Addon Discrete Size Investments in Technology

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0.1 Introduction

In the base version of Balmorel, endogenous investment in technology capacity is specified by a continuous variable VGKN. One consequence of this is that unrealistically sized investments may be found. Although this may be acceptable in some contexts, it may be undesirable in others.

The addon AGKNDISC permits specification that for any technology the investment must be in one out of a pre-specified number of sizes, e.g. either 200, 500 or 700 MW (or none at all). This condition may apply to some or all of the technologies.

0.2 Input data

The technologies have the same data (given i GDATA) irrespective if they are to be invested with discrete or continuous sizes. Those that are to be invested with discrete sizes have additional data as described in the sequel.

Set AGKNDISCAG

SET AGKNDISCAG(AAA,GGG) 'Areas for possible location of discrete capacity investments in technologies'. Input data.

Set AGKNDISCAG is supposed to be a subset of AGKN.

If a particular technology 'Gx' has been defined as discrete size investments in an area 'Ay', it will automatically be impossible to have continuous size investments in this combination ('Ay','Gx') of area and technology.

Note that the condition of discrete investment is on the combination (AAA,G). This means that a particular technology 'Gz' may be permitted continuous size endogenous investments in some area 'Aw' while being conditioned to discrete size investments in others.

Set AGKNDISCGSIZESET

SET AGKNDISCGSIZESET 'Set of possible sizes for discrete capacity investments in technologies'. Input data.

Define for instance "SET AGKNDISCGSIZESET / AGKNDISCGSIZE1, AGKNDISCGSIZE2, AGKNDISCGSIZE3 /;" to permit up to three different sizes (in addition to the no investment possibility).

Set AGKNDISCGDATASET

SET AGKNDISCGDATASET 'Technology investment data types for discrete capacity size investments'. Input data.

This set specifies three obligatory elements:

AGKNDISCSIZE 'Size (MW)'
AGKNDISCINVCOST 'Investment cost (MMoney)'
AGKNDISCOMFCOST 'Annual operating and maintenance costs (MMoney)'

Note that the units of the two latter elements are MMoney, not Money/MW or similar.

Note that the data is independent of the area. If this is unsatisfactory, define two or more technologies that differ only only in this respect and use AGKNDISCAG to specify the possible locations of each of them.

Parameter AGKNDISCGDATA

PARAMETER AGKNDISCGDATA(GGG,AGKNDISCGSIZESET,AGKNDISCGDATASET) 'Technology investment data for discrete capacity size investments'. Input data.

This parameter specifies for each technology and each element in AGKNDISCGSIZESET the values for each element in AGKNDISCGDATASET.

If 0 (or nothing) is specified as value for 'AGKNDISCSIZE' for a certain element in AGKNDISCGSIZESET this means that this element in AGKNDISCGSIZESET is not considered an option (thus, the number of elements in AGKNDISCGSIZESET indicates the maximum possible number of discrete sizes, the actual number used depends on the individual technology).

0.3 Internals

Set IAGKNDISCAG

SET IAGKNDISCAG(AAA,G) 'Area, technology for discrete size investment, where technology may be invested based on AGKN and implicit constraints'. Internal.

This internal set is very much similar to IAGKN. And similarly to the AGKNDISCAG/AGKN pair, it is supposed to be a subset of IAGKN.

Parameter IAGKNDISCDIFFCOST

PARAMETER IAGKNDISCDIFFCOST(AAA,G,AGKNDISCGSIZESET, AGKNDISCGDATASET) 'Investment costs in relation to discrete capacity size investments, as difference for each size (Money) (Addon AGKNDISC)'. Internal.

One characteristic of the economy related to endogenous investments in the base version of Balmorel is that the cost associated with an investments is proportional to the size of the invested capacity (it is a linear model). In contrast, the cost related to discrete size investments need not be proportional to the size, since the cost is specified individually for each element in AGKNDISCGSIZESET.

The AGKNDISC addon uses the same variables VGKN to represent the endogenous investment as does the base version of Balmorel, and there is therefore a proportional cost term in the objective function QOBJ. This term is eliminated through the construction of IAGKNDISCDIFFCOST:

```
IAGKNDISCDIFFCOST(IA,G,AGKNDISCGSIZESET, AGKNDISCGDATASET)$AGKNDISCAG(IA,G)
=
AGKNDISCGDATA(G,AGKNDISCGSIZESET,'AGKNDISCINVCOST')
- AGKNDISCGDATA(G,AGKNDISCGSIZESET,'AGKNDISCSIZE')*GOMFCOST(IA,G)
- AGKNDISCGDATA(G,AGKNDISCGSIZESET,'AGKNDISCSIZE')*GINVCOST(IA,G);
```

As seen, in IAGKNDISCDIFFCOST the proportional terms are subtracted from the discrete size related terms in AGKNDISCGDATA. It is noted that VGKN can take only values AGKNDISCGDATA(G,AGKNDISCGSIZESET,'AGKNDISCSIZE') (or zero), see equation QAGKNDISCCONT.

IAGKNDISCDIFFCOST (multiplied by VGKNDISC) is added to the objective function.

0.4 Variables

VGKNDISC

BINARY VARIABLE VGKNDISC(AAA,G,AGKNDISCGSIZESET) 'New generation capacity in relation to discrete capacity size investments (binary)'.

Note that the variables VGKNDISC may be considered as being internal, they will not normally be of interest once the solution is found. The endogenously found technology capacity is given by VGKN.L also in case of discrete size endogenous investments.

0.5 Equations, model and solve

Equation QAGKNDISC01

QAGKNDISC01(AAA,G) 'At most one of the specified discrete capacity size investments is chosen (0/1)'

This equation ensures that at most one of the binary values in VGKNDISC(*,*,AGKNDISCGSIZESET) can take the value 1.

Equation QAGKNDISCCONT

QAGKNDISCCONT(AAA,G) 'The invested capacity must be one of the specified sizes or zero (MW)'

This equation ensures that VGKN can take only values specified in AGKNDISCGDATA(*,*,'AGKNDISCSIZE').

Model and solve

The equations are to be included in model Balbase2.

The model is of type MIP (mixed integer programming), therefore the solve statement must specify "using MIP". This is ensured by the control setting "$Setglobal SOLVEMIP yes". It is of course assumed that the users has a solve capable of solving MIP problems.

0.6 Error, printing and similar

Some output is printed to file /printout/gkn_ag.out.

0.7 File, folder and include structure

The new code input is held in a number of files located in folder /addon/AGKNDISC/. Data input is found in files agkndiscag.inc, agkndiscgdataset.inc, agkndiscgdata.inc, agkndiscgsizeset.inc in the data folder.

Output may be printed to file /printout/gkn_ay.out from file /printinc/gkn_ay.inc.

Variables, equations and other internal items are in folder /addon/agkndisc/.

The files are included into the model at appropriate places by statements of the form "$ifi %AGKNDISC%==yes $include '...';".

0.8 Add-on controls

The application of the addon is controlled by $Setglobal AGKNDISC, where a yes specifies that the addon be applied.

Relevant only for BB2.

See the comments on model type MIP above.

0.9 Some observations and interpretations

Calculation time

The problem to be solved is of the MIP type, it is well known that in general this may imply long calculation time.

Prices

Key concepts to be considered about this (and any other) investment model are the short run marginal costs (SRMC) and the long run marginal costs (LRMC). The point here is that standard solvers for MIP problems for derivation of the electricity price will provide only values similar to the SRMC. Further, there seems to be no other formulation that is suitable for standard solvers and that will indicate the LRMC.

Consider an example given in relation to investment in an electricity only unit, however, the same considerations apply for heat only and chp types of units.

Assumptions are as follows. SRMC: 100 Money/MWh; investment size: 100 MW; investment annuity cost for 100 MW: 5400000 Money; to be distributed over 1000 hours during the year of investment; demand to be covered by this unit each of the 1000 hours: 90 MW. It is further assumed that the unit is marginal (viz., price setting) in the hours considered.

This implies that each hour the consumption has to 'pay' 5400 Money in order to cover the investment annuity cost, or 5400/90 = 60 Money/MWh. Thus, in order to get exactly covered the costs, the electricity price should be SRMC+60 = 160 Money/MWh. However, a standard solver will usually give the value 60, i.e. the SRMC.

A tiny GAMS model that may verify this example is given here.

```
* Begin model
$Title Discrete size investments - illustration of prices
SCALAR SRMC "Variable cost (Money/MWh)" /100/;
SCALAR INVCOSTANNUITY "Annual invest. cost each relevant hour (Money)" /5400/;
SCALAR CAPACITY "Capacity considered invested (MW)" /100/;
SCALAR DEMAND "Fixed demand (MW)" /90/;
FREE VARIABLE VOBJ "Objective function variable: costs (Money)";
POSITIVE VARIABLE VGEN_T "Generation (MW)";
BINARY VARIABLE VGKNDISC "Investment decision (0/1)";
EQUATION QOBJ "Objective function equation: costs (Money)";
EQUATION QEEQ "Electricity balance (MW)";
EQUATIONS QCAPACITY "Investment must take place if production is positive";
QOBJ.. VOBJ =E= VGEN_T*SRMC + VGKNDISC*INVCOSTANNUITY;
QEEQ.. VGEN_T =E= DEMAND;
QCAPACITY.. VGEN_T =L= CAPACITY*VGKNDISC;
MODEL DISCRETESIZEINVESTMENT /ALL/;
SOLVE DISCRETESIZEINVESTMENT MINIMIZING VOBJ USING MIP;
DISPLAY VGEN_T.L, VGKNDISC.L;
DISPLAY "Intuitively this would be the electricity price (Money/MWh):", QEEQ.M;
* End model
```

A number of alternatives may be considered.

Alternative 1. Do not use the agkndisc addon. This will give the LRMC in the LP model, but will not in general give a size of new investment that comply with any specific discrete size.

In relation to the above example observe the following for a LP formulation . The quantity invested will be 90 MW (not 100). The investment related cost to be covered by each relevant hour is 5400*(90/100)/90 = 54 Money/MWh. The average cost is then 154 Money/MWh, and this is also the marginal cost, i.e., the LRMC. A standard solver will for this LP model usually return the expected 154. This may be verified by substituting "using MIP" by "using RMIP" (this will then result in a LP model) in the solve statement in the above model and then resolving.

Alternative 2. As Alternative 1, but then round down the found investment sizes to the nearest acceptable discrete size. This may resolve the problem (i.e., it will give LRMC and discrete sizes), however, it will not in general ensure that the capacities provide a feasible solution (due to shortage of capacity).

Alternative 3. As Alternative 1, but then round up the found investment sizes to the nearest acceptable discrete size (which has to be assumed to exist). This will give the LRMC and discrete sizes. But if the full capacity is not exploited in the peak load hour the units will not have their investments' annuity costs covered at this value of LRMC. Moreover, it may be argued (if the investments are assumed to be distributed

over efficiently competing companies) that it may only be possible to achieve the SRMC due to competition, because there is over-capacity.

So, in general it seems that either quantities (viz., discrete ones) or prices (viz., LRMC) will be intuitive and appropriate, but not both in the same model.

Integrated horison investment model

The present addon may be used with the integrated horison investment model; details will be described later.

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