Consistency between the TIMES Activity-Capacity Relationships and the Objective Function

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1 Introduction

The main motivation behind defining TIMES model periods to be longer than one year is to avoid the model size increasing too much when long model horizons are analyzed. TIMES thus only produces one EQ_CAPACT equation for each period and every TS within the representative year M(t) of that period. In the standard formulation of TIMES, both the activities and capacities are assumed to be *constant* within each period, representing the average activity and the average available capacity in the period. This has been clearly indicated already in Part I of the documentation, in Section 4.4.3 *Use of capacity* (Part I), where the available capacity in period t is referred to as CAP(r,v,t,p). The concept of the average available capacity has been further explained in Part II of the documentation, Section 4.10 *VAR_NCAP(r,v,p)*. The internal parameter COEF_CPT(r,v,t,p), which defines the fraction of capacity built in period v being available in period t, has been explained in Section 5.3.6 Equation: EQ(l)_CAPACT.

There is also an alternative formulation available in TIMES, which assumes *linear evolution* of activities and capacities between milestone years. This is another way of achieving a comparable simplification of the model when using period lengths longer than 1 year.

2 Discrepancy

The simplifications due to periods longer than one year do not as such lead to any inconsistencies in the activity-capacity relationships. The equations EQ(l)_CAPACT will always ensure sufficient (average or linearly evolving) capacity for producing the (average or linearly evolving) activity, and there is nothing in them imposing any overcapacity either.

However, in the objective function the capacity-related costs (investment cost and fixed operating costs) are always accounted using detailed cost spreads, which may result in some variation in the total capacity within the model periods. Since many years now, the ETSAP community has been well aware of the small discrepancies that are caused by the differences in the assumptions concerning the capacity evolution between the objective function and the more simplified representation of the capacities and activities in the model, when period lengths are greater than 1. These discrepancies are manifested by a small overestimation (or underestimation) of the investments and/or fixed costs in many cases.

3 Illustrative example

In addition to spreading the costs resulting from investments into a series of annual payments, a major refinement of the TIMES objective function is that the physical investment itself does not occur in a single year, but rather as a series of annual increments (see Part II, Section 5.2.2). For example, in the investment Case 1.a the investments are spread into D(t) successive annual increments, as illustrated in Figure 1 below.

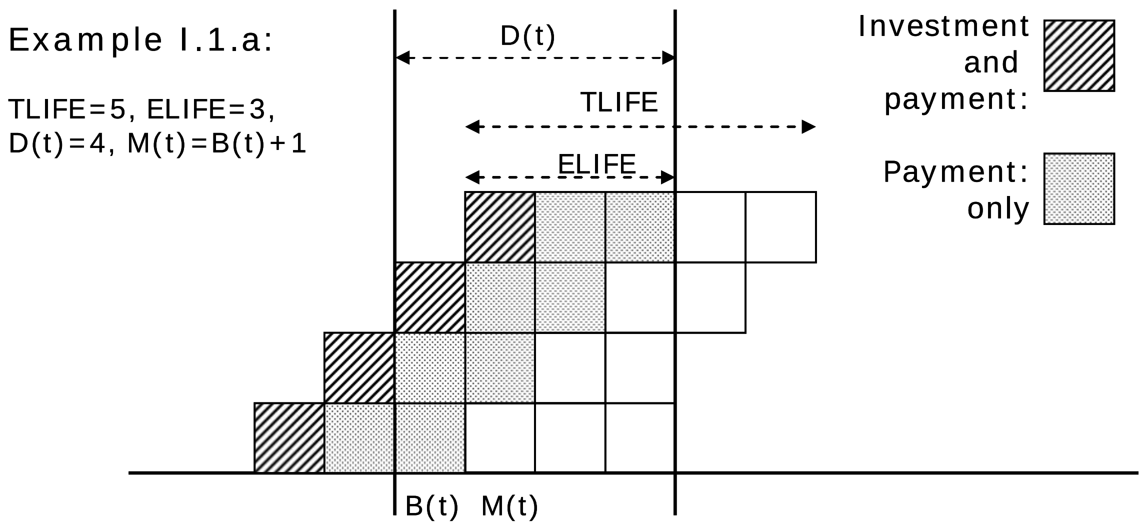

Figure 1. Illustration of the spreading of the physical investment in Investment Case 1.a, over D(t) years. In this example, D(t)=4, which results in four successive increments of new installed capacity.

Note that although in Figure 1 the capacity increments start in the previous period *t-1*, in the "physical" model there is actually no capacity assumed to be available in the previous period. In addition, only a single, average value of the capacity is actually assumed to be available in the periods *t* and *t+1*. The detailed investment spreads are thus only assumed in the objective function.

We can use this example for analyzing the impact of the discrepancies between the simplified assumptions about the activities and capacities within each period and the more detailed spreading of the investment and fixed costs in the objective function, as illustrated in Figure 1. It should be clear that such discrepancies cannot occur if all periods of the model are *single-year periods*, with D(t)=1 for all t. The impacts of the discrepancies can thus be analyzed by comparing the results from an accurate single-period model to those from a model with four-year periods, as in the example.

Let us consider a very simple test model, which basically includes only a single process producing a single demand, with the characteristics shown in Figure 1. Assume that we have six consecutive four-year model periods, with the milestone years 2010, 2014, 2018, 2022, 2026 and 2030. The demand is defined to be evolving linearly between the milestone years, from 2010 to 2030. Figure 2 illustrates the resulting evolution of the demand and thus also the activity of the example process.

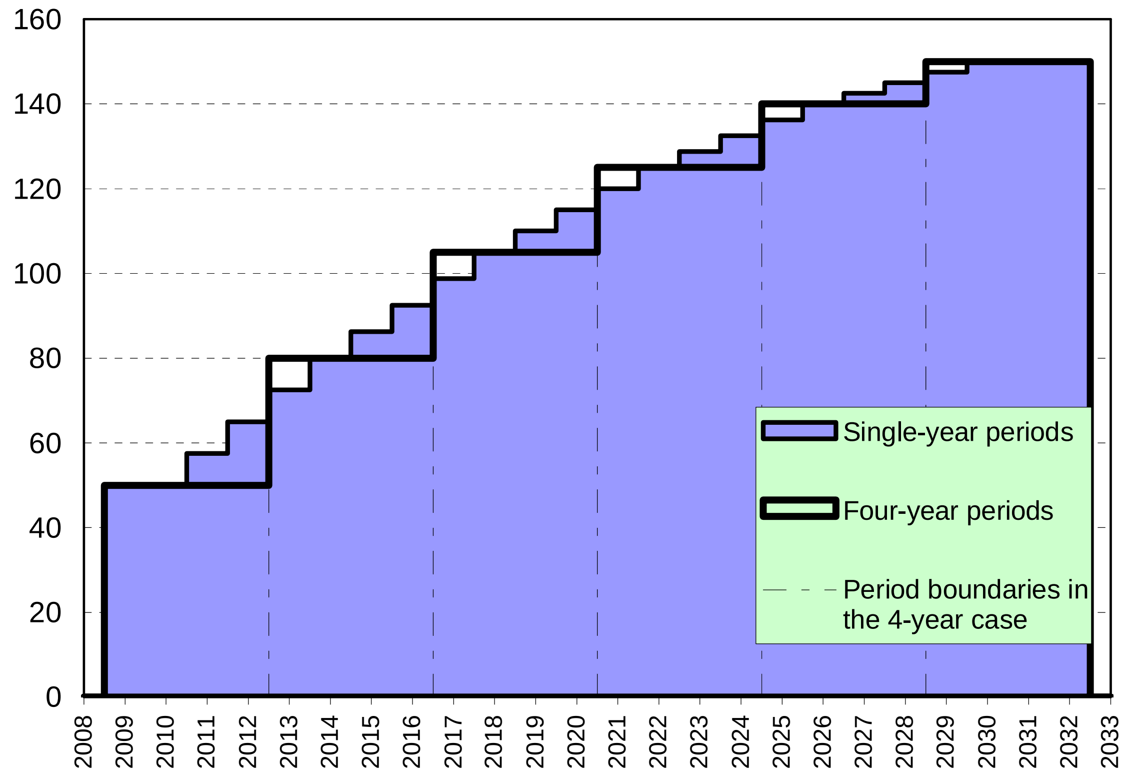

Figure 2. Comparison of the evolution of the activity level in a simple example model between the accurate single-year period case and the case of four-year period lengths.

Assume that we apply a general discount rate of 5 % in the test model, and use only constant unit costs in the test model. Because we have only a single process producing the demand, we can now immediately calculate the expected difference in the overall costs between the two model variants (1-year period case vs. 4-year period case), if the objective function is consistent. The difference can be calculated directly from the difference in the discounted areas under the two curves in Figure 2.

<u>Conjecture:</u> Assuming constant unit costs, the objective function will be consistent with the simplified assumptions about the activities and capacities within each period, if the total discounted costs will be 2.425 % smaller in the 4-year case compared to the 1-year case. In addition, the results should show this same difference in the investment, fixed O&M, and variable costs.

We can run the four-year period model also with several different user options:

1. The standard TIMES formulation (STD-4YR)
2. The standard TIMES formulation with the OBLONG switch (STD+4YR)
3. The MOD variant of the TIMES objective formulation (MOD-4YR)
4. The LIN variant of the TIMES objective formulation (LIN-4YR)

The results that are most relevant to the present discussion are presented below in Table 1. The accurate single-year period case (STD-1YR) is listed as the first scenario for each result parameter.

Table 1. Results for the marginal cost of the demand as well as for the objective function components in the test cases. EQ_CombalM represents the marginal cost for the demand, and the other result parameters are related to the objective function components and the total OBJ.

				Period							Difference
Attribute	**Scenario**	**Commo**	**UserCo**	**-**	**2010**	**2014**	**2018**	**2022**	**2026**	**2030**	**to STD-1YR**
EQ_CombalM	STD-1YR	ELC	-		40.49760	40.49760	40.49760	40.49760	40.49760	40.49760	0.000%
EQ_CombalM	STD-4YR	ELC	-		41.75236	41.75585	41.73885	41.82152	41.41960	43.37372	3.653%
EQ_CombalM	STD+4YR	ELC	-		40.49760	40.49760	40.49760	40.49760	40.49760	40.49760	0.000%
EQ_CombalM	MOD-4YR	ELC	-		40.49760	40.49760	40.49760	40.49760	40.49760	40.49760	0.000%
EQ_CombalM	LIN-4YR	ELC	-		40.49760	40.49760	40.49760	40.49760	40.49760	40.49760	0.000%
Reg_wobj	STD-1YR	CUR	FIX	15111.09							0.000%
Reg_wobj	STD-4YR	CUR	FIX	15413.76							2.003%
Reg_wobj	STD+4YR	CUR	FIX	14744.66							-2.425%
Reg_wobj	MOD-4YR	CUR	FIX	14744.66							-2.425%
Reg_wobj	LIN-4YR	CUR	FIX	15111.09							0.000%
Reg_wobj	STD-1YR	CUR	INV	33240.77							0.000%
Reg_wobj	STD-4YR	CUR	INV	33906.57							2.003%
Reg_wobj	STD+4YR	CUR	INV	32434.70							-2.425%
Reg_wobj	MOD-4YR	CUR	INV	32434.70							-2.425%
Reg_wobj	LIN-4YR	CUR	INV	33240.77							0.000%
Reg_wobj	STD-1YR	CUR	VAR	12844.42							0.000%
Reg_wobj	STD-4YR	CUR	VAR	12532.96							-2.425%
Reg_wobj	STD+4YR	CUR	VAR	12532.96							-2.425%
Reg_wobj	MOD-4YR	CUR	VAR	12532.96							-2.425%
Reg_wobj	LIN-4YR	CUR	VAR	12844.42							0.000%
ObjZ	STD-1YR	-	-	61196.28							0.000%
ObjZ	STD-4YR	-	-	61853.29							1.074%
ObjZ	STD+4YR	-	-	59712.32							-2.425%
ObjZ	MOD-4YR	-	-	59712.32							-2.425%
ObjZ	LIN-4YR	-	-	61196.28							0.000%

The marginal cost for the demand can be viewed as the most important result with respect to the economic consistency of the model, because the marginal costs will, in general, drive the selection between competing technologies in the model. From the test case results we can see that the marginal costs are fully consistent in all other cases except in the STD-4YR case (the standard TIMES formulation). However, the discrepancy in the STD-4YR case is not large; on the average it is only 3.7% (average difference over all periods).

From the results for the objective function, we can see similar results: The total value of the objective function differs *exactly by the amount expected* (2.425%) in the STD+4YR and MOD-4YR cases, and therefore we can conclude that they are indeed consistent with respect to their objective function. In the LIN-4YR case the value of the objective function is exactly the same as in the accurate STD-1YR case, which is also fully as expected, because the linear formulation can fully reproduce the assumed linearly evolving demand between the milestone years.

Conclusion 1: When using period lengths greater than one year, the TIMES standard formulation may result in small inconsistencies in the marginal costs and objective function due to the differences between the detailed cost accounting in the objective function and the simplified activity-capacity assumptions in the model. However, the magnitude of these inconsistencies can be expected to be at most a few per cent.

Conclusion 2: The TIMES standard formulation with the OBLONG switch eliminates the impacts of the differences between the detailed cost accounting in the objective function and the simplified activity-capacity assumptions in the model. The results are thus economically consistent with any period lengths.

Conclusion 3: The TIMES alternative objective formulations MOD and LIN eliminate the impacts of the differences between the detailed cost accounting in the objective function and the simplified activity-capacity assumptions in the model. The results are thus economically consistent with any period lengths.

Insofar as the small impacts of the discrepancies in the standard formulation of TIMES are considered undesirable, the use of the OBLONG switch can thus be recommended. Alternatively, the users may also consider using the alternative objective formulations, which also eliminate the impact of such discrepancies.