous. 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

$$\begin{aligned} \text{RCTAX}(r) &= [1.0 / \text{PIND}(r)] \\ &\quad * [\text{NCTAXB}(\text{REGTOBLOC}(r)) - 0.01 * \text{NCTAXLEV}(r) * p(r)] \end{aligned}$$

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

$$\begin{aligned} \text{pfd}(i,j,r) &= \text{SHVDFANC}(i,j,r) * [\text{pm}(i,r) + \text{tfd}(i,j,r)] \\ &+ 100.0 * \text{CO2DFVDFA}(i,j,r) * \text{NCTAXB}(\text{REGTOBLOC}(r)) \end{aligned}$$

where SHVDFANC represents the share of the carbon-tax-free value in the carbon-tax-paid value, $\text{VDFANC}(i,j,r) / \text{VDFA}(i,j,r)$, and CO2DFVDFA represents carbon intensity, $\text{CO2DF}(i,j,r) / \text{VDFA}(i,j,r)$. Note that this reduces to the standard GTAP equation

$$\text{pfd}(i,j,r) = \text{pm}(i,r) + \text{tfd}(i,j,r)$$

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.

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:

$$\begin{aligned} \text{DVCO2TRA}(r) &= \text{CO2Q}(r) * \text{NCTAXLEV}(r) * 0.01 * \text{gco2q}(r) \\ &- \text{CO2T}(r) * \text{NCTAXLEV}(r) * 0.01 * \text{gco2t}(r) \\ &+ [\text{CO2Q}(r) - \text{CO2T}(r)] * \text{NCTAXB}(\text{REGTOBLOC}(r)) \end{aligned}$$

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

$$\text{DTBALCTRA}(r) = \text{DTBAL}(r) + \text{DVCO2TRA}(r)$$

Just as corresponding to the nominal merchandise trade balance DTBAL we define a trade balance ratio DTBALR, so likewise corresponding to the nominal DTBALCTRA we define a ratio DBALCAR. Holding these fixed we can enforce trade balance conditions without sacrificing price homogeneity.

$$100 * \text{INCOME}(r) * \text{DBALCAR}(r) = 100 * \text{DTBALCTRA}(r) - \text{TBALCTRA}(r) * y(r)$$

Emission trading also enters into regional income:

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

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.

Production

As described in Technical Paper 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.

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,

$$\begin{aligned} qf(i,j,r) = & -af(i,j,r) + qf("nely",j,r) \\ & - ELNEL(j,r) * [pf(i,j,r) - af(i,j,r) - pf("nely",j,r)] \end{aligned}$$

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.

Welfare decomposition

Arising from the previous changes are two changes in the welfare decomposition. First, net emission trading revenue `DVC02TRA` 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.

Closure

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

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. For these experiments, we fix the trade balance inclusive of emission trading revenue,

Table 1: Closure swaps

Endogenous to exogenous	Exogenous to endogenous
DBALCAR	cgdslack
cgdslack("RoW")	DBALCAR("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.

exogenizing DBALCAR and endogenizing 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 DBALCAR exogenous for all regions: because the trade balances necessarily sum to one, 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 DBALCAR 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 flexi- bility mechanisms		With emission trading among Annex 1 countries		With worldwide emission trading	
	% reduction in emissions	1997 USD per tonne of carbon ^a	% reduction in emissions	1997 USD per tonne of carbon ^a	% reduction in emissions	1997 USD per tonne of carbon ^a
USA	-36	126	-26	77	-12	29
EU	-22	139	-14	77	-6	29
EEFSU	5	0	-27	75	-13	28
Jpn	-32	222	-16	77	-6	29
RoA1	-36	171	-21	77	-9	29
EEx	4	0	3	0	-7	29
ChInd	1	0	1	0	-33	28
RoW	4	0	4	0	-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	1.00	-0.26	0.55	-0.15	0.18
EU	-0.39	0.33	-0.23	0.21	-0.04	0.12
EEFSU	-0.41	-0.86	2.76	0.94	0.65	0.05
Jpn	-0.54	1.32	-0.23	0.66	-0.06	0.42
RoA1	-1.20	-0.65	-0.81	-0.55	-0.40	-0.38
EEx	-1.01	-3.04	-0.74	-2.21	-0.53	-1.47
ChInd	0.07	0.01	0.05	-0.02	0.48	0.76
RoW	0.16	0.26	0.13	0.21	0.11	0.33

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.