Linking TIAM with MACRO to study Macro-Economic Policy Impacts

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The Global ETSAP-TIAM Model (LP) and the MACRO Submodel (NLP)

ETSAP-TIAM: A multi-regional partial equilibrium model

- based on the TIMES energy system modeling tools of IEA-ETSAP
- 15 world regions with trade in energy commodities
- Detailed in technology representation in all sectors
- Maximizes the cumulative discounted surplus of consumers & producers
- Integrates climate module for assessing climate impacts

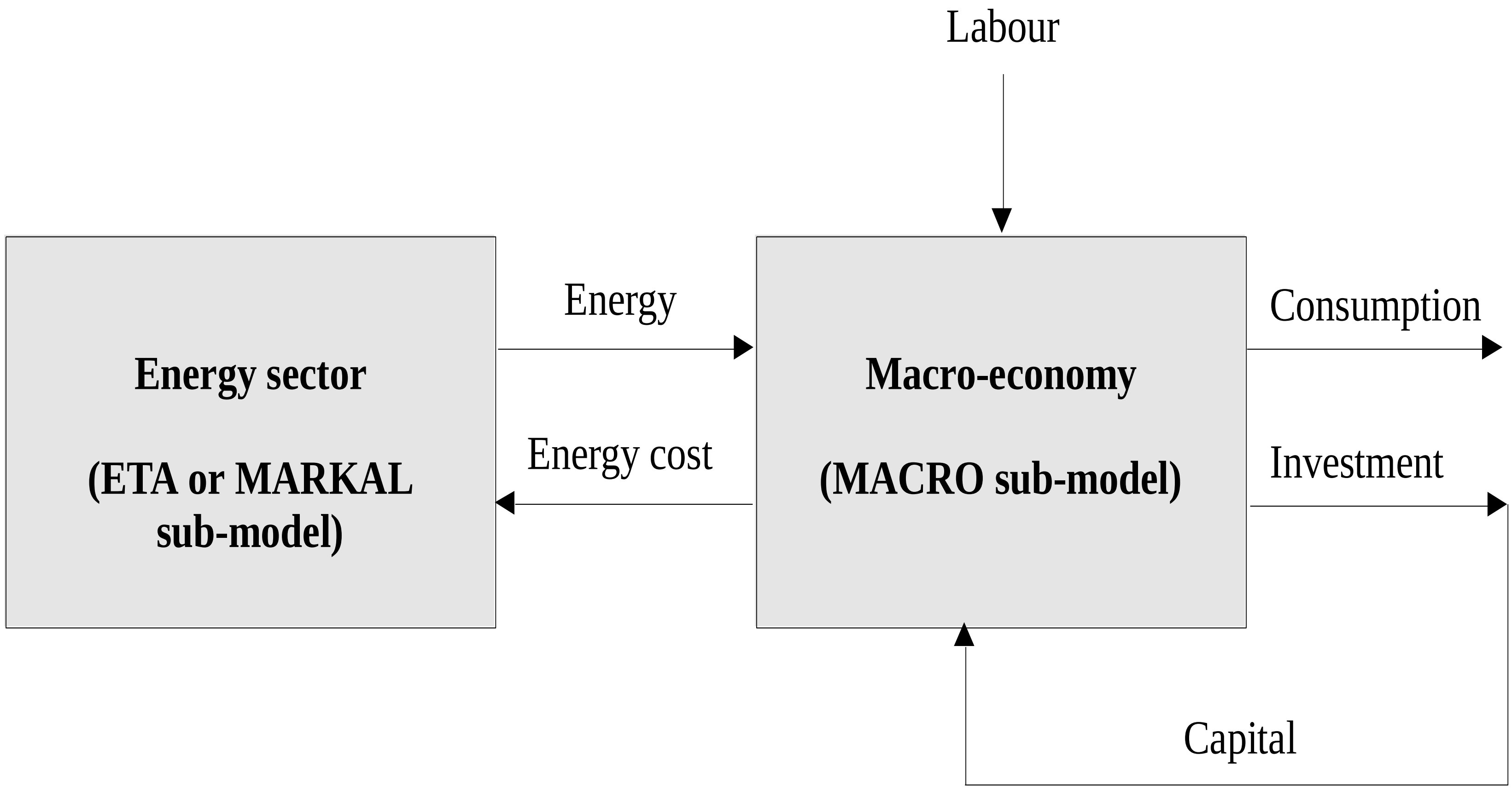
MACRO: An optimal growth general equilibrium model

- Origins in the Eta-Macro model of Alan S. Manne
- A single-agent neoclassical optimal growth model,
- i.e. a dynamic inter-temporal GE model that maximizes
- the cumulative and discounted utility of a generic
- consumer-producer agent

Linking of TIAM and Macro to a large hybrid model is

solvable only iteratively and via decomposition to an LP (TIMES) and NLP (MACRO) sub-problems

Overview of TIMES-MACRO



The TIMES-MACRO Stand-Alone Model

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

$$Max\ U = \sum_{t=1}^{T} \sum_{r} nwt_r \cdot pwt_t \cdot \ln(C_{r,t}) \cdot e^{\left(-\delta_{r,t} \cdot \Delta t\right)}$$

- Subject to the following constraints:

Production function: $$Y_{rt} = \langle a_{rt} \cdot K_{rt}^{\rho_r \alpha_r} \cdot L_{rt}^{\rho_r (1-\alpha_r)} + \sum_i b_{ri} \cdot D_{rti}^{\rho_r} \rangle^{1/\rho_r}$$

Use of output: $$Y_{rt} = C_{rt} + I_{rt} + EC_{rt} + NTX(nmr)_{rt}$$

Capital formation function: $$K_{rt} = (1-\delta)^{N_t} \cdot K_{rt-1} + 0.5 \cdot N_t \cdot (I_{rt} + (1-\delta)^{N_t} \cdot I_{rt-1})$$

Terminal condition for last period T: $$K_{rT} \cdot (g_{rT} + \delta_{rT}) \le I_{rT}$$

The quadratic supply function: $$EC_{rt} = \alpha_{rt} + \sum_i \beta_{rti} \cdot DM_{rti}^{\ 2}$$

Demand decoupling factors: $$DM_{rti} = D_{rti} \cdot \prod_{\tau=1,t} (1 - ddf_{r\tau i})^{N_\tau}$$

Global net exports NTX must balance: $$\sum_r NTX_{rt,trd} = 0;\ \forall\ t, trd$$

Defining the Quadratic Supply Functions (QSF) that replaces TIAM in TMSA

- As the energy systems in TIAM and in TIAM-Macro are the same, the full TIAM can be replaced by a QSF, defined as:

$$EC_{r,t} = \alpha_{r,t} + \sum_i \beta_{r,t,i} \cdot DM^2_{r,t,i}$$

- The derivative of the Energy Cost *EC* with respect to demand *DM* defines the equilibrium price *P* at the TIAM solution:

$$\partial EC_{r,t} / \partial DM_{r,t,i} = P_{r,t,i} = 2 \cdot \beta_{r,t,i} \cdot DM_{r,t,i}$$

$$\Rightarrow \qquad \beta_{r,t,i} = \frac{P_{r,t,i}}{2 \cdot DM_{r,t,i}}$$

$$\alpha_{r,t} = EC_{r,t} - \sum \beta_{r,t,i} \cdot DM^2_{r,t,i}$$

Attention: In orfer to have EC and DM used as model variables in TMSA with some degree of freedom (i.e., with representative shadow prices and energy cost) any costraint of importance for the energy system should be already taken into account in TIAM as e.g., a carbon constraint, or a climate forcing constraint.

Calibration Algorithm for TIAM-MACRO

- Calibration of the demand decoupling factors (DDFs) is based on the following decisions / observations (Kypreos, 1996):
  - The energy system in TIAM and TIAM-Macro should be the same
  - The following two equations (definition of DDF and the first order maximization condition of CES) can be solved for the unknown DDF factors:

$$DM_{r,t,i} = D_{r,t,i} \cdot \prod_{\tau=1,t} (1 - ddf_{r,\tau,i})^{N_\tau} = D_{r,t,i} \cdot F_{r,t,i}$$

$$DM_{r,t,i} = F_{r,t,i}^{1-\sigma_r} \cdot Y_{r,t} \cdot \left(\frac{P_{r,t,i}}{b_{r,i}} \right)^{-\sigma_r} , \quad ddf_{r,t1,i} = 0$$

- Iteration between the two models not necessary for calibration, but the TIAM-LP Baseline needs to solved only once
- The Macro model needs to be solved iteratively until the DDF factors and labor growth rates converge

Defining the Negishi Weights (NW)

- We start with initial Negishi weights proportional to the regional GDP (or from a previous solution).
- To balance the intertemporal trade deficits weights should be proportional to regional consumption increased by the net exports of traded goods. Prices (the dual of the trade constraints) are normalized the price of the numeraire good and the asked error of weights should be below 10-6:

$$\pi'_{t,trd} = \pi_{t,trd} \cdot \pi_{t,nmr} / \pi_{t1,nmr}$$

$$NW_r = \sum_{t,trd} \pi'_{t,trd} \cdot NTX_{r,t,trd} + \sum_t \pi'_{t,nmr} \cdot C_{r,t}$$

$$nwt_r = NW_r / \sum_k NW_k$$

- The price of the numeraire is defined in MSA while prices of all other traded products are defined in TIAM

Decomposition Algorithm

- **Solving the Baseline Calibration:**
  - First, solve TIAM as LP defining the Quadratic Supply Functions (QSF) for the useful energy demands in all regions
  - Next, define the initial DDF and labor growths, and solve the Macro model with the QSF as an NLP welfare maximization problem
  - Then iterate adjusting for DDF, labor growths and the Negishi weights until demands and growths stabilize together with the NW
- **Solving the Policy Scenarios:**
  - First, solve the partial equilibrium TIAM under policy constraints, and calculate initial QSFs for the Macro sub-model
  - Next, solve the Macro sub-problem applying the calibrated DDFs and labor growth rates, deriving adjusted demand levels
  - Then, iterate between the TIAM LP and Macro NLP sub-problems until the demand levels and Negishi weights stabilize

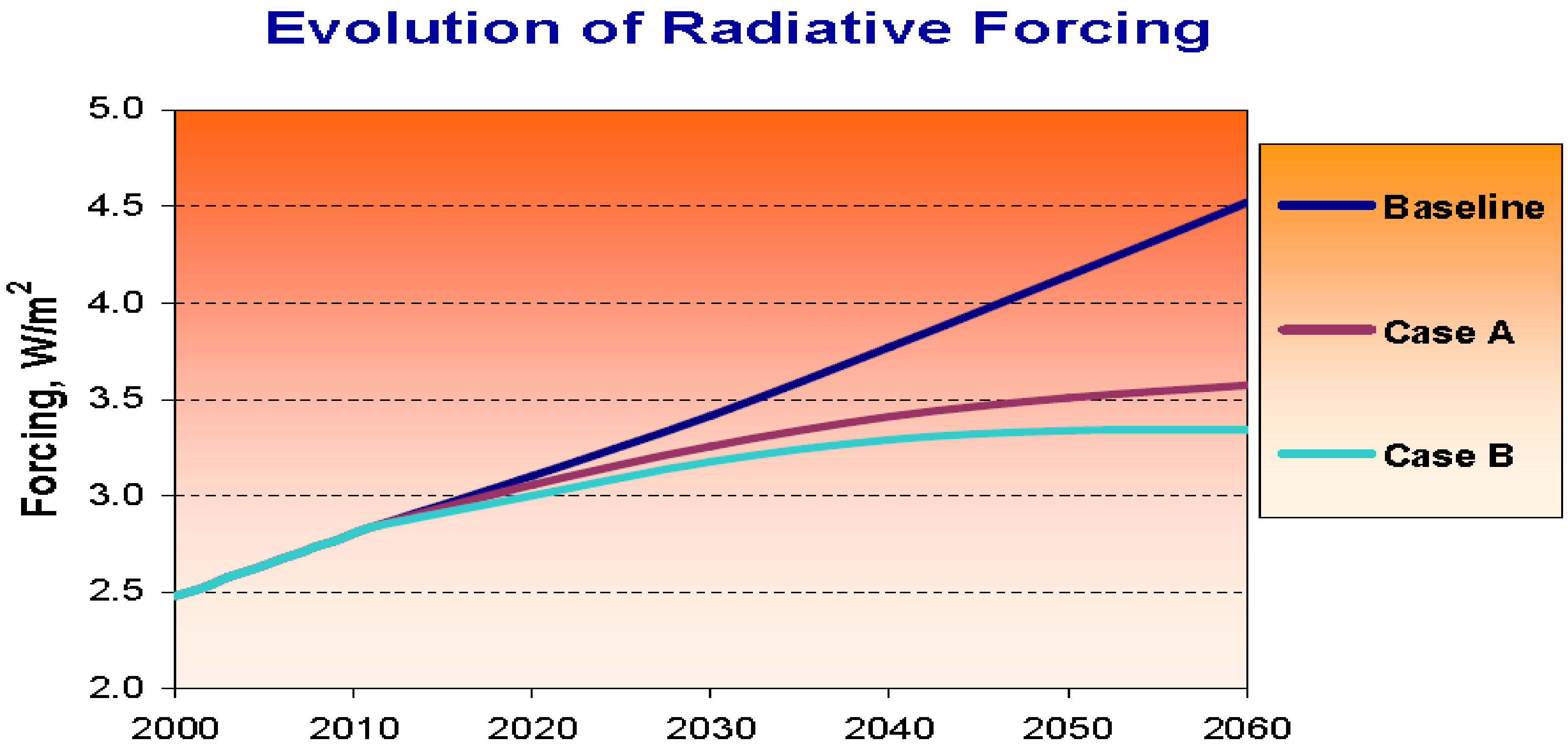
Performance of the Algorithm

- Test runs with subsets of the ETSAP-TIAM model (→2060):
  - Single-region model for the USA (run also with TIMES-Macro)
  - Six-region model (EEU + WEU + USA + AFR + CHI + MEA)
  - Ten-region model (6 above + JPN + CSA + IND + ODA)
  - Full 15-region model (10 above + AUS + CAN + FSU + MEX+ SKO)
- The USA model results validated well against TIMES-Macro
- Test results indicate that TIMES-MSA may be even 100 times faster than the hard-linked TIMES-Macro (~170 min. for USA)

TIAM-Macro	Model size		Run time (minutes)	
Test model	Equations	Variables	Calibration	Policy run
TIAM-USA	30,500	52,800	<1	2
TIAM-6R	198,900	508,300	4	28
TIAM-10R	318,200	674,100	7	58
TIAM-15R	457,600	864,000	11	89

(Windows 7 64-bit workstation, solution in single thread)

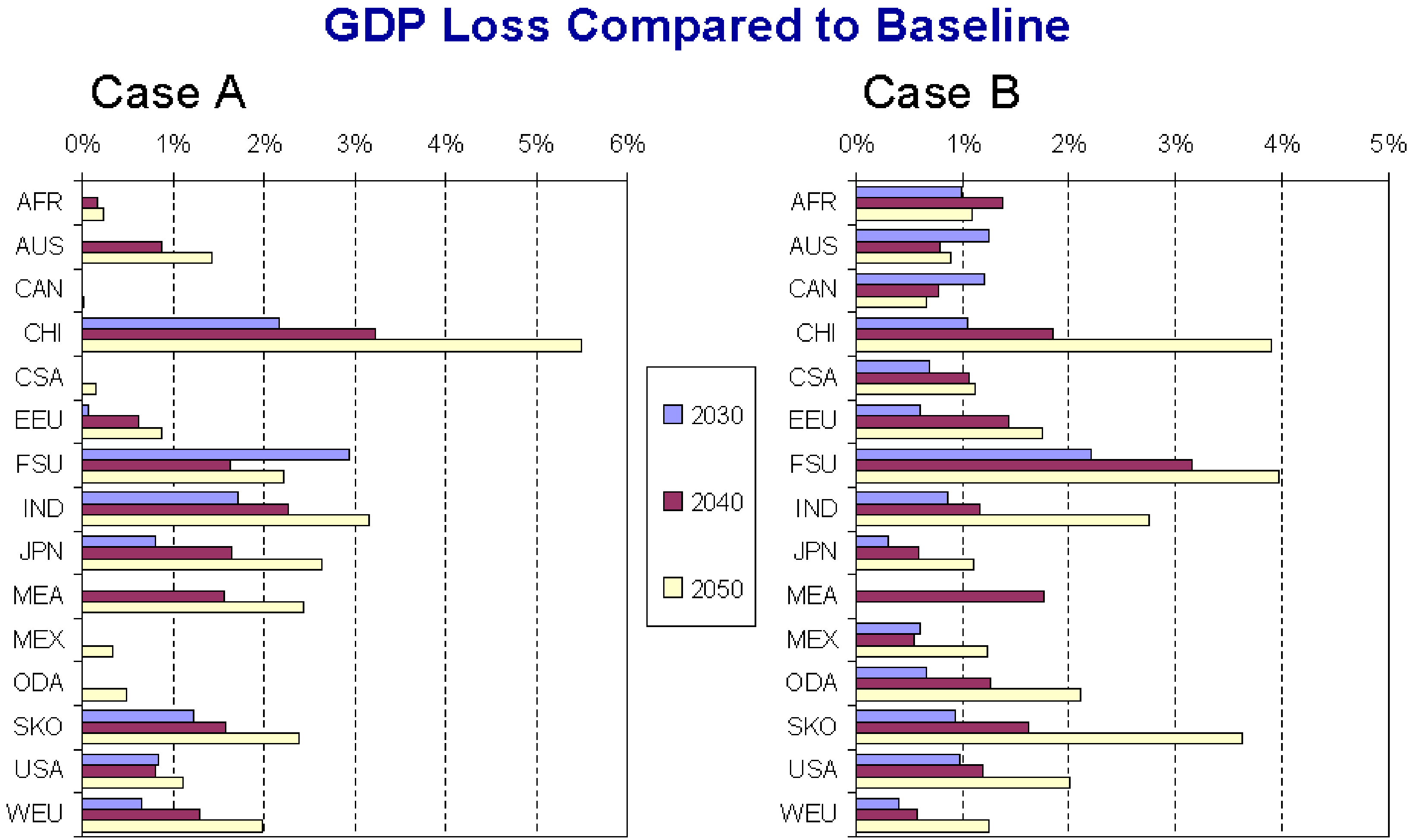
Climate Policy Test Runs



A: Regional targets are resempling long-term pledges presented by various countries

B: Regional targets are resempling a CO_2e concentration of 550 ppm

Climate Policy Test Runs



Conclusions and Future Work

Key accomplishments:

Any TIMES-MACRO models can now be calibrated and solved efficiently just by activating a switch in the model run and by defining a few macroeconomic input parameters

For the first time, the Global TIAM-MACRO can be solved efficiently to get Pareto optimal solutions for second-best policies with full technological details by region as in TIAM

Possible future work:

1. Add a model option to include non-linear damages due to climate change in the global welfare maximization and perform IA
2. Submit a report describing all the work to a peer-review Journal
3. Implement MSA using MCP formulation instead of NLP
4. Implement LbD and LbS options and technology clusters