Solving TIAM-MACRO for studying economic impacts of carbon mitigation policies

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Outline

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- Accomplishment and Conclusions
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Coordinates of TIAM-MACRO

- **TIAM-MACRO** is a multi regional LP TIAM model, soft linked with a NLP **MACRO-economic stand alone** model.
- **TIAM-MACRO** is a hybrid growth model combining '**bottom-up'** & **'top-down'** approaches
- **TIAM-MACRO** provides Pareto optimal or second best solutions maximizing the Negishi weigted global welfare.
- **Traded commodities are**: *oil, gas, synthetic fuels, coal, bio-fuels, CO2 permits, and a numeraire good that represents all other non-energy exports.*

Calibration algorithm for the DDF factors of TIAM

Calibration is based on the following decisions/observations (Kypreos, 1996):

- the energy system in MARKAL and in MARKAL-MACRO should be the same
- the next two equations (i.e., the definition of DDF and the first order maximization condition of CES) can be solved for the unknown ***ddf*** *factors*

$$\text{dedinition} \qquad DM_{irt} = D_{irt} \cdot \prod_{\tau=1,t} (1 - ddf_{ir\tau})^{nypp} = D_{irt} \cdot F_{irt}$$

$$CES\ Maximization \qquad DM_{irt} = Y_{tr} \cdot F_{irt}^{1-\sigma_r} \cdot \left(\frac{P_{irt}}{b_{irt}} \right)^{-\sigma_r}, \quad ddf_{ir0} = 0$$

- iterations between the two models are necessary as the production function applies to the total economic output and not the exogenous GDP alone.

Defining the Quadratic Cost Supply Functions (QSF) of TIAM

As the energy systems in TIAM and in TMSA are the same the full TIAM could be substituted in TMSA by a QSF defined as:

$$EC_{rt} = c_{rt} + \sum_i d_{rti} \cdot DM_{rti}^{\;2} \quad \text{quadratic cost supply function}$$

The derivative of Energy Cost in respect to demand *DM defines* the price *P.*

$$\partial EC_{rt} / \partial DM_{rti} = P_{rti} = 2 \cdot d_{rti} \cdot DM_{rti}$$

$$\text{we have} \quad \mathrm{d}_{rti} = \frac{P_{rti}}{2 \cdot DM_{rti}} \quad \text{and}$$

$$c_{rt} = EC_{rt} - \sum_i \mathrm{d}_{rti} \cdot DM_{rti}^{\;2}$$

The one page TIAM-MACRO Stand Alone Model

Maximize the global welfare U defined as the Negishi weighted discounted log of regional consumption

$$U = \sum_{rt} NW_r \cdot \log(C_{rt}) \cdot e^{(-\delta_{rt} \cdot \Delta t)}$$

Subject to the following constraints:

CES Production function	$Y_{tr} = \langle a_r \cdot K_{tr}^{\rho_r \alpha_r} \cdot L_{tr}^{\rho_r (1-\alpha_r)} + \sum_i b_{ri} \cdot D_{rti}^{\rho_r} \rangle^{1/\rho_r}$
The use of output	$Y_{tr} = C_{tr} + I_{tr} + EC_{tr} + NTX(nmr)_{tr}$
Capital formation function	$K_{tr} = (1-\delta)^{nypp} \cdot K_{t-1,r} + 0.5nypp \cdot (I_{tr} + (1-\delta)^{nypp} I_{t-1,r})$
Terminal condition last period T	$K_{Tr} \cdot (g_{Tr} + \delta_{Tr}) \le I_{Tr}$
The quadratic supply function	$EC_{tr} = \alpha_{tr} + \sum_i \beta_{itr} \cdot DM_{itr}^{\;2}$
Demand Decoupling Factors	$DM_{itr} = D_{itr} \cdot \prod_{\tau=1,t} (1 - ddf_{i\tau r})^{nypp}$
The sum of global net exports NTX must balance	$\sum_r NTX_{rt,trd} = 0 \,;\, \forall\, t, trd$
Exports XRT are greater than net exports NTX	$NTX_{rt,trd} \le XRT_{rt,trd} \forall\, \mathrm{r}, t, trd$

Defining the Negishi weights of TIAM-SA

The initial NW are proportional to cumulative and discounted GDP per region.

To balance for inter-temporal trade deficits over time we adjust the weights in an iterative approach following T. Rutherford.

The weights are adjusted using the normalized price of the traded products and the inverse of the marginal regional utility i.e., the regional consumption.

$$NW_r = \sum_{t,g} \pi_{g,t} \cdot XTR_{g,r,t} + \sum_{t} \pi_{nmr,t} \cdot C_{r,t} \text{ and } W_r = NW_r / \sum_{r} NW_r$$

The price of the numéraire good is estimated in TIAM-SA,

while its price of the first period normalizes the prices of traded commodities :

$$\pi_{g,t} = \pi_{g,t} / \pi_{nmr,t0}$$

The prices of traded fuels are estimated in TIAM.

How TIAM-MACRO is solved?

BASELINE:

1) We fist solve TIAM as LP defining the Quadratic Supply Functions (QSF) for the energy sub-systems of regions
2) Next we define the first DDF and solve the global MACRO SA model with known QSF approximations as a NLP welfare maximization problem
3) Then we iterate adjusting for DDF and the NW until demands and growth stabilize together with the NW. Prices of numéraire good are defined in TMSA , while TIAM solutions define the prices of fuels, iteratively.

CARBON CONSTRAINT:

We solve first the partial equilibrium TIAM under a carbon constraint to get new QSFs.
Then, we solve the global MACRO-SA problem (we apply the calibrated DDF of the baseline plus the initial growth of labor force) to get the new NWs and macro-economic impact and the feed-back on demands. We iterate until demands and NW stabilize.

Conclusions about the project

- The NLP hard-link of MERGE and TIMES is defined, solved and applied in a case study.
  Now, the cost of national policies can be assessed within a global model under consistent technological change, resource use and demand feed-backs.
  Vice-versa, the impact of global policies on the national level can be quantified specifying all details of the energy system development.
- The MSA is first verified for the US TIMES-MACRO which is solved first directly and then via the decomposition algorithm; computing time is reduced 100 times; while the GDP error of less than 10-4 to +10-5. Thus...
- For the first time, any TIMES-MACRO model can be calibrated and solved efficiently by just activating a switch in TIMES and by defining a few scalars (Macroeconomic data).
- For the first time, the Global TIAM-MACRO is solved efficiently to get Pareto optimal or second best solutions with full description of technological details by region based on TIAM.

Future Activities (optional)

1. We need documentation for the outreach of the new models, as e.g.,
   - **Publication(s)**
   - **User's guide**
2. Include in TMSA a NLP climate model formulation for applying constraints on forcing, DT,etc.
3. Development of a mini TIAM-SA (mTSA) as a consistent Scenario Storyline Generator (SSG) based on …
   - exogenous AEEIF to match energy intensities
   - consistent economic growth, energy use and investments in the energy sectors as function of the assumed storyline to be obtained by solving mTSA
   - generic supply and demand technologies in TIAM
   - explicit buildings and transport submodels in some regions or demand drivers in others