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Towards Improved ETSAP Tools

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Present limits, desirable improvements

1. What theoretical framework is necessary to couple the present economic approach with the simulation approach of environment / technological sciences and with decision theories?
2. How to increase the power of solution algorithms and graphic interfaces?
3. How to embed more expert systems characteristics?

1 – Theoretical framework

The problem here is to develop mathematically sound theories and tools that can implement the coupling of multi-regional MARKAL-TIMES partial economic equilibrium models with:

1. environment / earth-systems models,
2. general economic equilibrium technology explicit models,
3. possibly in a game theoretic fashion, and with
4. longer term non macroeconomic development drivers.

1.1 – *Environment / earth system models*

Environmental systems are often described by complex non-linear simulation models (SM, e.g. Eulerian models to describe ozone episodes, General Circulation Models to describe climate change). How permit a coherent dialogue between these models?

- Soft-linking: the results of the Simulation Model are fed into the MARKAL TIMES model, it finds a new socio-economic equilibrium, and the new emission profiles are fed back into the simulation model, till both solutions converge.
- Simplified hard-linking: a reduced subset of one model is inserted into the full size other model, without changing the method.
- Coherent dialogue: The basic idea is to use MARKAL TIMES as an “oracle” and the Simulation Model as another oracle; both of them send information to a master program, which queries the oracles in order to converge to an optimal configuration.

1.2 – General economic equilibrium technology explicit models

Is it possible to extend the MARKAL TIMES approach – technology rich, clairvoyant and based upon the substitution of alternatives – to represent the full economy of the system, and its development in a closed way, as in Computable General Equilibrium models?

- Soft-linking: MT provides Marginal Abatement Costs to the CGEM and the CGEM feedbacks a new general economic framework.
- Hard-linking: to extend to several production functions the present simplified MARKAL-MACRO approach, where the whole economy is represented by just one Production Function.
- Closed I/O framework: by making use of Von Neumann rectangular I/O matrixes – where every sector has more than one producer and each producer can deliver more than one commodity – and improving the equilibrium concept from the static to the dynamic dimension and to allocate investments.

1.3 – *In a game theoretic fashion*

Recent multi-regional MARKAL TIMES models calculate cooperative forms of equilibria. Some game theoretic reasoning should be involved when one looks at the geopolitical consequences of major changes in the economy (e.g. oil, climate, etc.).

- In a first experiment to use MT models in a non-cooperative game on carbon emissions abatement, the damage cost is expressed as linear function of cumulated emissions and this gives rise to simplistic Nash equilibrium solutions.
- If we have non-linear cost functions associated with carbon concentrations, the Nash equilibria will be much more difficult to compute. Under some simplifying assumptions it should still be possible to formulate an overarching “non-cooperative” game, involving the strategic decisions of regional carbon abatement, with a Nash equilibrium solution obtained via the solution of variational inequalities.

1.4 – Longer term development drivers

Economic values calculated by MARKAL TIMES models at equilibrium are expressed in present real term monetary units (the “numeraire”). Prices in years far away from the present are difficult to compare with present prices.

Is it possible to use alternative “units” to measure producers profits and consumers utility? Since the equilibrium points result from the interplay between supply curves (mainly technology and resource driven) and demand curves (eventually driven by the social propensity to consume), it would be interesting to study variants of MT models based upon different “numeraires”, either socially oriented (e.g. population, labour force) or technology oriented (long term technological progress, innovation cycles).

2 – Algorithms

The analyses would benefit from the availability of new / improved algorithms for:

1. Quicker solutions of non linear programming problems;
2. Increasing the choice possibilities of efficient huge LP solvers; and
3. More stable solutions of linear problems with huge dimensions: approaching one million equations / variables and ten million matrix coefficients;
4. Laying out automatically in a more compact graphical form the Reference Energy System.

2.1 – Quicker non linear programs solvers

Several variants of MARKAL TIMES models, i.e.

- The general equilibrium version, MARKAL-MACRO
- The version that internalises some externalities (DAMAGE)
- The Endogenous Technology Learning (ETL), etc.

use a non linear objective function, or some non linear constraints, or both. However, analysts tend to avoid these more powerful formulations for practical reasons, because the solution times of non linear variants is normally an order of magnitude or more greater than the equivalent linear problem (e.g.: 10 hours instead of one hour).

It would be useful to have more and more powerful non linear solvers.

2.2 – More choice of efficient solvers

Recent multi-regional global MT models are huge: about half a million equations, half a million variables and ten million matrix coefficients).

Solvers available as freeware or shareware cannot even cope with the dimension of the problem, or if they do, they cannot converge to feasible / optimal solutions.

Commercially available solvers have a great spread in cost and performance: the cheapest ones, if they arrive to a solution, may require 20 or more times as compared to the fastest ones.

More choice of the fastest solvers might avoid monopolies, reduce prices (recently up to 9000\$ per licence) and make the tools (more readily) available across the world.

2.3 – More stable solutions of huge LP

Recent multi-regional global MT models are huge: about half a million equations, half a million variables and ten million matrix coefficients or more. When these dimensions are approached, the theorem of uniqueness seems to evaporate due to numerical instabilities.

While global indicators and values are stable to the last few significant digits, solution values of non degenerate decision variables and shadow prices are significantly different, depending on the solver, the solution algorithm and the starting point.

Theoretical studies and experiments on the numerical stability of large scale LP can identify conditions for more reliable solutions.

2.4 - Compact graphical layout of RES

In the technical economic modelling approach underlying MT models, the inter-connection of commodity markets and technologies is called Reference Energy System (RES).

The graphical representation of the RES is essential to understand

- if the model responds to the type of analysis required,
- where are the bottlenecks of markets / technologies;
- what branches / chains are too specific or too generic compared to the “value” of the corresponding sector;

It would be of great help to analysts the availability of algorithms capable of compacting the RES and drawing it in an ordered and contained form, without the need of spending days in drawing it manually or patching hundreds of sheets to the walls.

3 – *Expert systems*

One way to improve the quality of the analyses and to spread their use is to embody in ETSAP tools some *expert system* capabilities. This can include procedures capable of:

1. relating more directly MARKAL TIMES models to decision makers questions (decision support systems);
2. making possible the cooperation of different teams to build and analyse the same model (multi-tasking); and
3. tracing back from any equilibrium solution value to the subset of input data explaining it.

3.1 – Decision support systems: input

The objective is to construct models tailor-made to decision makers questions. Procedures have to be developed capable of:

- Adding to the tools the set of policy relevant questions (what is the cost of producing 20% of TPES out of new renewables; what is the effect of adding a subsidy to ...);
- Identifying market and technologies more relevant to each question;
- Asking the appropriate input data for translating each question in quantitative elements;
- generating the additional decision variable, resource constraints, scenarios appropriate to the questions

3.2 – Decision support systems: output

The aim is to simplify the transformation of the numerical model results into answer to decision makers. Although the reporting chain has been recently hugely improved, it would help to add:

- modules connecting the each decision maker question to the results where answers are provided;
- Procedures to help the user exploring the robustness of the answers;
- Procedures to provide the significance of each question / answer in explaining the behaviour of the system and its development.

3.3 – Networking different expertise

In theory a single person can develop and analyse the model of a simple energy system.

In most cases however it helps to make interdisciplinary teams work together, each contributing diversified pieces of knowledge.

The goal is to implement a framework that combines Web technologies, Data Base Management Systems and object oriented programming with ETSAP tools in order to develop and exploit the same model at distant locations.

3.4 – Backwards sensitivity analyses

The problem is to build "expert procedures" capable of tracing back from an equilibrium solution the subset of input data explaining specific solution values.

The starting point is provided by some post-optimal direct sensitivity analyses (what changes in the solution when an input element changes?)

The question of the backward sensitivity analysis is: what input changes are necessary to achieve a desired result?

- Value flows: what sets/elements drive the most significant economic values of the system and its development?
- Causality flows: what input determines a result?