

## Download GAMS Programs:

<ftp://ftp.zew.de/pub/zew-docs/div/td-bu.pdf>

### Part 1: MCP Formulation

```
1 $Title  Static maquette of integrated TD/BU hybrid model
2
3 *      Model formulation in MCP
4
5 *=====
6 * Model code for stylzed integrated bottom-up/top-down analysis of energy
7 * policies based on:
8 *
9 *          ZEW Discussion Paper 05-28
10 *      Integrating Bottom-Up into Top-Down:
11 *          A Mixed Complementarity Approach
12 *
13 * Contact the authors at: boehringer@zew.de; tom@mpsge.org
14 *=====
15
16 * For plotting the results you must have installed the gnuplot-shareware
17 * (see http://debreu.colorado.edu/gnuplot/gnuplot.htm for downloads)
18
19 *=====
20 *      List of parameters subject to sensitivity analysis
21 *      The user can change the default settings.
22
23 * Choice of key elasticities:
24 *      Elasticity of substitution in final consumption
25 $if not setglobal esub_c $setglobal esub_c 0.5
26
27 *      Elasticity in gas supply
28 $if not setglobal esub_gas $setglobal esub_gas 1.5
29
30 *      Elasticity in coal supply
31 $if not setglobal esub_coal $setglobal esub_coal 3
32
33 *      Elasticity in oil supply
34 $if not setglobal esub_oil $setglobal esub_oil 1.5
35
36
37 * Choice of resource availability for renewables:
38 * (as a fraction of base-year total electricity production)
```

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39 *      Potential wind supply - (%)
40 $if not setglobal p_wind $setglobal p_wind 10
41
42 *      Potential solar supply - (%)
43 $if not setglobal p_sun $setglobal p_sun 10
44
45 *      Potential biomass supply - (%)
46 $if not setglobal p_trees $setglobal p_trees 10
47
48
49 * Cost disadvantage of initial slack technologies:
50 *      Wind energy premium (%)
51 $if not setglobal c_wind $setglobal c_wind 10
52
53 *      Solar energy premium (%)
54 $if not setglobal c_solar $setglobal c_solar 10
55
56 *      Biomass energy premium (%)
57 $if not setglobal c_biomass $setglobal c_biomass 10
58
59
60 * Other central model assumptions:
61 *      Time horizon (short, long)
62 *      N.B.: For short-run analysis capital is immobile across sectors
63 $if not setglobal horizon $setglobal horizon long
64
65 *=====
66
67
68 *      Assign user-specific changes of default assumptions
69 scalar  shortrun      Flag for short-run capital mobility/1/;
70
71 $if "%horizon%"=="long" shortrun=0;
72
73 *      Elasticities of substitution (ESUB)
74 scalar  esub_c      Elasticity of substitution in final demand /%esub_c%/
75          esub_ele    ESUB between electricity and oil in final demand /0.5/
76          esub_k_e    ESUB between capital and energy in ROI production /0.5/
77          esub_l_ke   ESUB between labor and other inputs in ROI production /0.8/;
78
79 set     t           Electricity Technologies (current and future)
80          /coal,gas,nuclear,hydro,wind,solar,biomass/;
81

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82 set      xt(t)   Existing technologies /coal,gas,nuclear,hydro/;
83
84 set      nt(t)   New vintage technologies /wind,solar,biomass/;
85
86 set      ff      Fossil fuel inputs /coa, gas, oil/;
87
88 set      n       Natural resources /wind, sun, trees/;
89
90
91 set      res(t)  Renewable energy sources /hydro, wind, solar, biomass/;
92
93 *       The following data table describes an economic equilibrium in
94 *       the base year:
95
96
97 table sam Base year social accounting matrix
98
99         roi     coa     gas     oil     ele     ra
100 roi     200     -5      -5      -10     -10     -170
101 coa           15              -15
102 gas                15              -15
103 oil                    30              -30
104 ele     -10              60      -50
105 capital -80              -20     100
106 labor   -110    -5      -5      -10              130
107 rent           -5      -5      -10              20      ;
108
109 parameter carbon(ff) Carbon coefficients /oil 1, gas 1, coa 2/;
110
111 scalar  carblim      Carbon target /0/;
112
113 parameter esub_ff(ff) Elasticity of substitution in fossil fuel production
114           /gas %esub_gas%, coa %esub_coal%, oil %esub_oil%/;
115
116 *       The following data tables describes electricity generation in
117 *       the base year as well as the technology coefficients for technologies
118 *       which are inactive in the base year (wind, solar, biomass). Inactive
119 *       technologies are by defaults %c****% more costly.
120
121 table xtelec Electricity technologies - extant (initially active)
122
123         coal     gas     nuclear hydro
124 ele     20      20              12      8

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125 roi      -1    -1      -8
126 gas              -15
127 coa      -15
128 capital  -4    -4      -4    -8;
129
130
131 table ntelec Electricity technologies - new vintage (initially inactive)
132
133      wind    solar    biomass
134 ele      1.0    1.0    1.0
135 roi     -.2    -.3    -.4
136 capital -.9    -.8    -.7
137 wind    -1.0
138 sun              -1.0
139 trees              -1.0;
140
141
142 *      Adjust the cost coefficients for initially inactive technologies
143 *      according to user assumptions:
144 set xk /roi, capital/;
145
146 ntelec(xk,"wind")    = ntelec(xk,"wind")    * (100+%c_wind%)/110;
147 ntelec(xk,"solar")  = ntelec(xk,"solar")  * (100+%c_solar%)/110;
148 ntelec(xk,"biomass") = ntelec(xk,"biomass") * (100+%c_biomass%)/110;
149
150
151 *      Specify limits (resource or policy constraints) to the availability
152 *      of technologies
153
154 parameter limit      Electricity supply limits on extant technologies /
155      nuclear          12
156      hydro            8 /;
157
158 parameter nrsupply(n) Natural resource supplies (fraction of base output)/
159      wind              %p_wind%
160      sun               %p_sun%
161      trees             %p_trees% /;
162
163 nrsupply(n) = nrsupply(n)/100 * sam("ele","ele");
164
165 parameter c0      Baseyear final consumption;
166 c0 = (-sam("roi","ra")-sam("ele","ra")-sam("oil","ra"));
167

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168
169 set      quota(t)  Flag for technologies contributing to green quota;
170 quota(t) = no;
171
172 scalar  share      Target share for green quota /0/;
173
174 *        By default we might set target share for green quota at base year level
175 share = sum(t$res(t), xtelec("ele",t))/sum(t, xtelec("ele",t));
176 display share;
177
178 scalar
179      dd      Flag for double dividend policy analysis /0/,
180      ls      Flag for lump-sum revenue-recycling      /0/,
181      vat      Flag for VAT revenue recycling          /0/,
182      g0      Base year public consumption            /0/,
183      tc0     Base year consumption tax                /0/;
184
185
186 positive variables
187 *        Activitiy levels
188 roi      Aggregate output
189 ele(t)   Production levels for electricity by technology
190 s(ff)    Fossil fuel supplies
191 c        Aggregate consumption (utility) formation
192 g        Public good provision
193
194 *        Price levels
195 proi     Price of aggregate output
196 pele    Price of electricity
197 pf(ff)   Price of oil and gas
198 pl       Wage rate
199 pk       Price of malleable capital for X (and NT elec)
200 pr(ff)   Rent on fossil fuel resources
201 pn(n)    Rent on natural resources
202 pc       Consumption (utility) price index
203 pg       Price of public consumption
204 plim(t)  Shadow price on electricity expansion
205 pkx(t)   Price of capital to extant technologies
206 pcarb    Carbon tax rate
207
208 *        Income variables
209 ra       Representative household
210 govt     Government

```

211

212 \*       Endogenous taxes or subsidies

213 tau      Uniform subsidy rate on renewable energy;

214

215 positive variables

216 phi\_ls   Lump-sum recycling

217 phi\_tc   Consumption tax recycling;

218

219

220 equations

221

222 \*       Zero profit conditions for activities linked to activity levels

223 zprf\_roi       Zero profit condition for macro production sector

224 zprf\_ele(t)   Zero profit condition for alternative electricity supply technologies

225 zprf\_s(ff)    Zero profit condition for fossil fuel supplies

226 zprf\_c        Zero profit condition for aggregate utility formation

227 zprf\_g        Zero profit condition for public good formation

228

229 \*       Market clearance conditions for goods linked to prices

230 mkt\_proi      Market clearance condition for macro production good

231 mkt\_pele      Market clearance condition for electricity

232 mkt\_pf(ff)    Market clearance condition for fossil fuels coal and gas

233 mkt\_pl        Market clearance condition for labor

234 mkt\_pk        Market clearance condition for malleable capital

235 mkt\_pr(ff)    Market clearance conditions for fossil fuel resources

236 mkt\_pn(n)     Market clearance conditions for natural resources

237 mkt\_pcarb     Market clearance condition for carbon

238 mkt\_pkx(t)    Market clearance condition for capital inputs to extant power production

239 mkt\_plim(t)   Market clearance condition for capacity on electricity expansion

240 mkt\_pc        Market clearance for aggregate utility good

241 mkt\_g         Market clearance for public good

242

243 \*       Income balance for representative household linked to income level

244 inc\_ra        Budget constraint for representative household

245 inc\_govt      Budget constraint for government

246

247 \*       Additional constraints

248 sub\_res       Endogenous subsidy to achieve renewable energy quota

249 eqy\_ls        Equal yield constraint for lump-sum recycling

250 eqy\_tc        Equal yield constraint for consumption tax recycling

251

252 parameter

253 theta\_l\_roi   Cost share of labor in ROI production

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254 theta_ele_roi    Cost share of electricity in capital-electricity composite of ROI
255 theta_r_ff(ff)   Cost share of fossil fuel resource in fossil fuel production
256 theta_l_ff(ff)   Cost share of labor in non-resource input of fossil fuel production
257 theta_roi_ff(ff) Cost share of ROI in ROI-labor composite of fossil fuel production
258 theta_ele_c      Cost share of electricity in oil-electricity composite of final consumption
259 theta_roi_c      Cost share of ROI in final consumption
260 theta_roi_t(t)   Cost share of ROI in electricity production by technology t
261 theta_k_t(t)     Cost share of capital in electricity production by technology t
262 theta_ff_t(ff,t) Cost share of fossil fuel in electricity production by technology t;
263
264 theta_roi_c      = -sam("roi","ra")/c0;
265 theta_l_roi      = (-sam("labor","roi"))/sam("roi","roi");
266 theta_ele_roi    = (-sam("ele","roi"))/((-sam("capital","roi")) + (-sam("ele","roi")));
267 theta_r_ff(ff)   = (-sam("rent",ff))/((-sam("rent",ff)) + (-sam("roi",ff)) + (-sam("labor",ff)));
268 theta_roi_ff(ff) = (-sam("roi",ff)) / ((-sam("roi",ff)) + (-sam("labor",ff)));
269 theta_ele_c      = (-sam("ele","ra"))/((-sam("ele","ra")) + (-sam("oil","ra")));
270 theta_roi_t(t)$xt(t) = (-xtelec("roi",t)/xtelec("ele",t));
271 theta_k_t(t)$xt(t)   = (-xtelec("capital",t)/xtelec("ele",t));
272 theta_ff_t(ff,t)$xt(t) = (-xtelec(ff,t)/xtelec("ele",t));
273 theta_roi_t(t)$nt(t) = (-ntelec("roi",t)/ntelec("ele",t));
274 theta_k_t(t)$nt(t)   = (-ntelec("capital",t)/ntelec("ele",t));
275 theta_l_ff(ff)     = (-sam("labor",ff))/((-sam("labor",ff))+(-sam("roi",ff)));
276
277 *           Definition of zero profit conditions
278 zprf_roi..
279   (theta_l_roi*pl**(1-esub_l_ke) + (1- theta_l_roi)
280   *(theta_ele_roi*pele**(1-esub_k_e) + (1-theta_ele_roi)*pk**(1-esub_k_e))
281   **((1-esub_l_ke)/(1-esub_k_e))**(1/(1-esub_l_ke))
282   =G= proi;
283
284 zprf_ele(t)..
285   {theta_roi_t(t)*proi+ sum(ff,theta_ff_t(ff,t)*pf(ff))
286   + (theta_k_t(t)*pkx(t))$shortrun
287   + (theta_k_t(t)*pk)$not shortrun
288   + plim(t)$limit(t)
289   }$xt(t)
290   +
291   {theta_roi_t(t)*proi + theta_k_t(t)*pk + sum(n, (-ntelec(n,t))*pn(n))}$nt(t)
292   =G= pele*(1+tau$quota(t));
293
294 zprf_s(ff)..
295   (theta_r_ff(ff)*pr(ff)**(1-esub_ff(ff)) + (1-theta_r_ff(ff))*( theta_l_ff(ff)*pl
296   + (1-theta_l_ff(ff))*proi)**(1-esub_ff(ff))**(1/(1-esub_ff(ff)))

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297     + ((carbon(ff)*pcarb))$carblim
298         =G= pf(ff);
299
300 zprf_c..
301     (theta_roi_c*((proi*(1+tc0*phi_tc$dd))/(1+tc0$dd)**(1-esub_c)
302     + (1-theta_roi_c)*(theta_ele_c*pele**(1-esub_ele)
303     + (1-theta_ele_c)*pf("oil")**(1-esub_ele))**((1-esub_c)/(1-esub_ele))**1/(1-esub_c))
304         =G= pc;
305
306 zprf_g$dd..
307     proi =G= pg;
308
309 *     Definition of market clearance conditions
310 mkt_proi..
311     roi*sam("roi","roi") =G=
312     sum(xt, ele(xt)*(-xtelec("roi",xt)/xtelec("ele",xt)))
313     + sum(nt, ele(nt)*(-ntelec("roi",nt)))
314     + sum(ff, (-sam("roi",ff))*s(ff)* ((theta_r_ff(ff)*pr(ff)**(1-esub_ff(ff))
315     + (1-theta_r_ff(ff))*( theta_l_ff(ff)*pl
316     + (1-theta_l_ff(ff))*proi)**(1-esub_ff(ff))**1/(1-esub_ff(ff)))
317     /( theta_l_ff(ff)*pl + (1-theta_l_ff(ff))*proi)**esub_ff(ff))
318     + (-sam("roi","ra")/(1+tc0$dd))*c*( pc/(proi*(1+(tc0*phi_tc)$dd))*(1+tc0$dd)**esub_c
319     + (g0*g)$dd;
320
321 mkt_pele..
322     sum(t, ele(t)) =G=
323     (-sam("ele","ra"))*c*(pc/(theta_ele_c*pele**(1-esub_ele)
324     + (1-theta_ele_c)*pf("oil")**(1-esub_ele))**1/(1-esub_ele))**esub_c
325     * (((theta_ele_c*pele**(1-esub_ele)
326     + (1-theta_ele_c)*pf("oil")**(1-esub_ele))**1/(1-esub_ele))/pele)**esub_ele
327     + (-sam("ele","roi"))*roi*(proi/((theta_ele_roi*pele**(1-esub_k_e)
328     + (1-theta_ele_roi)*pk**(1-esub_k_e))**1/(1-esub_k_e))**esub_l_ke
329     * ((theta_ele_roi*pele**(1-esub_k_e)
330     + (1-theta_ele_roi)*pk**(1-esub_k_e))**1/(1-esub_k_e))/pele)**esub_k_e;
331
332 mkt_pf(ff)..
333     sam(ff,ff)*s(ff) =G=
334     sum(xt, (-xtelec(ff,xt)/xtelec("ele",xt))*ele(xt))
335     + (-sam(ff,"ra"))*c*(pc/(theta_ele_c*pele**(1-esub_ele)
336     + (1-theta_ele_c)*pf("oil")**(1-esub_ele))**1/(1-esub_ele))**esub_c
337     * (((theta_ele_c*pele**(1-esub_ele)
338     + (1-theta_ele_c)*pf("oil")**(1-esub_ele))**1/(1-esub_ele))/pf("oil"))**esub_ele;
339

```



```

340 mkt_pl..
341     sam("labor","ra") =G=
342     (-sam("labor","roi"))*roi*(proi/pl)**esub_l_ke
343     + sum(ff, (-sam("labor",ff))*s(ff)* ((theta_r_ff(ff)*pr(ff)**(1-esub_ff(ff))
344     + (1-theta_r_ff(ff))*( theta_l_ff(ff)*pl
345     + (1-theta_l_ff(ff))*proi)**(1-esub_ff(ff))**(1/(1-esub_ff(ff)))
346     /( theta_l_ff(ff)*pl + (1-theta_l_ff(ff))*proi)**esub_ff(ff));
347
348 mkt_pk..
349     (-sam("capital","roi")+sum(xt,(-xtelec("capital",xt))$(not shortrun)) =G=
350     (-sam("capital","roi"))*roi*(proi/((theta_ele_roi*pele**(1-esub_k_e)
351     + (1-theta_ele_roi)*pk**(1-esub_k_e))**(1/(1-esub_k_e))))**esub_l_ke
352     *((theta_ele_roi*pele**(1-esub_k_e)
353     + (1-theta_ele_roi)*pk**(1-esub_k_e))**(1/(1-esub_k_e))/pk)**esub_k_e
354     + sum(xt$(not shortrun),(-xtelec("capital",xt)/xtelec("ele",xt))*ele(xt))
355     + sum(nt,(-ntelec("capital",nt))*ele(nt));
356
357 mkt_pr(ff)..
358     (-sam("rent",ff)) =G=
359     (-sam("rent",ff))*s(ff)* ((theta_r_ff(ff)*pr(ff)**(1-esub_ff(ff))
360     + (1-theta_r_ff(ff))*( theta_l_ff(ff)*pl
361     + (1-theta_l_ff(ff))*proi)**(1-esub_ff(ff))**(1/(1-esub_ff(ff)))/pr(ff)** esub_ff(ff));
362
363 mkt_pn(n)..
364     nrsupply(n) =G= sum(nt,(-ntelec(n,nt))*ele(nt));
365
366 mkt_pkk(xt)$shortrun..
367     (-xtelec("capital",xt)) =G= (-xtelec("capital",xt)/xtelec("ele",xt))*ele(xt);
368
369 mkt_plim(xt)$limit(xt)..
370     limit(xt) =G= ele(xt);
371
372 mkt_pcarb$carblim..
373     carblim =G= sum(ff,(carbon(ff)*sam(ff,ff))*s(ff));
374
375 mkt_pc ..
376     c0*c =G= ra/pc ;
377
378 mkt_g$dd ..
379     g0*g =G= govt/pg ;
380
381 *     Income definition for representative household
382 inc_ra..

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383 (-sam("capital","roi")+sum(xt,(-xtelec("capital",xt)))$(not shortrun))*pk
384 + sum(xt$shortrun, (-xtelec("capital",xt))*pkx(xt))
385 + sam("labor","ra")*pl
386 + sum(ff,(-sam("rent",ff))*pr(ff))
387 + sum(n, nrsupply(n)*pn(n))
388 + (carblim*pcarb)$carblim$(not dd)
389 + sum(xt$limit(xt), limit(xt)*plim(xt))
390 - sum(t$quota(t), pele*ele(t)*tau)
391 - (pc*phi_ls)$dd
392 =G= ra;
393
394 *      Income definition for government
395 inc_govt$dd..
396 (carblim*pcarb)$carblim + pc*phi_ls
397 + ((-sam("roi","ra")/(1+tc0$dd))*c
398 *( pc/(proi*(1+(tc0*phi_tc)$dd)))*(1+tc0$dd)**esub_c)*proi*tc0*phi_tc
399 =G= govt;
400
401 *      Endogenous subsidy to assure renewables quota
402 sub_res$card(quota)..
403 sum(t$res(t), ele(t)) =G= share*sum(t, ele(t));
404
405 *      Endogenous equal yield constraints
406 eqy_ls$dd..
407 g =G= 1;
408
409 eqy_tc$dd..
410 g =G= 1;
411
412
413 *      Define MCP model
414 model mcp_hybrid / zprf_roi.roi, zprf_ele.ele, zprf_s.s, zprf_c.c, zprf_g.g,
415 mkt_proi.proi, mkt_pele.pele, mkt_pf.pf, mkt_pl.pl,
416 mkt_pk.pk, mkt_pr.pr, mkt_pn.pn, mkt_pcarb.pcarb,
417 mkt_pkx.pkx, mkt_plim.plim, mkt_pc.pc, mkt_g.pg, inc_ra.ra,
418 sub_res.tau, inc_govt.govt, eqy_ls.phi_ls, eqy_tc.phi_tc
419 /;
420
421 *      Benchmark initialization
422
423 *      In the base year new-vintage technologies are inactive
424 *      and the prices of backstop natural resources are zero
425 *      Extant technologies with capacity limits are assumed to

```

```

426 *      operate at the upper bound with a zero shadow value in the
427 *      base year
428
429 ele.l(nt) = 0;
430 pn.l(n)   = 0;
431 plim.l(xt) = 0;
432
433 ele.l(xt) = xtelec("ele",xt);
434
435 *      Initialize activities and prices
436 roi.l = 1; ele.l(xt)= xtelec("ele",xt);  s.l(ff) = 1; c.l = 1;
437 proi.l = 1; pele.l = 1; pf.l(ff) = 1; pl.l = 1; pk.l = 1; pr.l(ff) = 1;
438 pxx.l(t)$((-xtelec("capital",t))$shortrun) = 1; plim.l(t) = 0;
439 pn.l(n) = 1; pc.l = 1;
440
441 *      Install lower bounds on prices to avoid division by zero in MCP formulation
442 proi.lo = 1e-5; pele.lo = 1e-5; pf.lo(ff) = 1e-5; pl.lo = 1e-5; pk.lo = 1e-5;
443 pr.lo(ff) = 1e-5; pxx.lo(t)$((-xtelec("capital",t))$shortrun) = 1e-5; pc.lo = 1e-5;
444
445 *      Tie down "active" model specification
446 phi_tc.fx = 1; phi_ls.fx = 0;
447 g.fx = 0; pg.fx = 0; govt.fx = 0; pcarb.fx = 0;
448 pxx.fx(t)$ (not (-xtelec("capital",t))$shortrun) = 0;
449 tau.fx$(not card(quota)) = 0;
450 plim.fx(t)$ (not limit(t)) = 0;
451
452 *      In the base year we have no new-vintage electricity and the prices of backstop
453 *      natural resources are zero:
454
455 ele.l(nt)      = 0;
456 pn.l(n)       = 0;
457 pcarb.l       = 0;
458 pxx.l(t)$((-xtelec("capital",t))$shortrun) = 1;
459
460 ra.l =        (-sam("capital","roi")+sum(xt,(-xtelec("capital",xt)))$(not shortrun))*pk.l
461              + sum(xt$shortrun, (-xtelec("capital",xt))*pxx.l(xt))
462              + sam("labor","ra")*pl.l
463              + sum(ff,(-sam("rent",ff))*pr.l(ff))
464              + sum(n, nrsupply(n)*pn.l(n))
465              + (carblim*pcarb.l)$carblim
466              + sum(xt$limit(xt), limit(xt)*plim.l(xt))
467              - sum(t$quota(t), pele.l*ele.l(t)*tau.l)
468              - (pc.l*phi_ls.l)$dd;

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469
470 govt.l$dd = (carblim*pcarb.l)$carblim + pc.l*phi_ls.l
471             + (-sam("roi","ra")/(1+tc0$dd))*c.l*(pc.l/(proi.l*(1+tc0*phi_tc.l)$dd)
472             /(1+tc0$dd)**esub_c*pc.l*tc0*phi_tc.l;
473
474 *      Check the benchmark:
475 *      - marginal of all active activities must be zero
476 *      - marginal of all positive prices must be zero
477 *      - marginal of all positive incomes must be zero
478
479 mcp_hybrid.iterlim = 0;
480 solve mcp_hybrid using mcp;
481
482 *      Relax iteration limit for counterfactual policy analysis
483 mcp_hybrid.iterlim = 4000;
484
485 *=====
486 *      Analysis of policy scenarios (as laid out in the paper)
487 *
488 *      (i) gradual nuclear phase-out
489 *      (ii) target quota for renewables (green quota)
490 *      (iii) carbon taxation (environmental tax reform)
491
492
493 *      Define report parameters
494 parameter
495     ev(*)           Equivalent variation in income
496     supply(*,*)    Electricity supply by technology
497     carbtax(*)      Carbon permit price
498     subsidy         Subsidy rate on electricity from renewables
499     report          Report default parameter;
500
501 scalar epsilon /1.e-5/;
502
503 *=====
504 *      Scenario 1: Gradual nuclear phase-out
505
506 set     nsc Nuclear phase scenarios / 0, 25, 50, 75, 100/;
507
508 parameter limit_0      Base year capacity limits;
509 limit_0("nuclear") = limit("nuclear");
510
511 loop(nsc,

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512
513 *      Assign available capacity for nuclear power
514      limit("nuclear") = (1 - (ord(nsc)-1)/(card(nsc)-1))*limit_0("nuclear");
515 Display limit;
516 *      If nuclear capacity is set to zero, assure complete nuclear phase out
517      if ((not limit("nuclear")),
518          ele.fx("nuclear") = 0;
519          );
520      solve mcp_hybrid using mcp;
521      supply(nsc,t)      = ele.l(t) + epsilon;
522      ev(nsc)            = 100 * (c.l-1) + epsilon ;
523
524 );
525
526
527 $setglobal labels nsc
528 $setglobal gp_opt0 "set data style linespoints"
529
530 $setglobal gp_opt1 "set key below"
531 report(nsc,"ev") = ev(nsc);
532 $setglobal gp_opt2 "set title 'Welfare changes'"
533 $setglobal gp_opt3 "set xlabel 'Nuclear capacity reduction (% vis--vis BaU)'"
534 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
535 $libinclude plot report
536 display report;
537 report(nsc,"ev") = 0;
538
539 $setglobal gp_opt2 "set title 'Electricity supply by technology'"
540 $setglobal gp_opt3 "set xlabel 'Nuclear capacity reduction (% vis--vis BaU)'"
541 $setglobal gp_opt4 "set ylabel 'Activity level of technologies'"
542 $libinclude plot supply
543
544 *      Re-initialize parameterization for subsequent scenarios
545 limit("nuclear") = limit_0("nuclear");
546 ele.lo("nuclear") = 0; ele.up("nuclear") = +inf; ele.l("nuclear")=xtelec("ele","nuclear");
547
548
549 *=====
550 *      Scenario 2: Green quotas
551
552 set      qsc Green quota scenarios / 0 13, 5 18, 10 23, 15 28, 20 33/;
553 *      Note: We start from the base year situation without binding target
554 *      share and then increase the share iteratively by 5%.

```

```

555 *           The descriptive text for scenario set elements captures
556 *           the actual target level of green electricity as percent
557 *           in overall electricity production (base year quota is 13%).
558 *           The plot-command picks up the descriptive text as
559 *           scenario labels when produce a graphical exposition of results.
560
561 *           Assign initial level values for variables
562 roi.l = 1; ele.l(xt)= xtelec("ele",xt); s.l(ff) = 1; c.l = 1;
563 proi.l = 1; pele.l = 1; pf.l(ff) = 1; pl.l = 1; pk.l = 1; pr.l(ff) = 1;
564 pkx.l(t)$((-xtelec("capital",t))$shortrun) = 1; plim.l(t) = 0;
565 pn.l(n) = 1; pc.l = 1;
566 *           Install lower bounds on prices to avoid division by zero in MCP formulation
567 proi.lo = 1e-5; pele.lo = 1e-5; pf.lo(ff) = 1e-5; pl.lo = 1e-5; pk.lo = 1e-5; pr.lo(ff) = 1e-5;
568 pkx.lo(t)$((-xtelec("capital",t))$shortrun) = 1e-5; pc.lo = 1e-5;
569 ra.l = c0;
570
571 parameter share_0           Base year renewable share;
572 share_0 = share;
573
574 quota(res) = yes;
575 tau.lo = 0; tau.l = 0; tau.up = 0.99;
576
577 loop(qsc,
578 *           Assign target shares for renewables in electricity production
579           share = min(1, (share_0 + 20/100* (ord(qsc)-1)/(card(qsc)-1)));
580
581           solve mcp_hybrid using mcp;
582
583           supply(qsc,t) = ele.l(t) + epsilon;
584           ev(qsc) = 100 * (c.l-1) + epsilon;
585           subsidy(qsc) = 100*tau.l + epsilon;
586 );
587
588 $setglobal labels qsc
589
590 report(qsc,"ev") = ev(qsc);
591 $setglobal gp_opt2 "set title 'Welfare changes'"
592 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
593 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
594 $libinclude plot report
595 display report;
596 report(qsc,"ev") = 0;
597

```

```

598 $setglobal gp_opt2 "set title 'Electricity supply by technology'"
599 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
600 $setglobal gp_opt4 "set ylabel 'Activity level of technologies'"
601 $libinclude plot supply
602
603 report(qsc,"subsidy") = subsidy(qsc);
604 $setglobal gp_opt2 "set title 'Subsidy on renewables'"
605 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
606 $setglobal gp_opt4 "set ylabel 'Subsidy rate (% of electricity price)'"
607 $libinclude plot report
608 display report;
609 report(qsc,"subsidy") = 0;
610
611 *      Re-initialize parameterization for subsequent scenarios
612 share = share_0;
613 quota(res) = no;
614 tau.fx = 0;
615 *=====
616 *      Scenario 3: Carbon taxation (double dividend)
617
618 *      First re-specify base year (benchmark) to public good extension
619 mcp_hybrid.iterlim      = 0;
620
621 dd = 1;
622 g.lo = 0; g.up = + inf; govt.lo = 0; govt.up = + inf;
623 g0 = 0.2 *(-sam("roi","ra"));
624 tc0 = g0/((-sam("roi","ra")) - g0);
625 display g0, tc0;
626
627 *      Relax fixed variables
628 g.lo = 0; g.up = +inf; pg.lo = 0; pg.up = +inf; govt.lo = 0; govt.up = + inf;
629 pcarb.lo = 0; pcarb.up = + inf;
630
631 *      Initially, we assume that lump-sum transfers are active
632 *      as the equal-yield instrument
633 phi_ls.l = 0; phi_ls.lo = -inf; phi_ls.up = +inf;
634 phi_tc.fx = 1;
635
636 *      Assign base year carbon emissions (at shadow price of zero)
637 carblim = sum(ff, sam(ff,ff)*carbon(ff));
638 pcarb.l = 0;
639
640 *      Benchmark replication check for the model with public good extension

```

```

641 *      Initialize activities and prices
642 roi.l = 1; ele.l(xt)= xtelec("ele",xt);  ele.l(nt) = 0; s.l(ff) = 1; c.l = 1;
643 proi.l = 1; pele.l = 1; pf.l(ff) = 1; pl.l = 1; pk.l = 1; pr.l(ff) = 1; pg.l = 1;
644 pxx.l(t)$((-xtelec("capital",t))$shortrun) = 1; plim.l(t)$limit(t) = 0;
645 pc.l = 1; pn.l(n) = 0; ra.l = c0; govt.l = g0;
646
647 *      Install lower bounds on prices to avoid division by zero in MCP formulation
648 proi.lo = 1e-5; pele.lo = 1e-5; pf.lo(ff) = 1e-5; pl.lo = 1e-5; pk.lo = 1e-5; pr.lo(ff) = 1e-5;
649 pxx.lo(t)$((-xtelec("capital",t))$shortrun) = 1e-5; pc.lo = 1e-5; pg.lo = 1e-5;
650
651 *      Check the re-specified benchmark:
652 *      - marginal of all active activities must be zero
653 *      - marginal of all positive prices must be zero
654 *      - marginal of all positive incomes must be zero
655
656 mcp_hybrid.iterlim = 0;
657
658 solve mcp_hybrid using mcp;
659
660 *      Relax iteration limit
661 mcp_hybrid.iterlim = 4000;
662
663
664 *      Specification of carbon tax scenarios based on exogenous emission reduction targets
665 set      csc Carbon abatement scenarios scenarios / 0, 5, 10, 15, 20/;
666
667 parameter carbon_0      Benchmark capacity limits;
668 parameter ev_          Report parameter for welfare changes;
669
670 carbon_0 = carblim;
671
672 display carbon_0;
673
674 loop(csc,
675 *      Assign carbon emission limit
676      carblim = (1 - 0.2*(ord(csc)-1)/(card(csc)-1))*carbon_0;
677
678 *      Activate lump-sum transfer as recycling instrument
679 phi_ls.l = 0; phi_ls.lo = -inf; phi_ls.up = +inf;
680 phi_tc.fx = 1;
681
682      solve mcp_hybrid using mcp;
683

```



```

684         ev_(csc,"ls")           = 100 * (c.l-1) + epsilon;
685
686 *       Activate consumption tax as recycling instrument
687 phi_tc.l = 1; phi_tc.lo = -0.99; phi_tc.up = +inf;
688 phi_ls.fx = 0;
689         solve mcp_hybrid using mcp;
690
691         ev_(csc,"tc")           = 100 * (c.l-1) + epsilon;
692 );
693
694 $setglobal labels csc
695 $setglobal gp_opt2 "set title 'Welfare changes'"
696 $setglobal gp_opt3 "set xlabel 'Carbon emission reduction (in % vis--vis base year)'"
697 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
698 $libinclude plot ev_
699 display ev_;
700 ev_(csc,"tc") = 0; ev_(csc,"ls") = 0;
701
702 *       Re-initialize parameterization for subsequent policy scenarios
703 dd = 0; g0 = 0; tc0 = 0;

```

## Part 2: MPSGE Formulation

```
1 $Title  Static maquette of integrated TD/BU hybrid model
2
3 *      Model formulation in meta-language MPSGE
4 *      (see Rutherford 1995 for documentation)
5
6 *=====
7 * Model code for stylzed integrated bottom-up/top-down analysis of energy
8 * policies based on:
9 *
10 *          ZEW Discussion Paper 05-28
11 *          Integrating Bottom-Up into Top-Down:
12 *          A Mixed Complementarity Approach
13 *
14 * Contact the authors at: boehringer@zew.de; tom@mpsge.org
15 *=====
16
17 * For plotting the results you must have installed the gnuplot-shareware
18 * (see http://debreu.colorado.edu/gnuplot/gnuplot.htm for downloads)
19
20 *=====
21 *      List of parameters subject to sensitivity analysis
22 *      The user can change the default settings.
23
24 * Choice of key elasticities:
25 *      Elasticity of substitution in final consumption
26 $if not setglobal esub_c $setglobal esub_c 0.5
27
28 *      Elasticity in gas supply
29 $if not setglobal esub_gas $setglobal esub_gas 1.5
30
31 *      Elasticity in coal supply
32 $if not setglobal esub_coal $setglobal esub_coal 3
33
34 *      Elasticity in oil supply
35 $if not setglobal esub_oil $setglobal esub_oil 1.5
36
37
38 * Choice of resource availability for renewables:
39 * (as a fraction of base-year total electricity production)
40 *      Potential wind supply - (%)
41 $if not setglobal p_wind $setglobal p_wind 10
```

```

42
43 *      Potential solar supply - (%)
44 $if not setglobal p_sun $setglobal p_sun 10
45
46 *      Potential biomass supply - (%)
47 $if not setglobal p_trees $setglobal p_trees 10
48
49
50 * Cost disadvantage of initial slack technologies:
51 *      Wind energy premium (%)
52 $if not setglobal c_wind $setglobal c_wind 10
53
54 *      Solar energy premium (%)
55 $if not setglobal c_solar $setglobal c_solar 10
56
57 *      Biomass energy premium (%)
58 $if not setglobal c_biomass $setglobal c_biomass 10
59
60
61 * Other central model assumptions:
62 *      Time horizon (short, long)
63 *      N.B.: For short-run analysis capital is immobile across sectors
64 $if not setglobal horizon $setglobal horizon long
65
66 *=====
67
68
69 *      Assign user-specific changes of default assumptions
70 scalar  shortrun      Flag for short-run capital mobility/1/;
71
72 $if "%horizon%"=="long" shortrun=0;
73
74 *      Elasticities of substitution (ESUB)
75 scalar  esub_c      Elasticity of substitution in final demand /%esub_c%/
76         esub_ele    ESUB between electricity and oil in final demand /0.5/
77         esub_k_e    ESUB between capital and energy in ROI production /0.5/
78         esub_l_ke   ESUB between labor and other inputs in ROI production /0.8/;
79
80 set     t           Electricity Technologies (current and future)
81         /coal,gas,nuclear,hydro,wind,solar,biomass/;
82
83 set     xt(t)      Existing technologies /coal,gas,nuclear,hydro/;
84

```

```

85 set      nt(t)   New vintage technologies /wind,solar,biomass/;
86
87 set      ff      Fossil fuel inputs /coa, gas, oil/;
88
89 set      n       Natural resources /wind, sun, trees/;
90
91
92 set      res(t)  Renewable energy sources /hydro, wind, solar, biomass/;
93
94 *        The following data table describes an economic equilibrium in
95 *        the base year:
96
97
98 table sam Base year social accounting matrix
99
100         roi    coa    gas    oil    ele    ra
101 roi      200    -5    -5    -10   -10   -170
102 coa           15
103 gas           15    -15
104 oil                30    -30
105 ele      -10                60   -50
106 capital -80                -20   100
107 labor   -110   -5    -5    -10    130
108 rent           -5    -5    -10    20          ;
109
110 parameter carbon(ff) Carbon coefficients /oil 1, gas 1, coa 2/;
111
112 scalar  carblim      Carbon target /0/;
113
114 parameter  esub_ff(ff) Elasticity of substitution in fossil fuel production
115           /gas %esub_gas%, coa %esub_coal%, oil %esub_oil%/;
116
117 *        The following data tables describes electricity generation in
118 *        the base year as well as the technology coefficients for technologies
119 *        which are inactive in the base year (wind, solar, biomass). Inactive
120 *        technologies are by defaults %c****% more costly.
121
122 table xtelec Electricity technologies - extant (initially active)
123
124         coal    gas    nuclear hydro
125 ele      20    20        12    8
126 roi      -1    -1        -8
127 gas           -15

```

```

128 coa      -15
129 capital  -4   -4       -4   -8;
130
131
132 table ntelec  Electricity technologies - new vintage (initially inactive)
133
134         wind    solar    biomass
135 ele      1.0    1.0    1.0
136 roi      -.2    -.3    -.4
137 capital  -.9    -.8    -.7
138 wind     -1.0
139 sun              -1.0
140 trees                -1.0;
141
142
143 *      Adjust the cost coefficients for initially inactive technologies
144 *      according to user assumptions:
145 set xk /roi, capital/;
146
147 ntelec(xk,"wind")    = ntelec(xk,"wind")    * (100+%c_wind%)/110;
148 ntelec(xk,"solar")  = ntelec(xk,"solar")  * (100+%c_solar%)/110;
149 ntelec(xk,"biomass") = ntelec(xk,"biomass") * (100+%c_biomass%)/110;
150
151
152 *      Specify limits (resource or policy constraints) to the availability
153 *      of technologies
154
155 parameter limit      Electricity supply limits on extant technologies /
156     nuclear          12
157     hydro             8 /;
158
159 parameter nrsupply(n) Natural resource supplies (fraction of base output)/
160     wind              %p_wind%
161     sun                %p_sun%
162     trees              %p_trees% /;
163
164 nrsupply(n) = nrsupply(n)/100 * sam("ele","ele");
165
166 parameter c0      Baseyear final consumption;
167 c0 = (-sam("roi","ra")-sam("ele","ra")-sam("oil","ra"));
168
169
170 set      quota(t)  Flag for technologies contributing to green quota;

```

```

171 quota(t) = no;
172
173 scalar share Target share for green quota /0/;
174
175 * By default we might set target share for green quota at base year level
176 share = sum(t$res(t), xtelec("ele",t))/sum(t, xtelec("ele",t));
177 display share;
178
179 scalar
180 dd Flag for double dividend policy analysis /0/,
181 ls Flag for lump-sum revenue-recycling /0/,
182 vat Flag for VAT revenue recycling /0/,
183 g0 Base year public consumption /0/,
184 tc0 Base year consumption tax /0/;
185
186 * MPSGE formulation of the hybrid model
187 $ontext
188
189 $model:mps_hybrid
190
191 $sectors:
192 roi ! Aggregate output
193 ele(t) ! Production levels for electricity by technology
194 s(ff) ! Fossil fuel supplies
195 c ! Aggregate consumption (utility) formation
196 g$dd ! Public good provision
197
198 $commodities:
199 proi ! Price of aggregate output
200 pele ! Price of electricty
201 pf(ff) ! Price of oil and gas
202 pl ! Wage rate
203 pk ! Price of malleable capital for X (and NT elec)
204 pr(ff) ! Rent on fossil fuel resources
205 pn(n) ! Rent on natural resources
206 pc ! Consumption (utility) price index
207 pg$dd ! Price of public consumption
208 plim(t)$limit(t) ! Shadow price on electricity expansion
209 pkx(t)$((-xtelec("capital",t))$shortrun) ! Price of capital to extant technologies
210 pcarb$carblim ! Carbon tax rate
211
212 $consumers:
213 ra ! Representative household

```

```

214      govt$dd ! Government
215
216 $auxiliary:
217      tau$card(quota) ! Uniform subsidy rate on renewable energy
218      phi_ls$dd      ! Lump-sum recycling
219      phi_tc$dd      ! Consumption tax recycling
220
221
222 *      Aggregate output:
223
224 $prod:roi s:esub_l_ke ke:esub_k_e
225      o:proi q:sam("roi","roi")
226      i:pl   q:(-sam("labor","roi"))
227      i:pk   q:(-sam("capital","roi")) ke:
228      i:pele q:(-sam("ele","roi"))      ke:
229
230 *      Extant electricity:
231
232 $prod:ele(xt)
233      o:pele          q:1   raa:ra   n:tau$quota(xt)   m:(-1)$quota(xt)
234      i:proi          q:(-xtelec("roi",xt)/xtelec("ele",xt))
235      i:pf(ff)        q:(-xtelec(ff,xt)/xtelec("ele",xt))
236      i:pkx(xt)$shortrun q:(-xtelec("capital",xt)/xtelec("ele",xt))
237      i:pk$(not shortrun) q:(-xtelec("capital",xt)/xtelec("ele",xt))
238      i:plim(xt)$limit(xt) q:1
239
240 *      New vintage electricity:
241
242 $prod:ele(nt)
243      o:pele q:1   a:ra   n:tau$quota(nt) m:(-1)$quota(nt)
244      i:proi q:(-ntelec("roi",nt))
245      i:pk   q:(-ntelec("capital",nt))
246      i:pn(n) q:(-ntelec(n,nt))
247
248 $prod:s(ff) s:0 r:esub_ff(ff) xl(r):0
249      o:pf(ff)          q:sam(ff,ff)
250      i:pcarb$carblim q:(carbon(ff)*sam(ff,ff))
251      i:proi           q:(-sam("roi",ff))      xl:
252      i:pl             q:(-sam("labor",ff))     xl:
253      i:pr(ff)        q:(-sam("rent",ff))      r:
254
255 $prod:c s:esub_c e:esub_ele
256      o:pc             q:c0

```

```

257         i:proi          q:(-sam("roi","ra")/(1+tc0$dd)) p:(1+tc0$dd)
258 + a:govt$dd n:phi_tc$dd m:tc0$dd
259         i:pele          q:(-sam("ele","ra")) e:
260         i:pf("oil")     q:(-sam("oil","ra")) e:
261
262 $demand:ra
263         d:pc              q:c0
264         e:pk      q:(-sam("capital","roi")+sum(xt,(-xtelec("capital",xt)))$(not shortrun))
265         e:pkx(xt)$shortrun      q:(-xtelec("capital",xt))
266         e:pl              q:(sam("labor","ra"))
267         e:pr(ff)          q:(-sam("rent",ff))
268         e:pn(n)           q:nrsupply(n)
269         e:pcarb$carblim$(not dd) q:carblim
270         e:plim(xt)$limit(xt)    q:limit(xt)
271         e:pc$dd          q:(-1)          r:phi_ls$dd
272
273
274 $demand:govt$dd
275         d:pg      q:g0
276         e:pc      q:1          r:phi_ls
277         e:pcarb$carblim      q:carblim
278
279 $prod:g$dd
280         0:pg      q:g0
281         i:proi    q:g0
282
283
284 $constraint:tau$card(quota)
285         sum(t$res(t), ele(t)) =e= share*sum(t, ele(t));
286
287
288 $constraint:phi_ls$dd
289         g =e= 1;
290
291 $constraint:phi_tc$dd
292         g=e= 1;
293
294 $offtext
295 $sysinclude mpsgeset mps_hybrid
296
297 *      In the base year new-vintage technologies are inactive
298 *      and the prices of backstop natural resources are zero
299 *      Extant technologies with capacity limits are assumed to

```



```

300 *      operate at the upper bound with a zero shadow value in the
301 *      base year
302
303 ele.l(nt) = 0;
304 pn.l(n)   = 0;
305 plim.l(xt) = 0;
306
307 ele.l(xt) = xtelec("ele",xt);
308
309 *      Benchmark replication check
310 mps_hybrid.iterlim = 0;
311 $include mps_hybrid.gen
312 solve mps_hybrid using mcp;
313
314 display "The precision of the benchmark dataset is:", mps_hybrid.objval;
315 abort$(ABS(mps_hybrid.objval) gt 1e-4)"MPSGE model does not calibrate";
316
317
318 *      Relax iteration limit for counterfactual policy analysis
319 mps_hybrid.iterlim      = 4000;
320
321
322 *=====
323 *      Analysis of policy scenarios (as laid out in the paper)
324 *
325 *      (i)   gradual nuclear phase-out
326 *      (ii)  target quota for renewables (green quota)
327 *      (iii) carbon taxation (environmental tax reform)
328
329
330 *      Define report parameters
331 parameter
332     ev(*)           Equivalent variation in income
333     supply(*,*)    Electricity supply by technology
334     carbtax(*)      Carbon permit price
335     subsidy         Subsidy rate on electricity from renewables
336     report          Report default parameter;
337
338 scalar epsilon /1.e-5/;
339
340
341 *=====
342 *      Scenario 1: Gradual nuclear phase-out

```

```

343
344 set      nsc Nuclear phase scenarios / 0, 25, 50, 75, 100/;
345
346 parameter limit_0      Base year capacity limits;
347 limit_0("nuclear") = limit("nuclear");
348
349 loop(nsc,
350
351 *      Assign available capacity for nuclear power
352      limit("nuclear") = (1 - (ord(nsc)-1)/(card(nsc)-1))*limit_0("nuclear");
353 *      If nuclear capacity is set to zero, assure complete nuclear phase out
354      if ((not limit("nuclear")),
355          ele.fx("nuclear") = 0;
356      );
357 $include mps_hybrid.gen
358      solve mps_hybrid using mcp;
359      supply(nsc,t)      = ele.l(t) + epsilon;
360      ev(nsc)            = 100 * (c.l-1) + epsilon ;
361
362 );
363
364
365 $setglobal labels nsc
366 $setglobal gp_opt0 "set data style linespoints"
367
368 $setglobal gp_opt1 "set key below"
369 report(nsc,"ev") = ev(nsc);
370 $setglobal gp_opt2 "set title 'Welfare changes'"
371 $setglobal gp_opt3 "set xlabel 'Nuclear capacity reduction (% vis--vis BaU)'"
372 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
373 $libinclude plot report
374 display report;
375 report(nsc,"ev") = 0;
376
377
378 $setglobal gp_opt2 "set title 'Electricity supply by technology'"
379 $setglobal gp_opt3 "set xlabel 'Nuclear capacity reduction (% vis--vis BaU)'"
380 $setglobal gp_opt4 "set ylabel 'Activity level of technologies'"
381 $libinclude plot supply
382
383 *      Re-initialize parameterization for subsequent scenarios
384 limit("nuclear") = limit_0("nuclear");
385 ele.lo("nuclear") = 0; ele.up("nuclear") = +inf;

```

```

386 ele.l("nuclear")=xtelec("ele","nuclear");
387
388
389 *=====
390 *      Scenario 2: Green quotas
391
392 set      qsc  Green quota scenarios / 0 13, 5 18, 10 23, 15 28, 20 33/;
393 *      Note:   We start from the base year situation without binding target
394 *              share and then increase the share iteratively by 5%.
395 *              The descriptive text for scenario set elements captures
396 *              the actual target level of green electricity as percent
397 *              in overall electricity production (base year quota is 13%).
398 *              The plot-command picks up the descriptive text as
399 *              scenario labels when produce a graphical exposition of results.
400
401
402 parameter share_0      Base year renewable share;
403 share_0 = share;
404
405 quota(res) = yes;
406
407
408 loop(qsc,
409 *      Assign target shares for renewables in electricity production
410      share = min(1, (share_0 + 20/100* (ord(qsc)-1)/(card(qsc)-1)));
411
412 $include mps_hybrid.gen
413      solve mps_hybrid using mcp;
414
415      supply(qsc,t)   = ele.l(t) + epsilon;
416      ev(qsc)         = 100 * (c.l-1) + epsilon;
417      subsidy(qsc)    = 100*tau.l + epsilon;
418 );
419
420 $setglobal labels qsc
421
422 report(qsc,"ev") = ev(qsc);
423 $setglobal gp_opt2 "set title 'Welfare changes'"
424 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
425 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
426 $libinclude plot report
427 display report;
428 report(qsc,"ev") = 0;

```

```

429
430 $setglobal gp_opt2 "set title 'Electricity supply by technology'"
431 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
432 $setglobal gp_opt4 "set ylabel 'Activity level of technologies'"
433 $libinclude plot supply
434
435 report(qsc,"subsidy") = subsidy(qsc);
436 $setglobal gp_opt2 "set title 'Subsidy on renewables'"
437 $setglobal gp_opt3 "set xlabel 'Green quota in % of overall electricity supply'"
438 $setglobal gp_opt4 "set ylabel 'Subsidy rate (% of electricity price)'"
439 $libinclude plot report
440 display report;
441 report(qsc,"subsidy") = 0;
442
443 *      Re-initialize parameterization for subsequent scenarios
444 share = share_0;
445 quota(res) = no;
446 $exit
447 *=====
448 *      Scenario 3: Carbon taxation (double dividend)
449
450 *      First re-calibrate base year (benchmark) to public good extension
451 mps_hybrid.iterlim      = 0;
452
453 dd = 1;
454 g0 = 0.2 *(-sam("roi","ra"));
455 tc0 = g0/((-sam("roi","ra")) - g0);
456 display g0, tc0;
457
458 *      Initially, we assume that lump-sum transfers are active
459 *      as the equal-yield instrument
460 phi_ls.l = 0; phi_ls.lo = -inf; phi_ls.up = +inf;
461 phi_tc.fx = 1;
462
463 *      Assign base year carbon emissions (at shadow price of zero)
464 carblim = sum(ff, sam(ff,ff)*carbon(ff));
465 pcarb.l = 0;
466
467 *      Benchmark replication check for the model with public good extension
468 *      Initialize activities and prices
469 roi.l = 1; ele.l(xt)= xtelec("ele",xt); ele.l(nt) = 0; s.l(ff) = 1; c.l = 1;
470 proi.l = 1; pele.l = 1; pf.l(ff) = 1; pl.l = 1; pk.l = 1; pr.l(ff) = 1;
471 pkx.l(t)$((-xtelec("capital",t))$shortrun) = 1; plim.l(t)$limit(t) = 0;

```

```

472 pc.l = 1; pn.l(n) = 0; ra.l = c0; govt.l = g0;
473
474 mps_hybrid.iterlim = 0;
475 $include mps_hybrid.gen
476 solve mps_hybrid using mcp;
477
478 display "The precision of the re-specified benchmark dataset is:", mps_hybrid.objval;
479 abort$(ABS(mps_hybrid.objval) gt 1e-4)"MPSGE model does not calibrate";
480
481 *      Relax iteration limit
482 mps_hybrid.iterlim = 4000;
483
484
485 *      Specification of carbon tax scenarios based on exogenous emission reduction targets
486 set    csc Carbon abatement scenarios scenarios / 0, 5, 10, 15, 20/;
487
488 parameter carbon_0      Benchmark capacity limits;
489 parameter ev_           Report parameter for welfare changes;
490
491 carbon_0 = carblim;
492
493 display carbon_0;
494
495 loop(csc,
496 *      Assign carbon emission limit
497      carblim = (1 - 0.2*(ord(csc)-1)/(card(csc)-1))*carbon_0;
498
499 *      Activate lump-sum transfer as recycling instrument
500 phi_ls.l = 0; phi_ls.lo = -inf; phi_ls.up = +inf;
501 phi_tc.fx = 1;
502 $include mps_hybrid.gen
503      solve mps_hybrid using mcp;
504      ev_(csc,"ls")      = 100 * (c.l-1) + epsilon;
505
506 *      Activate consumption tax as recycling instrument
507 phi_tc.l = 1; phi_tc.lo = -0.99; phi_tc.up = +inf;
508 phi_ls.fx = 0;
509 $include mps_hybrid.gen
510      solve mps_hybrid using mcp;
511      ev_(csc,"tc")      = 100 * (c.l-1) + epsilon;
512 );
513
514 $setglobal labels csc

```

```
515 $setglobal gp_opt2 "set title 'Welfare changes'"
516 $setglobal gp_opt3 "set xlabel 'Carbon emission reduction (in % vis--vis base year)'"
517 $setglobal gp_opt4 "set ylabel 'Equivalent variation in income (%)'"
518 $libinclude plot ev_
519 display ev_;
520 ev_(csc,"tc") = 0; ev_(csc,"ls") = 0;
521
522 *      Re-initialize parameterization for subsequent policy scenarios
523 dd = 0; g0 = 0; tc0 = 0;
```