Imaclim-R: an innovative hybrid model to foster the dialog on sustainable pathways, energy policies and climate stabilization

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Outline

- Motivations
- Technical Features of the Imaclim-R model
- From sector-based expertise to global assessment
- New insights from the model
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What we would like to represent?

**Consistent long-run scenarios…**

- Plausible and tangible technological change pathways
- Binding physical constraints (asymptotes, technologies embodied in existing capital stock)
- Binding economic constraints (investment levels and allocation, terms of trade, final demand patterns, budget constraint)
- Explicit growth engine (partial or total catch-up, specialization, etc.)

**…to explore system-wide issues:**

- Mimetic development styles against sustainability
- Food-Energy-Sequestration issue
- Competitiveness and carbon leakage
- Transferable quotas and terms of trade
- Etc.
Policy-oriented motivations

- The need to assess **which instruments** can enhance pre-identified technical potentials in a real globalized economy, at different time horizons.

- A quantitative way to feed the dialog between **experts and stakeholders** around tricky issues: What costs? Macro feedbacks? Rebound effects? Rhythm of GHG mitigation? Barriers to be removed? Design of institutions?
A few modelling paradigms since the 80’s

**Simulation**

- **Edmonds Reilly**
  - AIM
  - MiniCam
  - ASF
  - WEM
  - TIMER
  - IPAC
  - PETRO

- **SGM**
  - Imaclim-R

**Optimization**

- **MARKAL**
  - MESSAGE
  - GET
  - TEESE
  - LEAP
  - LDNE
  - New Earth 21

- **Global 2100**
  - MARKAL MACRO
  - MESSAGE MACRO
  - MERGE
  - CETA
  - DNE21
  - MARIA
  - GRAPE

- **GREEN**
  - EPPA
  - AMIGA
  - GEMINI-E3
  - WORLDSCAN
  - GTEm
  - EDGE
  - WiaGEM

- **DICE**
  - RICE
  - RICE-FEEM
  - DEMETER
  - ENTICE(-BR)
  - Connecticut Model
  - COMBAT
  - Khana Chapman
  - MIND
Current issues not (or rarely) addressed in the climate policy literature

- Poor representation of the growth engine: large bifurcations cannot be treated \textit{at the margin} of baseline trajectories
- Broad spread of long run scenarios (e.g. SRES): a misunderstanding about uncertainty?
- Weak representation of medium-run dynamics: a lack of insights about the magnitude of transition costs
- Few attempts to use models of a non-perfect world with imperfect foresight and disequilibria: the idea that existing ‘barriers’ can be easily removed is not backed by quantitative assessment
The ‘C-T-L’ challenge of hybrid modelling
Well-known difficulties: Linking pre-existing models always intricate...

**Macro-economic growth models / CGEM**

Top-Down
- Physical Production Capacities?
- Stocks of equipments?
- Technologies?
- Structural content of growth?
- Financial constraints on investments?
- Demand dynamics? Relative prices?

Bottom-up

**Sector-specific models**
- Cost-effective planning and investments
- Technological choices
- Technical representation of the energy system

Which world in 2050?
Well-known difficulties: Linking pre-existing models always intricate... and often unsatisfying

**Macro-economic growth models / CGEM**

- Relative prices
- Budget constraints
- Savings
- Investment allocation
- Structural change

**Not only elasticities!**
- Technology dynamics
- Equipment stocks
- Infrastructures

**Sector-specific models**
- Cost-effective planning and investments
- Technological choices
- Physical representation of development styles

**Top-Down**

**Bottom-up**
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A recursive dynamic approach to disentangle short run constraints/adjustments and long run dynamics

Static equilibrium $t$

Updated technical and structural parameters (i-o coefficients, stocks, etc.)

Static equilibrium $t+1$

Dynamic modules:
- Productivity catch-up, Efficiency gains, substitutions, stocks' dynamics, reserves depletion, etc.

Snapshot of the economy at year $t$: Price-signals, profitability rates, Physical outputs

Short run equilibrium under capacity and technology constraints

Moving constraints
General features of the Imaclim-R model

1. A recursive dynamic framework:
   - Succession of **static equilibriums** under short-term constraints
     - Consistent Macroeconomic snapshot (inc GE effects)
     - Technology and capacity constraints
   - **Moving constraints** informed by reduced forms from BU models
     - Stock dynamics, technological asymptotes, technological choices

2. A comprehensive **price & physical quantities** account:
   - Energy (Mtoe), transportation (PKT) & material accounting
   - Hybrid matrices, physical production capacities, physical i/o coefficients
General features of the Imaclim-R model

- Utility maximization under income constraint does not explain well patterns of energy and transportation demand
  - Energy consumption does not provide satisfaction by itself but through the services (light, heating, devices) it delivers.
  - Transport consumption shows specific patterns: Zahavi's law (constant time-budget), rebound effect, congestion.
  - Energy consumption and transportation are driven and constrained by the ownership of durables, cars and square meters of housing (themselves driven by their prices)

- Explicit the technical potentials behind 'all-in-one' production functions
  - Distinguish short-term rigidities and long-term flexibilities (Marshall, Johansen, 1930): with rigid i-o coefficients on the short-run
  - Allows to incorporate all the information available from all sources on the dynamics of the i-o coefficients.
  - Back to the real 'envelope' of technical possibilities over the long-term: no mathematical constraints such as constant elasticity.
Static equilibrium under short-run constraints: demand

Utility maximization:

\[
U_k(\hat{C}_k, \hat{S}_k) = \prod_{\text{goods } i} \left( C_{k,i} - b n_{k,i} \right)^{\xi_{k,i}} \left( S_{k,j} - b n_{k,j} \right)^{\xi_{k,j}}
\]

Under two constraints:

\[
p_{tc_k} \cdot \text{Income}_k = \sum_i pArmC_{k,i} \cdot C_{k,i} + \sum_{\text{Energies } E_i} pArmC_{k,E_i} \cdot \left( S_{k,cars}^c \cdot \alpha_{k,E_i}^{cars} + S_{k,m}^m \cdot \alpha_{k,Ei}^{m} \right)
\]

\[
T_{disp_k} = \sum_{\text{means of transport } T_j} \int_0^{pkm_{j}} \tau_j(u) du
\]

Capacity=function ( infrastructures, equipments )
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Static equilibrium under short-run constraints: supply

- Short-term lock-in on technology and capacity (putty-clay capital), represented by a rigid cost function plus a flexible rate of capacity utilization

\[ p_{k,i} = \sum_j p_\text{Arm}IC_{j,i,k} \cdot IC_{j,i,k} + \left( \Omega_{k,i} \cdot w_{k,i} \right) \cdot l_{k,i} \cdot (1 + t\alpha_{k,i}^w) + \pi_{k,i} \cdot p_{k,i} \]
Additional features

- One-year time steps
- Walrasian equilibrium of all goods and services (Armington-type international trade)
- Capital flows fixed or endogenized
- Unemployment (wage curve)
- 12 regions (inc. USA, Europe, China, India, Brazil, OPEC, CIS)
- 12 sectors (5 energy supply and conversion, 3 transportation, building, energy-intensive industry, agriculture, composite)
Dynamic modules: the growth engine

- **A potential growth** the drivers of which are:
  - Demography
  - Saving rates (linked to the evolution of the pyramid of ages)
  - Catching up assumptions about labor productivity in each sector

- **Gaps between potential and real growth:**
  - Interaction with the energy sector
    - Price shocks
    - Maladaptation of installed equipment
    - Technology choices
  - Interaction with international markets
  - Representation of many sources of frictions on:
    - Capital flows
    - Investments derived from imperfectly expected increases of future demand and profitability
    - Rigidity of the terms of trade
  - Endogenous transitional disequilibrium with phases of over and under production capacities with related price cycles
Dynamic modules: sectoral modules

- An explicit **technology portfolio** for critical elements of the energy system
  - Power generation (Advanced coal, CCS, nuclear, various renewable…)
  - Light Duty Vehicles (Efficient ICE, Hybrid, plug-in Hybrid…)
  - Alternative liquid fuels (Biofuels, Coal to liquid…)

- An effort to represent **physical constraints** bearing on energy supply and demand
  - Temporal availability of oil resources
  - Load curve for power generation
  - Technical asymptotes for energy efficiency gains

- Including **Structural Change** within the ITC vs. ATC debate
  - R&D and learning-by-doing mechanisms applies to the sets of techniques
  - Endogenous Structural Change results from interactions between demand, supply, and ITC mechanisms
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Methods to integrate sector based expertise, links with B-U models and data

- **Exogenous prescription**
  - One input-output coefficient follows a prescribed temporal trend
  - Test of assumptions, macroeconomic consistency of scenarios

- **Reduced forms**
  - A function is calibrated to reproduce, at an aggregated level, the reaction of a technical coefficient to a signal
  - Calibration of the function with runs of a B-U model on the signal’s interval of variation

- **Compact models**
  - Optimization of the technological choices in one isolated sector under current and expected economic conditions
  - Simplified reproduction of a complex B-U modeling structure
  - Interaction with B-U models to calibrate reactions and evolutions of the technologies portfolio

- **An existing Bottom-up Model**: WEM-ECO (IEA), POLES, Markal France…
Ongoing development and quest for BU data/discussion

- **Current state of dynamic modules:**
  - Comprehensive Bottom-up submodels: electricity, fossil fuels, steel, cement, residential, cars
  - Reduced forms: transportation technologies and infrastructures, services, agriculture
  - Exogenous prescription: transportation input in sectors, material content of investment, material content of infrastructures

- **Advantages of this approach:**
  - Transparency and discussion along the scenario-generating process
  - Keeps open all the dynamics but still to be represented:
    - Specific modules devoted to the input-output structure in each sector
    - Critical ‘silent’ input-output coefficients (e.g. transportation in sectors)
    - Harder work but force us to explicit all the dynamics!
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No-policy scenario:
the mechanisms underlying the risks of increasing emissions

2000-2040:
-Structural change: growing importance of developing countries
-Back to coal in power generation

2040-2060:
High oil prices, biofuels

2060-2100:
Saturation of biofuels, Coal-to-Liquid
Policy scenarios

- **CO2 price 550 ppm**
- **CO2 price 450 ppm**
- **Emissions 550 ppm**
- **Emissions 450 ppm**
- **Emissions REF**
Policy scenarios: Effective reductions may differ from *ex ante* technical potentials

**Mean CO₂ reductions 2010-2030 (world)**

- Energy: 1.5 GtCO₂/year
- Transport: 1.0 GtCO₂/year
- Residential: 0.5 GtCO₂/year
- Industry: 2.5 GtCO₂/year
- Agriculture & Composite: 0.5 GtCO₂/year

50 W/m²/yr available but inertia!

Low carbon technologies under 100 $/tCO₂ but inertia
Policy scenarios: possible transition costs could explain the fears of decision-makers

Policy scenarios: possibly high transition costs must be avoided with fine-tuned measures

Thank you!

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