Alternative Objective Function Formulations in TIMES

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Background

- **Anomalies identified in the standard objective function**
  - Mostly related to variable period lengths
  - Discovered by GianCarlo Tosato, ETSAP Project Head
- **Original TIMES design partly based on MARKAL**
  - But MARKAL was not designed to handle variable period lengths?
- **The EFOM model generator was originally fully designed for using flexible variable period lengths**
- **Already in 2002 VTT initially implemented alternative TIMES formulations – based on the EFOM paradigm**
  - Linear evolution of flows and activities between milestone years
- **In February 2008, VTT offered to implement alternative formulations into the common TIMES code**

Alternative Formulations

- **Three different new formulations implemented:**
  - MOD: Modified period definitions and investment spreads
  - ALT: Same as MOD + enhanced capacity transfer coefficients
  - LIN: Same as ALT + linear evolution of flows / activities
- **Formulation can be selected by using a TIMES control switch OBJ in the run file:**
  - $SET OBJ MOD – use the MOD formulation
  - $SET OBJ ALT – use the ALT formulation
  - $SET OBJ LIN – use the LIN formulation
  - $SET OBJ AUTO (default) – auto-select between STD / MOD
  - $SET OBJ STD – force using the standard formulation
- **All new formulations support fully flexible milestone definitions (some limitations in standard formulation)**

The MOD Formulation

- **MOD stands for MODified objective formulation**
- **Periods are defined internally by TIMES**
  - B(t) and E(t) are set to be halfway between Milestone years
  - Only the first B(t) and the last E(t) need to be specified by user
- **Investment spreads for Case 1.a and 1.b are defined slightly differently:**
  - In Case 1.a the spread in Milestone T is M(T–1)+1,…, M(T)
  - In Case 1.b, if TLIFE is greater than M(T)–M(T–1), the spread for the first repeated cycle is similar to that in Case 1.a, and subsequent cycles appended have the same spread form
- **Milestones can be specified fully flexibly**
  - Standard formulation (STD) requires that Milestone years are always located at the middle of their period

The ALT Formulation

- **ALT stands for ALTernative objective formulation**
- **Includes all the MOD modifications, plus a few more**
- **Capacity transfer coefficients for newly installed capacities are defined slightly differently:**
  - The effective lifetime of technologies is calculated taking into account discounting
  - Only the last coefficient at the end of the lifetime is affected, and also the first coefficient if ILED is specified
  - No changes in the coefficients for PAST investments or RESID
- **Investment spreads for Case 1.b slightly different:**
  - The spread for the first repeated cycle is always similar to that in Case 1.a, to which subsequent cycles are appended
- **Variable costs adjusted to be in sync with investments**

The LIN Formulation

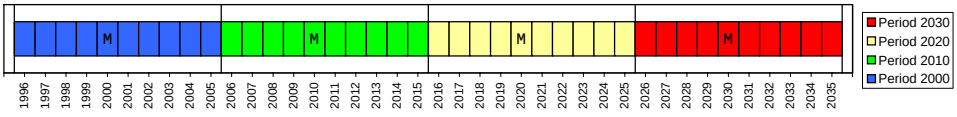
- **LIN stands for LINearized objective formulation**
- **Includes all of the ALT modifications except for the variable cost adjustments**
- **Additionally assumes linear evolution of flows and activities between Milestone Years**
  - Same assumption as in the EFOM paradigm
- **Diverts from the MARKAL paradigm, which assumes constant flows and activities within each period**
- **Necessary changes in model equations:**
  - EQ_OBJVAR: All variable costs in the objective function according to linear evolution of flows and activities
  - EQ_STGIPS: Linear evolution of IN/OUT flows assumed
  - Cumulative constraints: Linear evolution of flows assumed

Benchmark exercise

- **Compare the cost results of a simple model to those when using purely one-year periods (=Reference)**
  - Using one-year periods always gives most accurate results
  - Ideally, with longer periods the model should produce results almost identical to those when using one-year periods
- **Very simple example model:**
  - Only one demand linearly increasing from 2000 to 2030
  - One new technology with investment and fixed costs, TLIFE=20
  - One existing technology with RESID simulated by using CAP_BND and TLIFE=1, using annualized costs equal to new technology
  - Both technologies use a single fuel with linearly increasing price
  - General discount rate is 7%
- **Cost results from running with 4, 5 or 6 periods are compared to the corresponding reference results**

Benchmark exercise: Example 1

- **Four periods of equal length (2000, 2010, 2020, 2030)**
  - Periods according to standard formulation (M = milestone year):

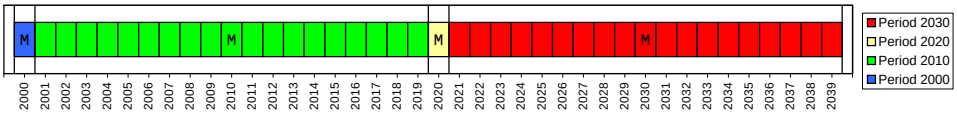


Benchmark Results	Reference	STD	MOD	ALT	LIN
Objective component values					
Investment costs (minus salvage)	417853	426659	426659	423271	423271
Fixed costs	378929	386915	386915	383843	383843
Variable costs	276664	273122	273122	278979	276664
Differences to reference					
Investment costs	0	2.1%	2.1%	1.3%	1.3%
Fixed costs	0	2.1%	2.1%	1.3%	1.3%
Variable costs	0	-1.3%	-1.3%	0.8%	0.0%

- **All formulations appear to perform well with equal period lengths**

Benchmark exercise: Example 2

- **Four periods, variable length (2000, 2010, 2020, 2030)**
  - Periods according to standard formulation (M = milestone year):

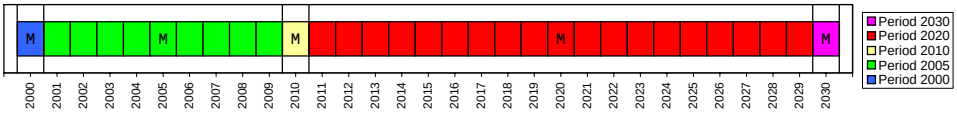


Benchmark Results	Reference	STD	MOD	ALT	LIN
Objective component values					
Investment costs (minus salvage)	345228	383005	355597	345228	345228
Fixed costs	313070	347327	322472	313070	313070
Variable costs	238674	249050	235133	240899	238674
Differences to reference					
Investment costs	0	10.9%	3.0%	0.0%	0.0%
Fixed costs	0	10.9%	3.0%	0.0%	0.0%
Variable costs	0	4.3%	-1.5%	0.9%	0.0%

- **Standard formulation (STD) shows considerable differences in investment and fixed costs**

Benchmark exercise: Example 3

- **Five periods, var. length (2000, 2005, 2010, 2020, 2030)**
  - Periods according to standard formulation (M = milestone year):

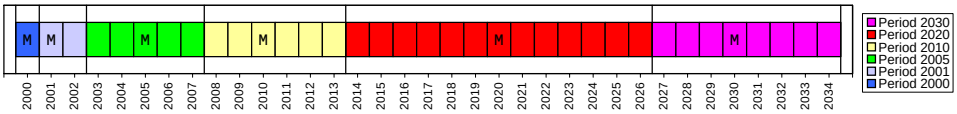


Benchmark Results	Reference	STD	MOD	ALT	LIN
Objective component values					
Investment costs (minus salvage)	315026	335742	321135	315026	315026
Fixed costs	285681	304467	291221	285681	285681
Variable costs	212997	217500	211147	214216	212997
Differences to reference					
Investment costs	0	6.6%	1.9%	0.0%	0.0%
Fixed costs	0	6.6%	1.9%	0.0%	0.0%
Variable costs	0	2.1%	-0.9%	0.6%	0.0%

- **Standard formulation (STD) shows still notable differences in investment and fixed costs**

Benchmark exercise: Example 4

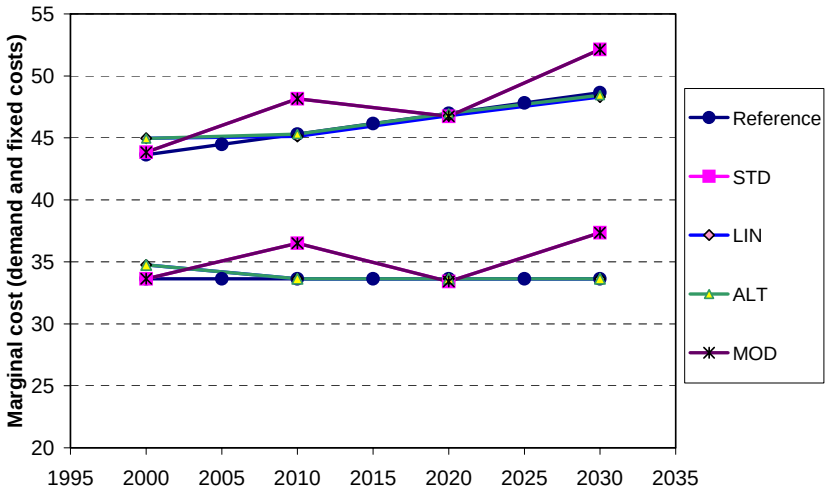
- **Six periods, variable (2000, 2001, 2005, 2010, 2020, 2030)**
  - Periods according to standard formulation (M = milestone year):



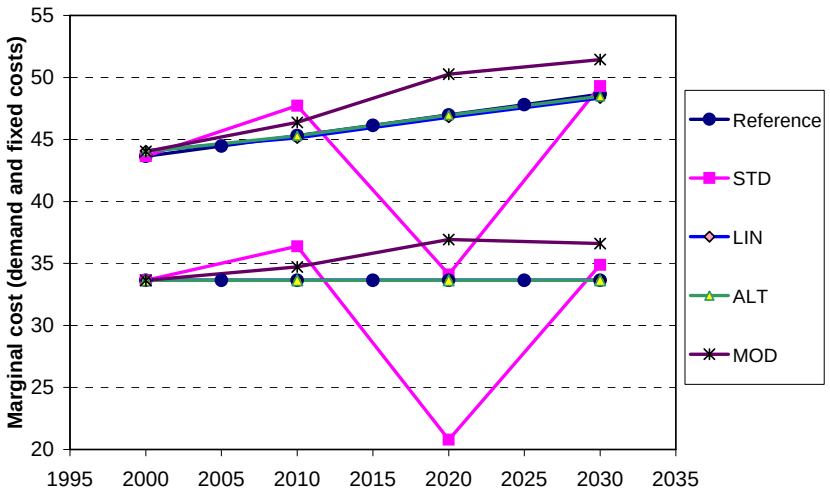
Benchmark Results	Reference	STD	MOD	ALT	LIN
Objective component values					
Investment costs (minus salvage)	330728	344604	335748	330728	330728
Fixed costs	299920	312504	304472	299920	299920
Variable costs	226346	227396	223971	227826	226346
Differences to reference					
Investment costs	0	4.2%	1.5%	0.0%	0.0%
Fixed costs	0	4.2%	1.5%	0.0%	0.0%
Variable costs	0	0.5%	-1.0%	0.7%	0.0%

- **Standard formulation (STD) shows still noticeable differences in investment and fixed costs**

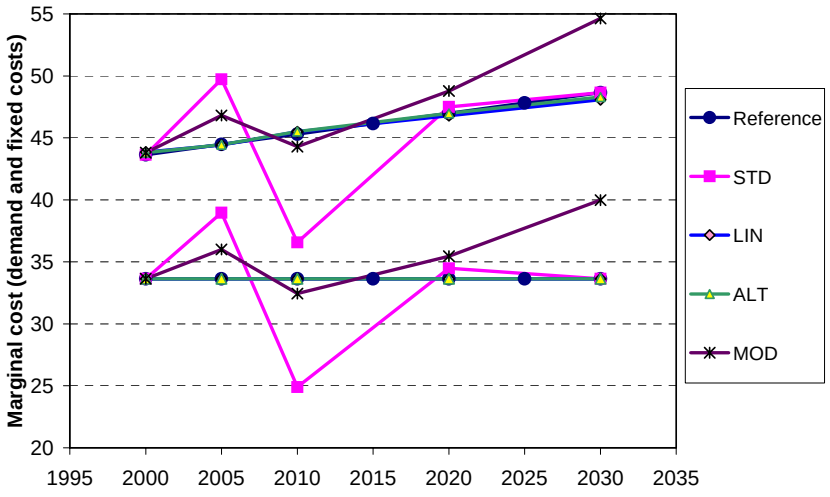
Marginal costs of demand: Example 1



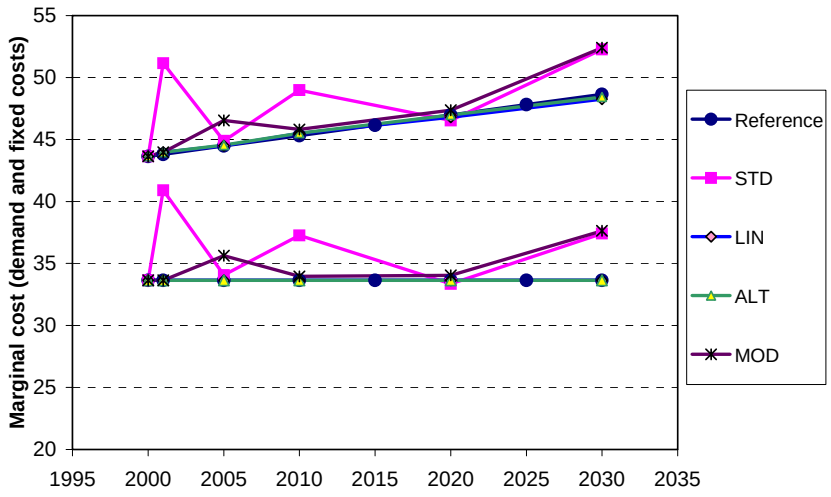
Marginal costs of demand: Example 2



Marginal costs of demand: Example 3



Marginal costs of demand: Example 4



Conclusions (1)

- **Benchmark shows that the standard formulation can lead to notable differences in investment & fixed costs**
  - Choice of Periods may affect technology competitiveness
- **The MOD formulation eliminates problems related to investment spreads in standard formulation**
  - Investment spreads in successive periods continue more smoothly
  - But variable costs are still not in sync with capacity availability
- **The ALT and LIN formulations further improve the independence of model results from period definitions**
  - The behaviour of models with one-year periods is well simulated
- **The LIN option can even give identical model results regardless of the milestones used in the model!**
  - Choice of Milestones no longer affects technology competitiveness

Conclusions (2)

- **Marginal cost differences in the standard formulation decrease along with smoother period definitions**
  - But unless all periods have equal length, the differences might still be significant in some individual periods, affecting competitiveness
- **The ALT and LIN formulations may thus be useful in models where flexible milestone years are needed**
  - Either for checking the consistency of results, or even for regular use
  - For further accuracy in cost accounting, the use of MID_YEAR may also be recommended with ALT / LIN
- **New formulations support fully flexible milestone years**
- **All three new formulations available in TIMES v2.7.0**
  - Results of the Benchmark exercise can be reproduced