Introduction to EPPA

The structure of EPPA6

Y.-H. Henry Chen

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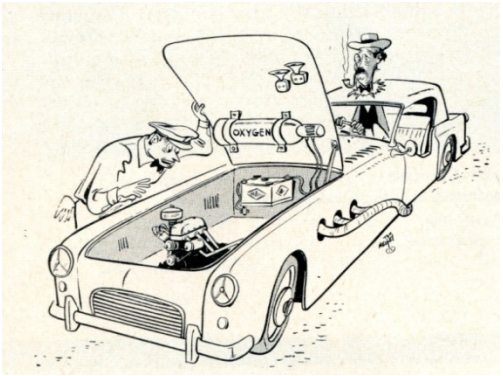
In collaboration with John Reilly, Sergey Paltsev, Mustafa Babiker, Angelo Gurgel, Tom Rutherford, Jennifer Morris, Niven Winchester, Kyung-Min Nam, Qudsia Ejaz, Claudia Octaviano, David Ramberg, and Paul Kishimoto.

Outline

1. Introduction
2. Settings
3. Structure
4. Guidelines
5. Applications

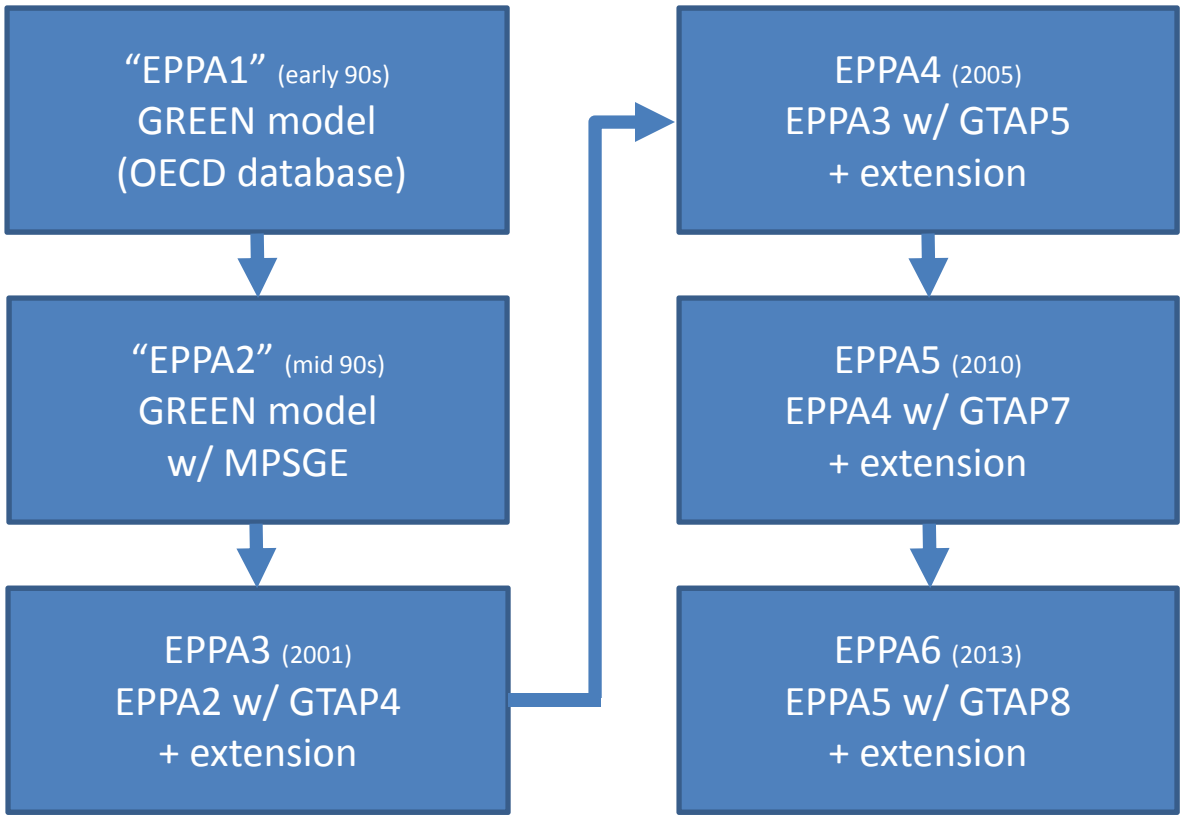


Introduction

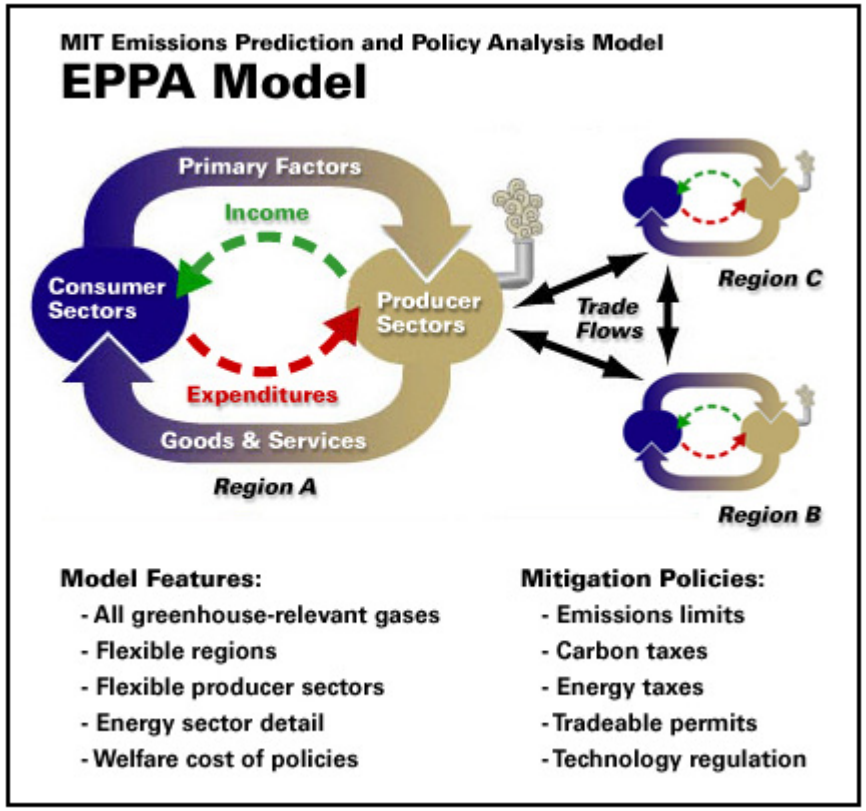
- EPPA is the human system module of IGSM
- A recursive dynamic CGE of the world economy
- Multi-region, multi-sector, multi-resource model
- Data: economics, energy use, GHGs emissions, engineering data, etc.

Introduction

- History of EPPA



Introduction



- Public released version is EPPA4, current versions are EPPA6 and EPPA5.
- Based on EPPA4 or EPPA5, various versions of EPPA were built for different studies:
  - EPPA-A w/ aviation
  - EPPA-APA w/ endogenous urban pollution abatement
  - EPPA-HE w/ health effects
  - EPPA-HTRN w/ household transportation details
  - EPPA-LUC w/ land use change and near-term biofuels
  - EPPA-ROIL w/ refining sector details

Source: Karplus (2011)

- EPPA6 and EPPA5 are not available to the public at this moment
- Please do not give them to any third party without the permission from JP

Introduction

- GTAP8:
  - 129 regions
  - 57 sectors
  - 5 primary factors
- Energy consumption:
  - IEA data (Narayanan et al., 2012)
- Emissions:
  - CO2 emissions are from IEA (2012), Boden et al. (2010), Riahi et al. (2007)
  - Non-CO2 GHGs and Non-GHGs are from EDGAR v.4.2 (European Commission, 2013)
- Backstop cost structure:
  - Relevant engineering data (Paltsev et al., 2010)

Settings

Regions in EPPA:

EPPA6			EPP5
USA	United States		USA
CAN	Canada		CAN
MEX	Mexico		MEX
JPN	Japan		JPN
ANZ	Australia & New Zealand		ANZ
EUR	Europe		EUR
ROE	Eastern Europe		ROE
RUS	Russia Plus		RUS
ASI	East Asia		ASI
KOR	South Korea		
IDZ	Indonesia		
CHN	China		CHN
IND	India		IND
BRA	Brazil		BRA
AFR	Africa		AFR
MES	Middle East		MES
LAM	Latin America		LAM
REA	Rest of Asia		REA

Sectors in EPPA:

EPPA6	EPPA5
CROP	CROP
LIVE	LIVE
FORS	FORS
FOOD	FOOD
COAL	COAL
OIL	OIL
ROIL	ROIL
GAS	GAS
ELEC	ELEC
EINT	EINT
OTHR	OTHR
DWE	-
SERV	SERV
TRAN	TRAN

Settings

Agriculture
- crop
- livestock
- forest

Non-agriculture
- food
- energy intensive
- other manufacturing
- transportation
- service
- dwelling

Energy Supply
- coal
- crude oil
- refined oil
- gas
- electricity

- biofuels*
- oil shale
- synthetic gas from coal
- hydrogen

- household
- non-household

- fossil
  - coal
  - gas
  - oil-fired
- nuclear
- hydro

- advanced nuclear
- IGCC w/ CCS
- NGCC
- NGCC w/ CCS
- wind
- bio-elec
- wind-bio
- wind-gas
- solar

Settings

- Agents
  - consumer
  - producer
  - government

- Statics
  - zero profit $[MC - MR \geq 0; Q \geq 0; (MC - MR) \cdot Q = 0]$
  - market clearing $[\mathrm{S} - D \geq 0; P \geq 0; (S - D) \cdot P = 0]$
  - income balance $[\mathrm{E} - I \geq 0; E \geq 0; (E - I) \cdot E = 0]$

- Dynamics
  - exogenously specified
  - endogenously determined

Settings

Schematic outline of world input-output table

		Country A Intermediate *Industry*	Country B Intermediate *Industry*	Rest of World Intermediate *Industry*	Country A Final domestic	Country B Final domestic	Rest of World Final domestic	Total
Country A	*Industry*	Intermediate use of domestic output	Intermediate use by B of exports from A	Intermediate use by RoW of exports from A	Final use of domestic output	Final use by B of exports from A	Final use by RoW of exports from A	Output in A
Country B	*Industry*	Intermediate use by A of exports from B	Intermediate use of domestic output	Intermediate use by RoW of exports from B	Final use by A of exports from B	Final use of domestic output	Final use by RoW of exports from B	Output in B
Rest of World (RoW)	*Industry*	Intermediate use by A of exports from RoW	Intermediate use by B of exports from RoW	Intermediate use of domestic output	Final use by A of exports from RoW	Final use by B of exports from RoW	Final use of domestic output	Output in RoW
		Value added	Value added	Value added				
		Output in A	Output in B	Output in RoW				

Settings

Market clearing for power sector

zero profit for hydro power

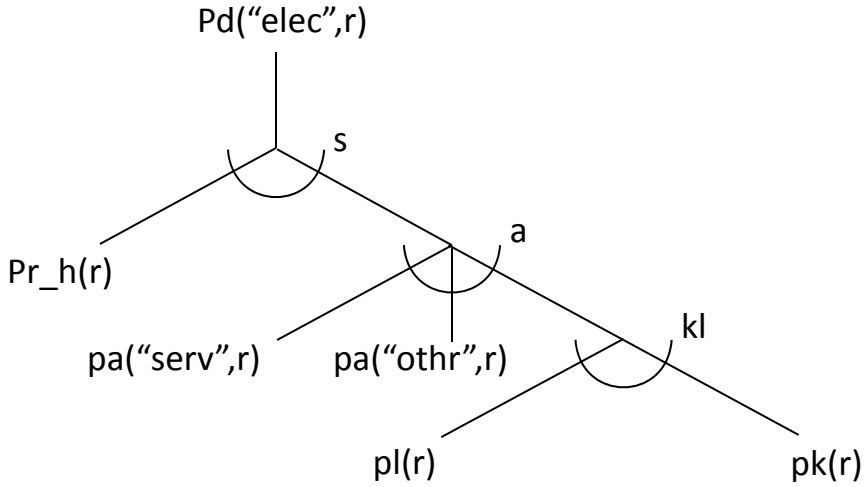
income balance for the representative agent

	d	n_e	h_e	en	govt	inv	yt	htrn	eid	eid_ghg	efd_ghg	tefd_ghg	edf	tedf	a	m	z	w	ra
pd	XP0	N_E0	H_E0				VST								D0	WTFLOW			
pen	ENE			EN0															
pg					G0														-GRG
pinv						INV0												INV0	
pt							ΣΣVST									ΣVTWR			
ptrn								TOTTRN									TOTTRN		
pai_c									EUSEP	EUSEP									
pai_g				XDP0+XMP0						EUSEP									
paf_g											HEUSEF						ENCE		
paf_gh								TRO				TEUSEF							
paf_c											HEUSEF		HEUSEF						
paf_ch												TEUSEF		TEUSEF					
pa	XDP0+XMP0	N_S0; N_OT0	H_S0; H_OT0		XDG0+XMG0	XDI0+XMI0		TOI; TSE; PURTRN	EUSEP				HEUSEF	TEUSEF	A0		XDC+XMC		
pm															XM0	XM0			
pu																	CONS0	CONS0	
pw																		W0	W0
pl	LABD	N_L0	H_L0																LABOR
pk	KAPD	N_K0	H_K0																CAPITAL
pf	FFACTD																		FFACT
pr		N_R0																	N_R
pr_h			H_R0																H_R
pcarb	OUTCO2								EIND*CJ*ε				HEFD*CJ*ε	TEFD*CJ*ε					CARBLIM

Settings

{example: hydro power}

The cost function of nuclear power has the same nesting structure.

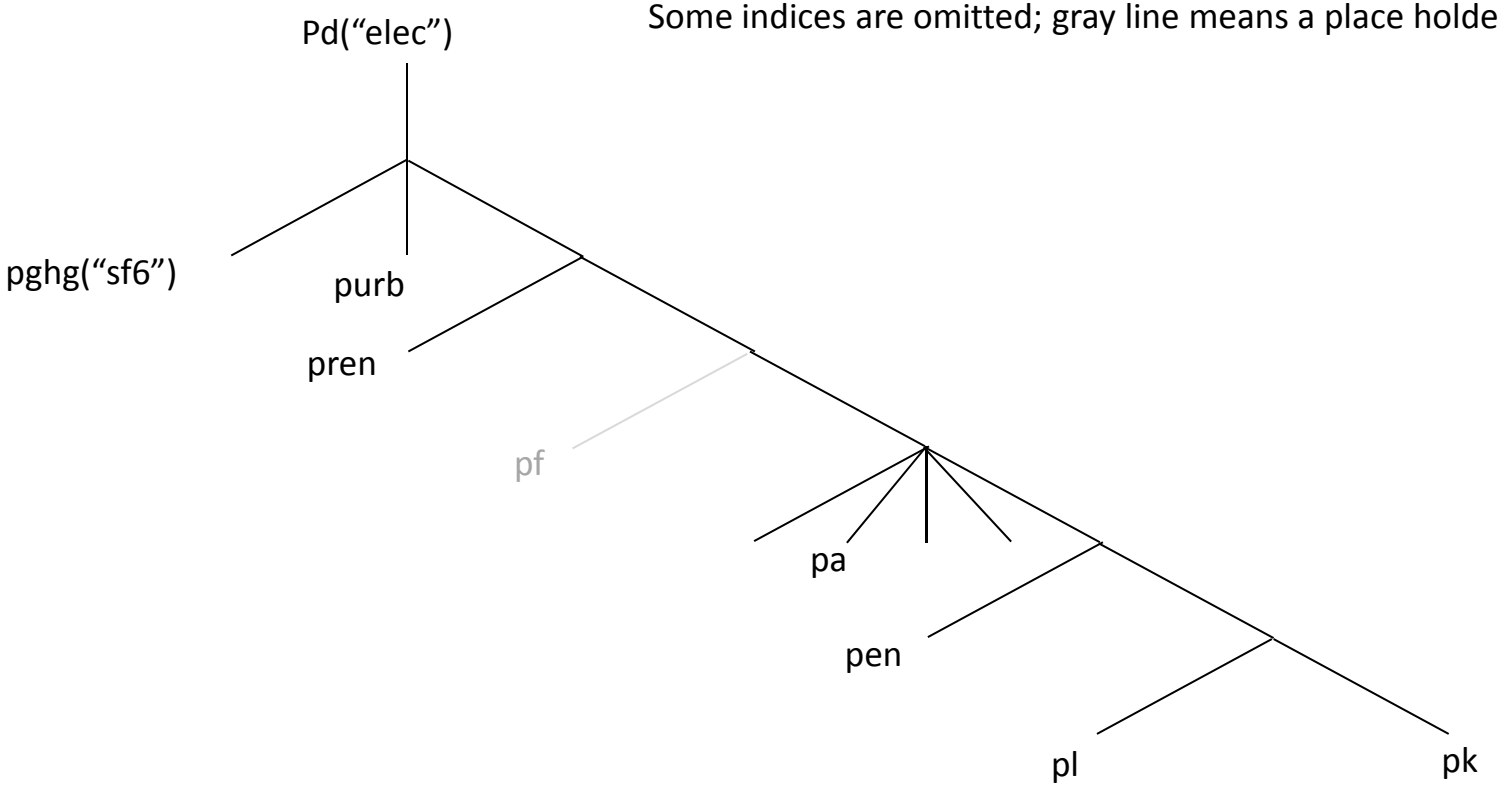



```
* hydro electric generation
$prod:h_e(r)$h_e0(r)    s:hsigma(r)  a:0 kl(a):1.0
   o:pd("elec",r)  q:h_e0(r)                              a:ra(r) t:td(r,"elec")
   i:pl(r)         q:h_l0(r)   p:pf0("lab","elec",r)   a:ra(r) t:tf("lab","elec",r)    kl:
   i:pk(r)         q:h_k0(r)   p:pf0("cap","elec",r)   a:ra(r) t:tf("cap","elec",r)    kl:
   i:pr_h(r)       q:h_r0(r)   p:pf0("cap","elec",r)   a:ra(r) t:tf("cap","elec",r)
   i:pa("serv",r)  q:h_s0(r)   p:pi0("serv","elec",r)  a:ra(r) t:ti("serv","elec",r)   a:
   i:pa("othr",r)  q:h_ot0(r)  p:pi0("othr","elec",r)  a:ra(r) t:ti("othr","elec",r)   a:
```

Settings

{example: fossil based generation}

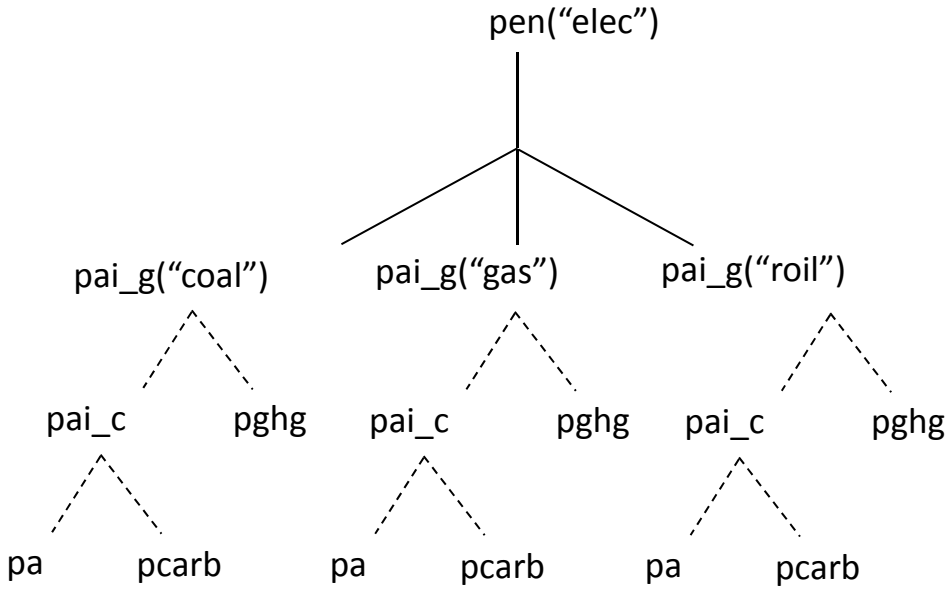
Some indices are omitted; gray line means a place holder.



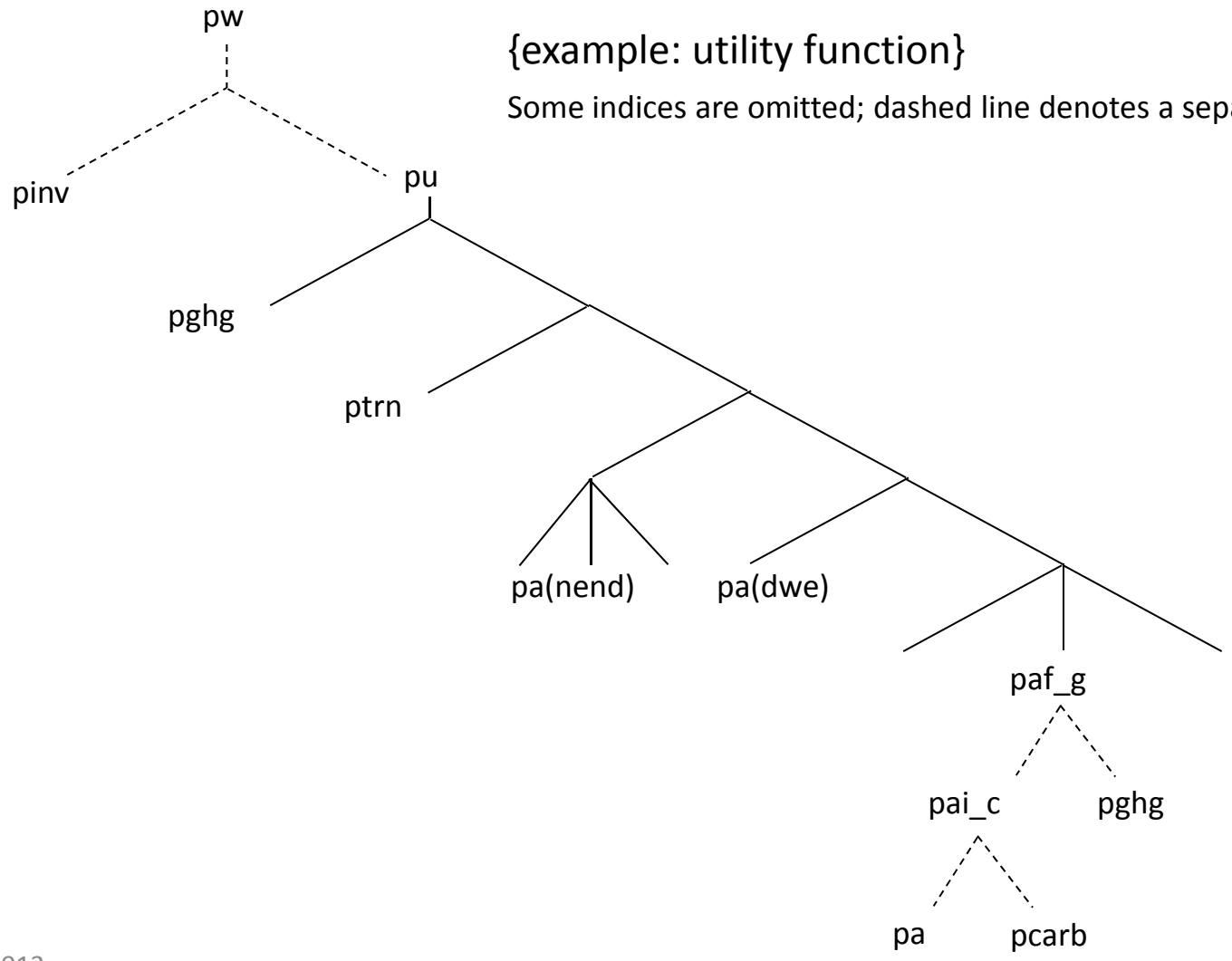
Settings

{example: fossil energy input to power sector}

Some indices are omitted; dashed line denotes a separate function.



Settings



{example: utility function}

Some indices are omitted; dashed line denotes a separate function.

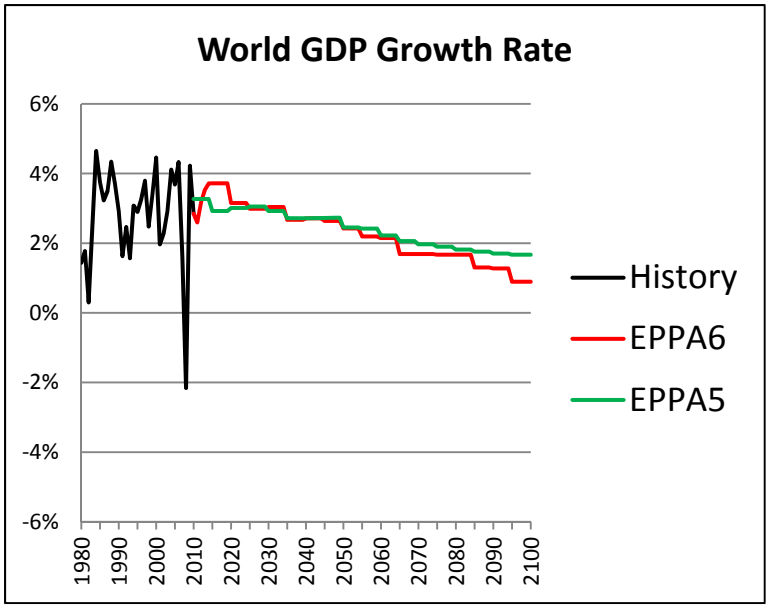
Settings

- Dynamics: exogenously specified:
  - Business-as-usual (BAU) GDP growth
  - Population growth
  - Factor-augmented productivity growths
  - Income elasticity for food (to calibrate the Stone-Geary preference)
  - Autonomous energy efficiency improvement (AEEI)
  - Fossil fuel endowments
  - Fixed factor supply (how fast a new technology grows)

- Dynamics: endogenously determined:
  - Capital accumulation
  - Fossil fuels depletion

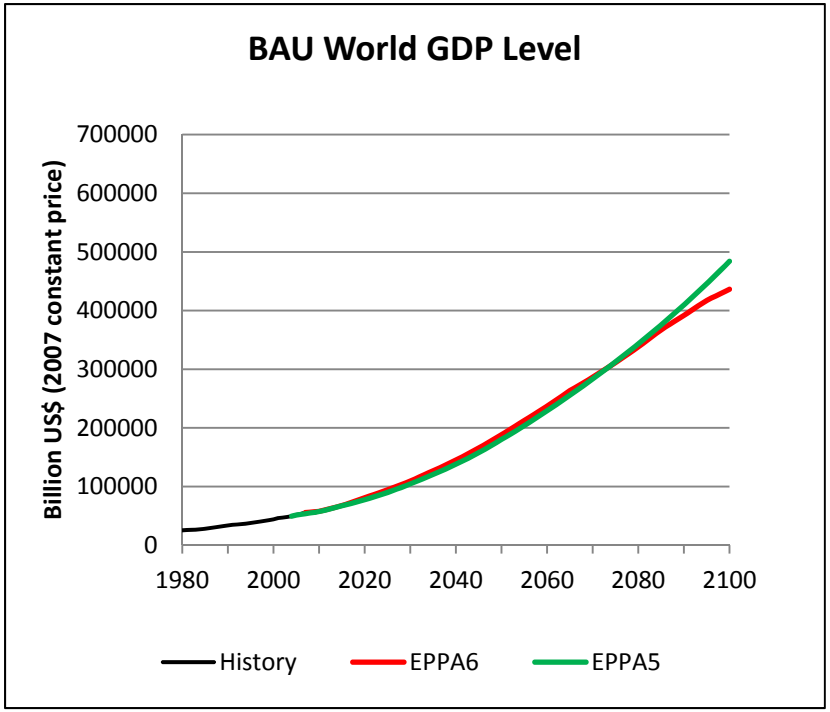
Settings

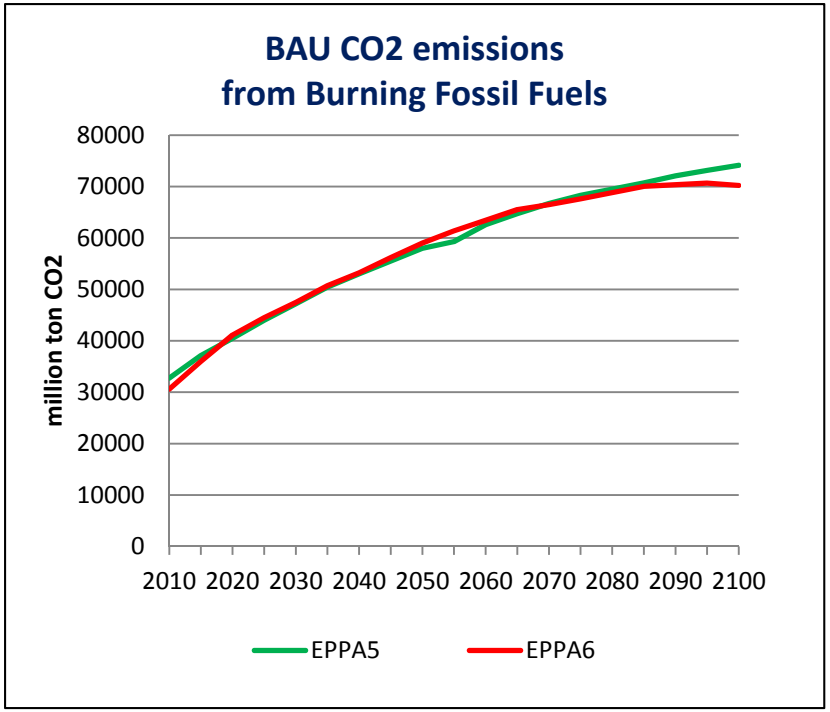
- GDP projection:
  - Up to 2017: World Economic Outlook (IMF, 2012)
  - Beyond 2017: Paltsev et al. (2010), and we adjust the regional GDP growths to reflect the latest prospects for long-term growths based on, for instance, Gordon (2012).



Settings

- GDP and emissions projections:





Settings

- On top of the given factor-augmented productivity growths:
  - We adjust the growths proportionally so for each region, the future BAU GDP matches the projection.
  - After setting GDP growth paths, the adjustment is done automatically during the BAU run.

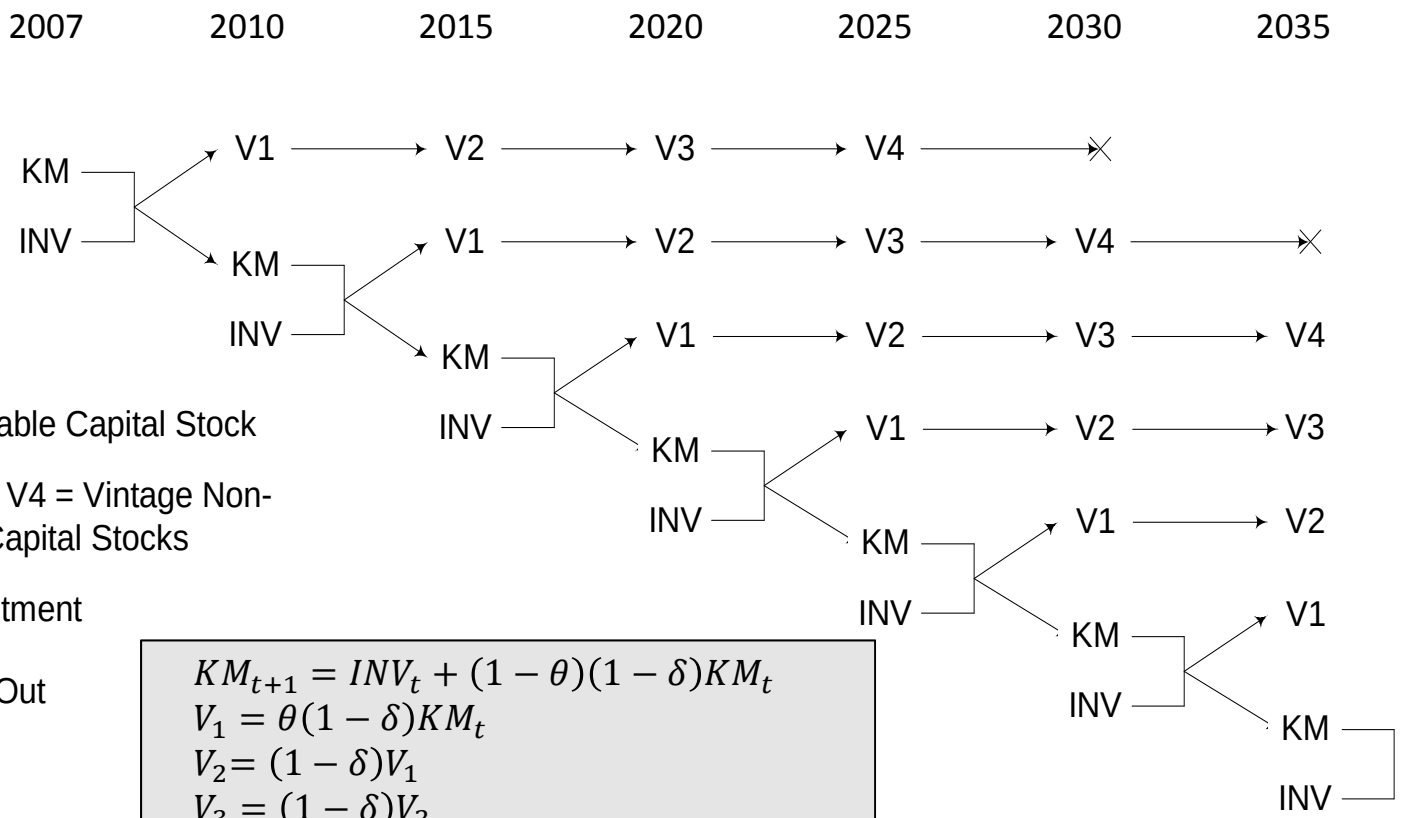
Settings

- Homothetic preference:
  - When income doubles, all consumption levels double
  - Income elasticity of each good equals one
- Non-homothetic preference:
  - When income increases, food consumption increases but the expenditure share may decrease
  - Income elasticity of food may be less than one
- Use the Stone-Geary setting to model the non-homothetic preference:
  - A Cobb-Douglas example: $U = (c - c^*)^{\alpha} y^{1-\alpha}$
  - Denote the income elasticity of c by η
  - For a given $c^* > 0$, $\eta \in (0,1)$ and $\eta \to 1^-$ as income increases
  - Alternatively, c^* could be calibrated by a given $\eta = [(c_0 - c^*)/c_0]/[(w_0 - c^*)/w_0]$

Settings

- Capital stock accumulation in EPPA:
  - Malleable capital (Non-sector-specific):
    $KM_{t+1} = INV_t + (1-\theta)(1-\delta)KM_t$
  - Vintage/nonmalleable capital (Sector-specific)
    $V_1 = \theta(1-\delta)KM_t$
    $V_2 = (1-\delta)V_1$
    $V_3 = (1-\delta)V_2$
    $V_4 = (1-\delta)V_3$

Settings



KM = Malleable Capital Stock

V1, V2, V3, V4 = Vintage Non-malleable Capital Stocks

INV = Investment

× = Phase Out

$$KM_{t+1} = INV_t + (1-\theta)(1-\delta)KM_t$$
$$V_1 = \theta(1-\delta)KM_t$$
$$V_2 = (1-\delta)V_1$$
$$V_3 = (1-\delta)V_2$$
$$V_4 = (1-\delta)V_3$$

Settings

- Fossil fuels depletion in EPPA:

  - Fossil fuels production will draw resources from existing reserves

    $R_{e,t+1} = R_{e,t} - 5F_{e,t}$

    $R_{e,t}$: fossil fuel reserve in period t

    $F_{e,t}$: total fossil fuel consumption in period t

    Remember EPPA runs in a 5-year interval (from 2010 onward)

Settings

- The fixed factor supply determines how fast a backstop technology grows:

$$bbres_{bt,r,t_0} = \max\left[0.0001, inish_{bt,r} \cdot outt_{g,r}\right] \text{ if the backstop output } bout_{r,t} = 0$$

$$bbres_{bt,r,t+1} = \max\left[bbres_{bt,r,t}, ba_{bt,r} \cdot \left(1 + bg_{bt,r}\right)^{t-1} \cdot \left(bsin_{bt,"ffa",r}\right) \cdot \left(bout_{r,t}\right)^{be_{bt,r}}\right]$$

  - A non-decreasing function
  - Eventually becomes non-binding

Settings

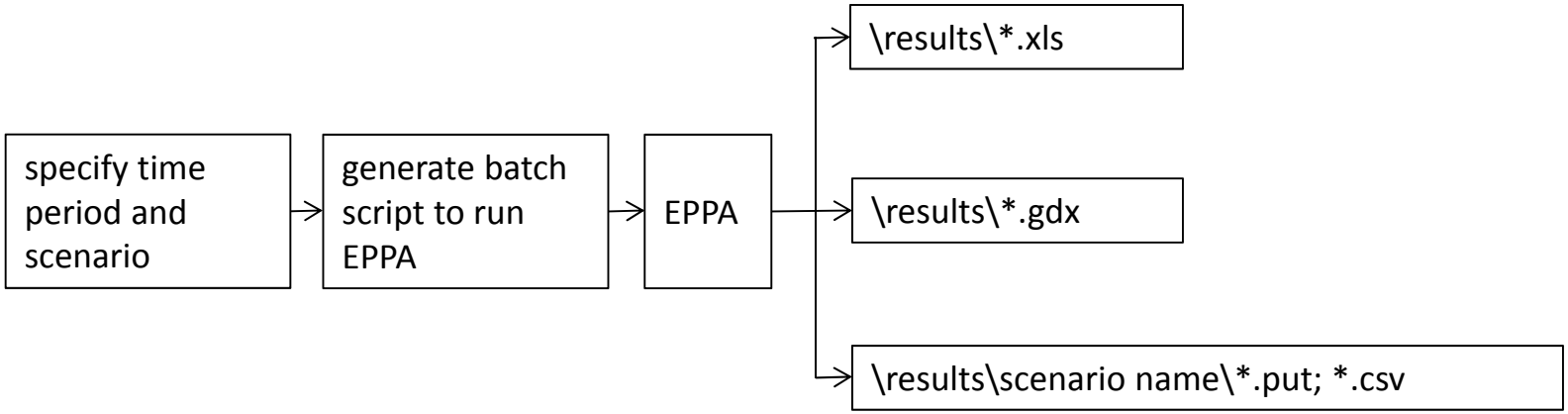
- Earlier versions of GTAP database do not present taxes on primary factors
- We incorporate these taxes from GTAP8 into EPPA6
- Easier to study tax reform/double dividend issues

Structure

23-Sep-2013	9:47:40a	<DIR>	.	
23-Sep-2013	9:47:40a	<DIR>	..	
21-Sep-2013	8:16:54p	<DIR>	active	=> run.gms; commandfile.bat; case files
23-Sep-2013	9:31:04a	<DIR>	core	=> static model, dynamic settings, etc.
21-Sep-2013	2:13:16p	<DIR>	data	=> economics, energy, GHGs, populations, etc.
23-Sep-2013	9:31:52a	<DIR>	logs	=> summary of solve status
23-Sep-2013	9:30:56a	<DIR>	lst	=> complete solve status
29-Jul-2013	5:38:02p	<DIR>	parameters	=> definition of parameters, sets, etc.
21-Sep-2013	4:14:22p	<DIR>	restart	=> files to restart the model after period one
21-Sep-2013	10:38:10p	<DIR>	results	=> model output
20-Sep-2013	10:59:46p	<DIR>	savepoint	=> files to speed up solution next time
25-Jul-2013	2:42:36p	<DIR>	uncertainty	=> uncertainty analysis

Structure

- EPPA is run in a 5-year interval from 2010 to 2100
- If the reference case is never run or is changed, it must be run before running the policy case (so the policy case can be run based on a correct benchmark)
- Otherwise, the policy case can be run alone



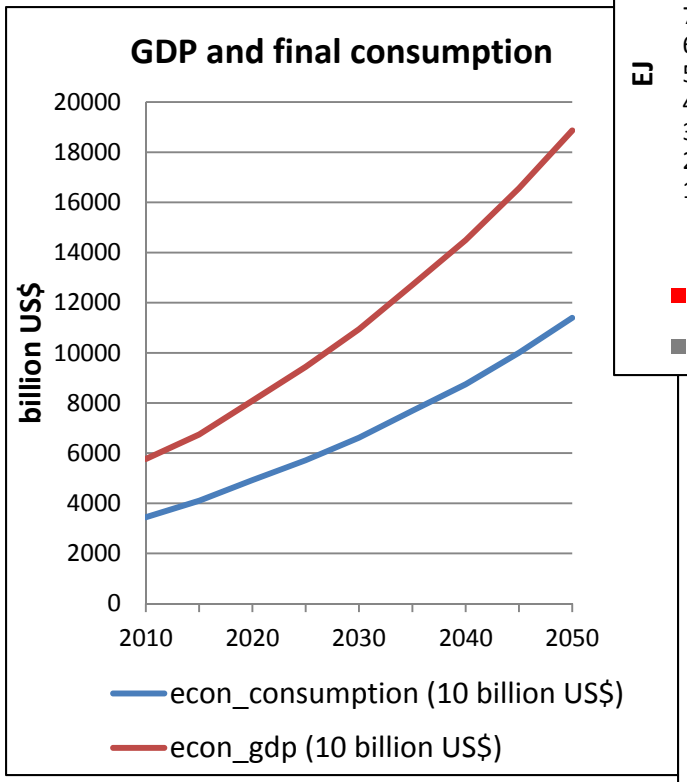
Structure

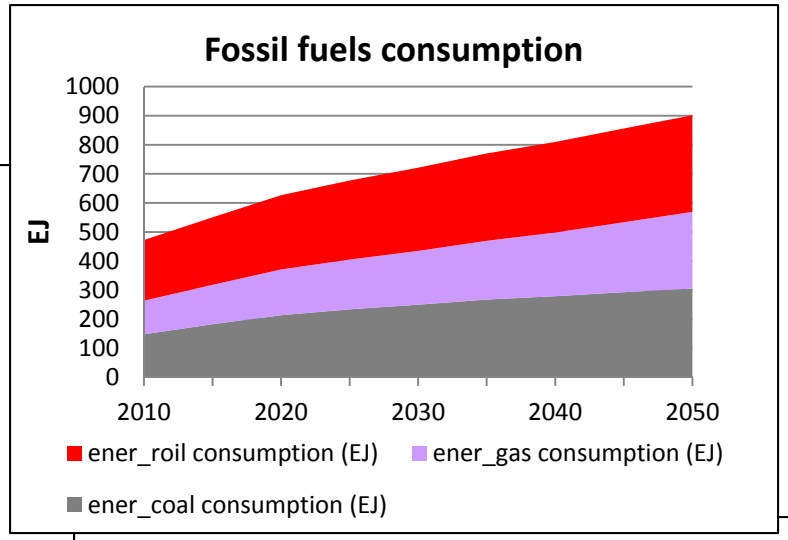
- How to run EPPA on PC up to year 2050

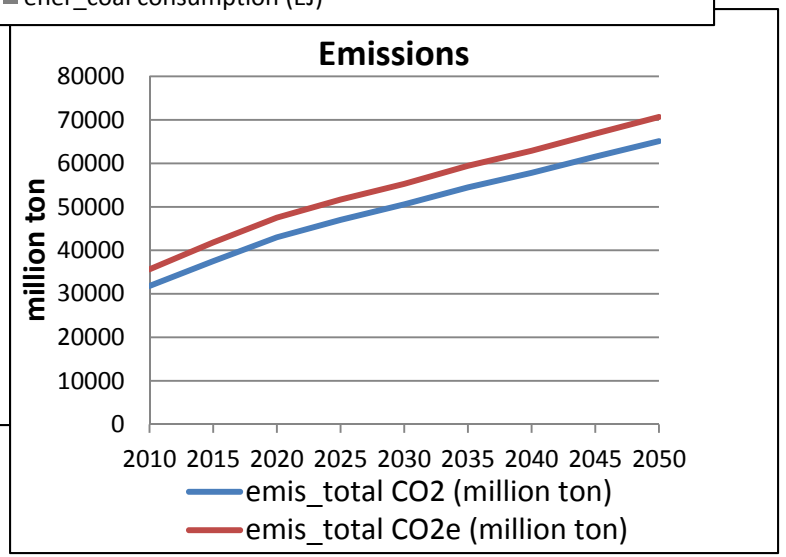
1) To run the reference (BAU) case v-ref-cas, in \active\, type
   gams run --csnm=v-ref --start=2007 --stop=2050
   (this generates commandfile.bat for running v-ref.cas).
2) Type ***commandfile***, and this will run v-ref
3) To run the policy case policy.cas, in \active\, type
   gams run --csnm=policy --start=2007 --stop=2050
   (this generates commandfile.bat for running policy.cas).
4) Type ***commandfile***, and this will run policy.

- Exercise 1:
  - run the reference case up to 2050
  - find the output (see the worksheet “data” in output_v-ref.xls, or the parameter “data” in all_v-ref.gdx)
  - What are the global GDP, final consumptions, emissions, fossil fuels use?

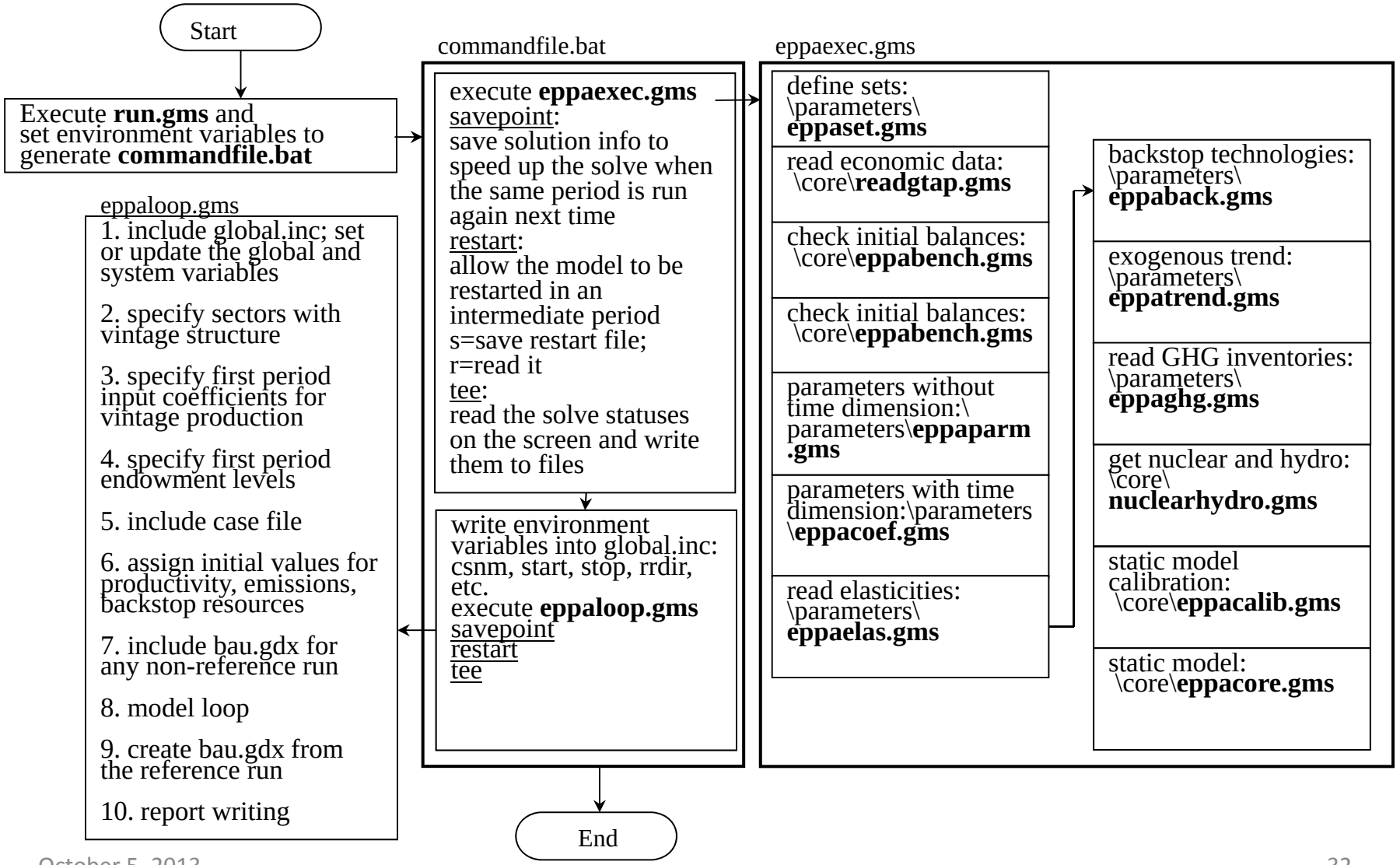
Structure


GDP and final consumption
billion US$
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
2010
2020
2030
2040
2050
econ_consumption (10 billion US$)
econ_gdp (10 billion US$)

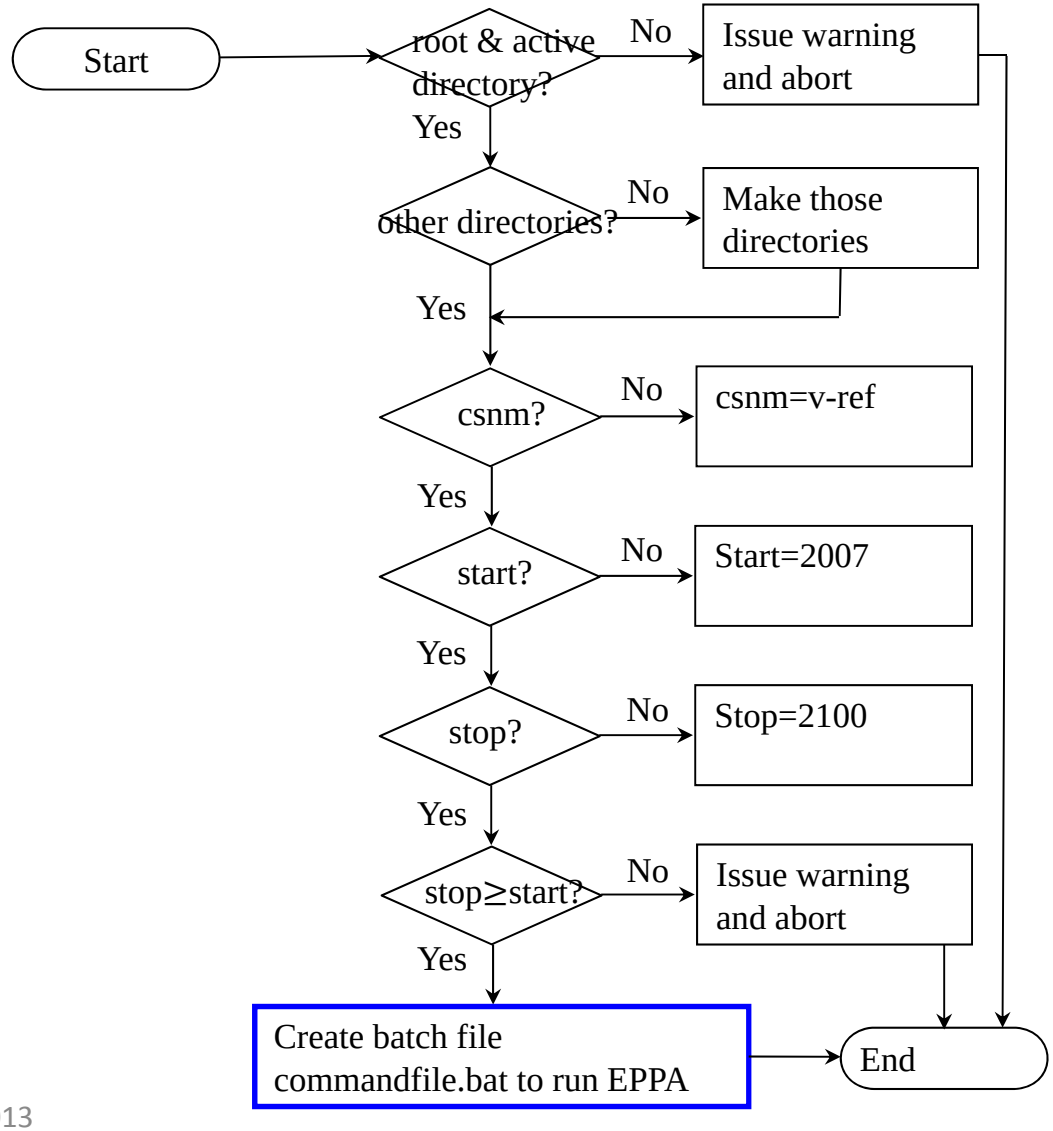

Fossil fuels consumption
EJ
1000
900
800
700
600
500
400
300
200
100
0
2010
2020
2030
2040
2050
ener_roil consumption (EJ)
ener_gas consumption (EJ)
ener_coal consumption (EJ)


Emissions
million ton
80000
70000
60000
50000
40000
30000
20000
10000
0
2010 2015 2020 2025 2030 2035 2040 2045 2050
emis_total CO2 (million ton)
emis_total CO2e (million ton)

Structure

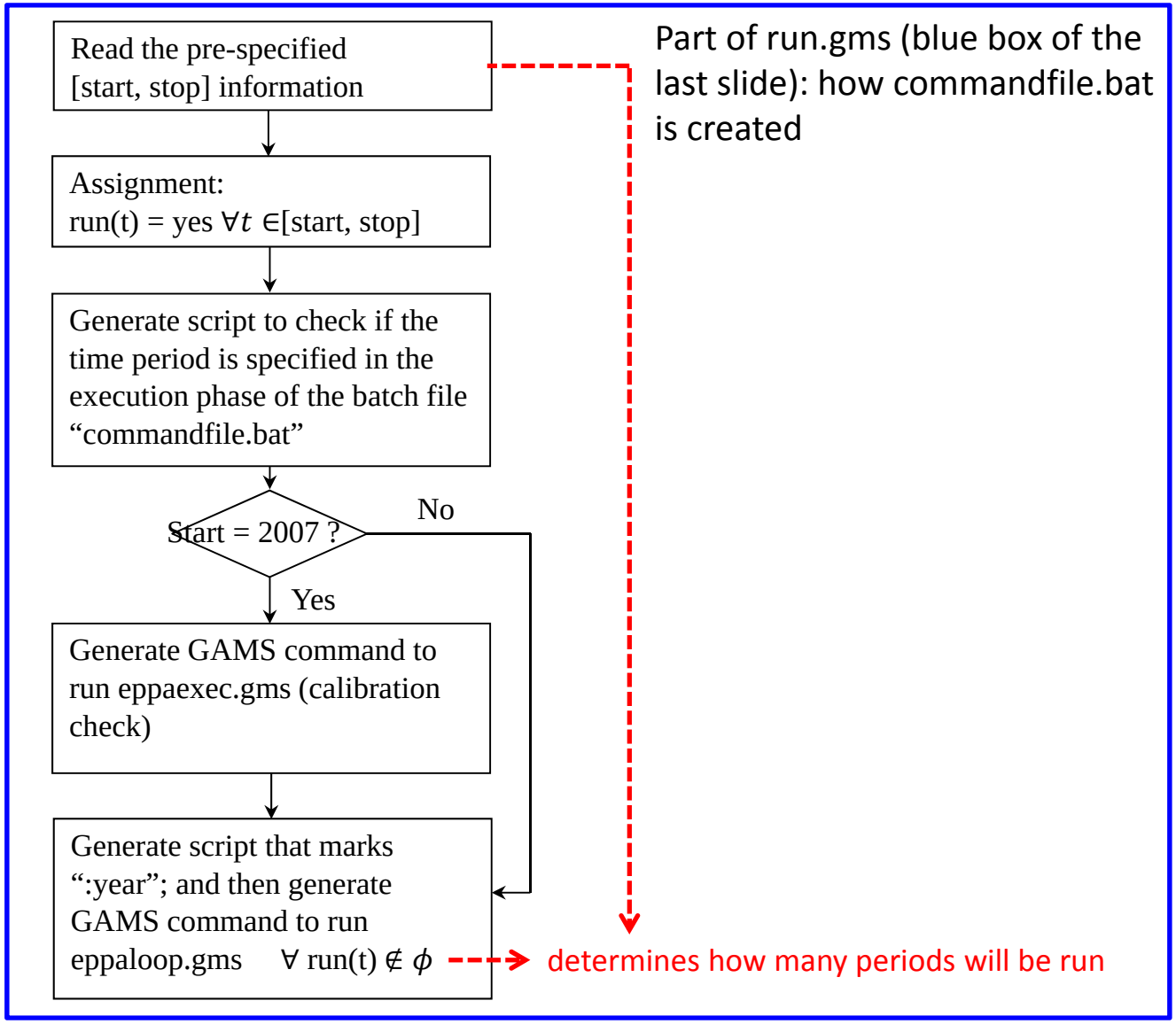

Start
Execute **run.gms** and set environment variables to generate **commandfile.bat**
commandfile.bat
execute **eppaexec.gms**
savepoint:
save solution info to speed up the solve when the same period is run again next time
restart:
allow the model to be restarted in an intermediate period
s=save restart file;
r=read it
tee:
read the solve statuses on the screen and write them to files
write environment variables into global.inc: csnm, start, stop, rrdir, etc.
execute **eppaloop.gms**
savepoint
restart
tee
eppaloop.gms
1. include global.inc; set or update the global and system variables
2. specify sectors with vintage structure
3. specify first period input coefficients for vintage production
4. specify first period endowment levels
5. include case file
6. assign initial values for productivity, emissions, backstop resources
7. include bau.gdx for any non-reference run
8. model loop
9. create bau.gdx from the reference run
10. report writing
eppaexec.gms
define sets: \parameters\ **eppaset.gms**
read economic data: \core**readgtap.gms**
check initial balances: \core**eppabench.gms**
check initial balances: \core**eppabench.gms**
parameters without time dimension:\ parameters**eppaparm .gms**
parameters with time dimension:\parameters **eppacoef.gms**
read elasticities: \parameters\ **eppaelas.gms**
backstop technologies: \parameters\ **eppaback.gms**
exogenous trend: \parameters\ **eppatrend.gms**
read GHG inventories: \parameters\ **eppaghg.gms**
get nuclear and hydro: \core\ **nuclearhydro.gms**
static model calibration: \core**eppacalib.gms**
static model: \core**eppacore.gms**
End

Structure

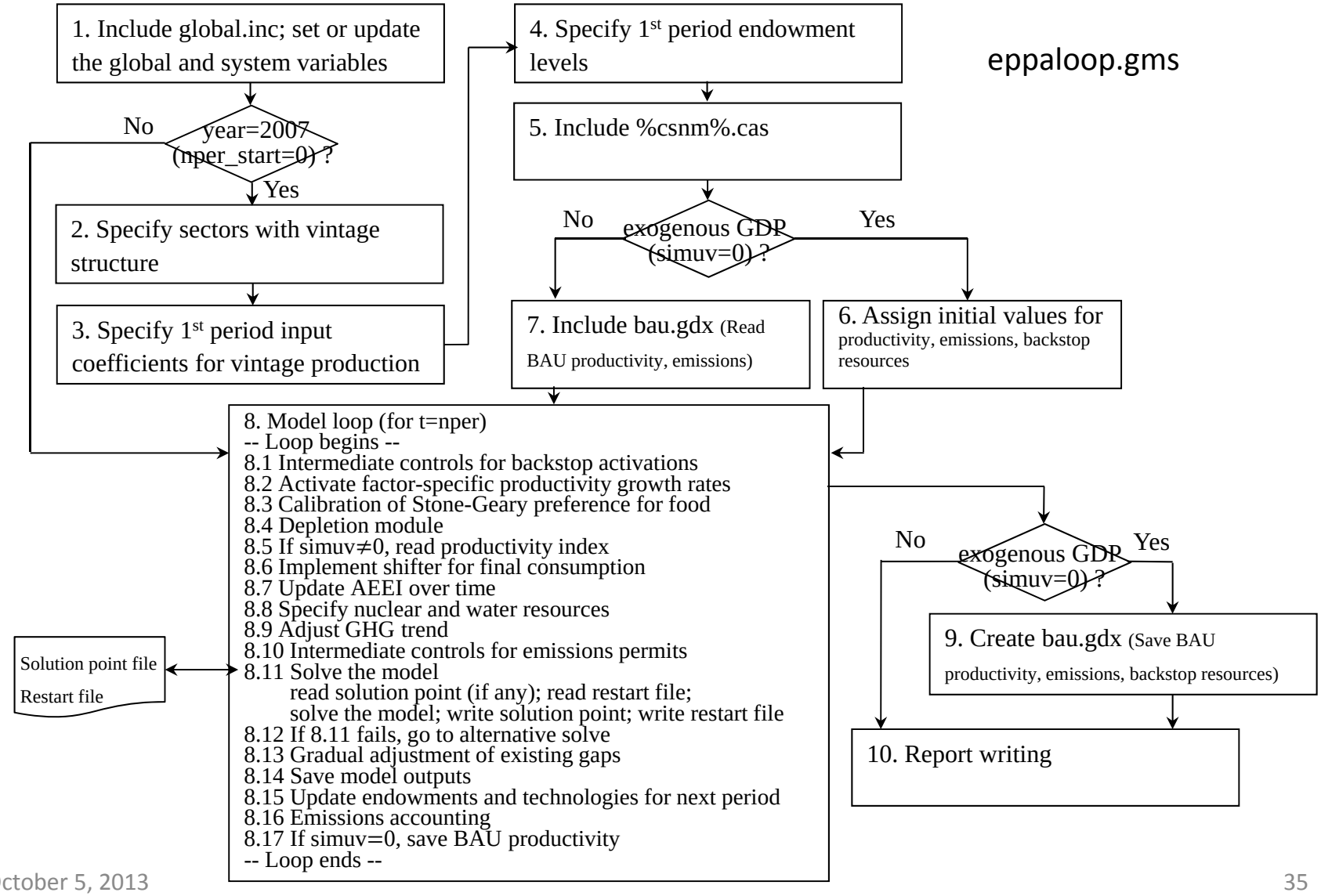


run.gms

Structure


Read the pre-specified [start, stop] information
Assignment: run(t) = yes ∀t ∈[start, stop]
Generate script to check if the time period is specified in the execution phase of the batch file "commandfile.bat"
Start = 2007 ?
No
Yes
Generate GAMS command to run eppaexec.gms (calibration check)
Generate script that marks ":year"; and then generate GAMS command to run eppaloop.gms ∀ run(t) ∉ ϕ
Part of run.gms (blue box of the last slide): how commandfile.bat is created
determines how many periods will be run

Structure



eppaloop.gms

Structure

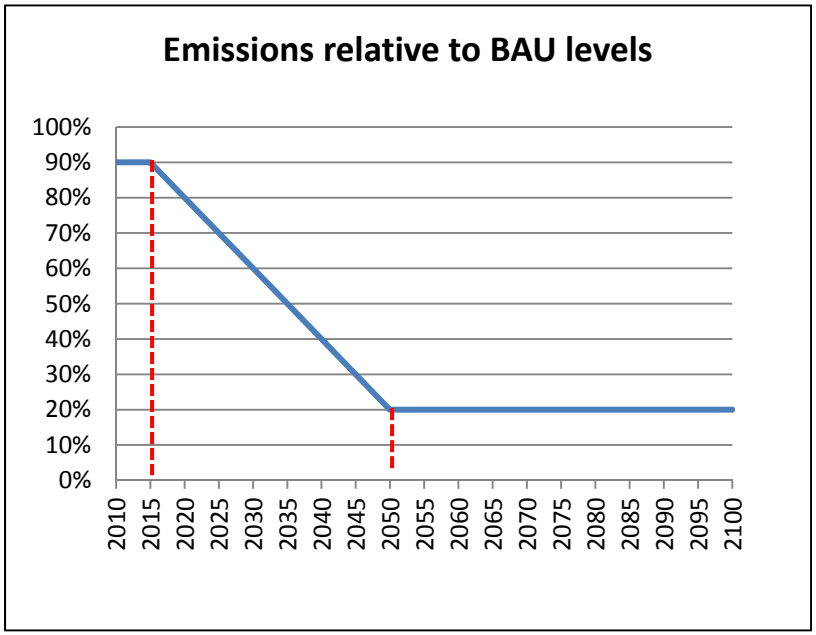
- Control panel for EPPA6 (\active*.cas):
  - simuv: =0 for exogenous GDP, =1 for endogenous GDP
  - vgequ: =0 for TFP only case, =1 for variable growth case
  - depper(ff): when will depletion module starts
  - available(*,r,t): when will technologies or policies become available
  - ert(t,r): emissions reduction ratio (relative to BAU)
  - cafelimt(t,r): cafe standard efficiency requirement
  - cflagf(r,t): flag for carbon policy on deforestation and cement emissions
  - co2cf(r,t): flag for non-tradable (national) CO2 permit
  - sco2cf(r,t): flag for non-tradable (sectoral) CO2 permit
  - tco2cf(r,t): flag for tradable (international) CO2 permit
  - ghgkf(r,t): flag for non-tradable (national) GHG permit
  - sghgkf(r,t): flag for non-tradable (sectoral) GHG permit
  - ghgkwf(r,t): flag for tradable (international) GHG permit
  - ghgt: activate trading between GHG and CO2 (1=trading; 0=no-trading)
  - urbnf(urb,r,t): flag for non-tradable(national) non-GHG permit

Structure

- Exercise 2
  - Open policy.cas
  - What kind of policies are imposed?
  - When will be those policies in place?

Structure

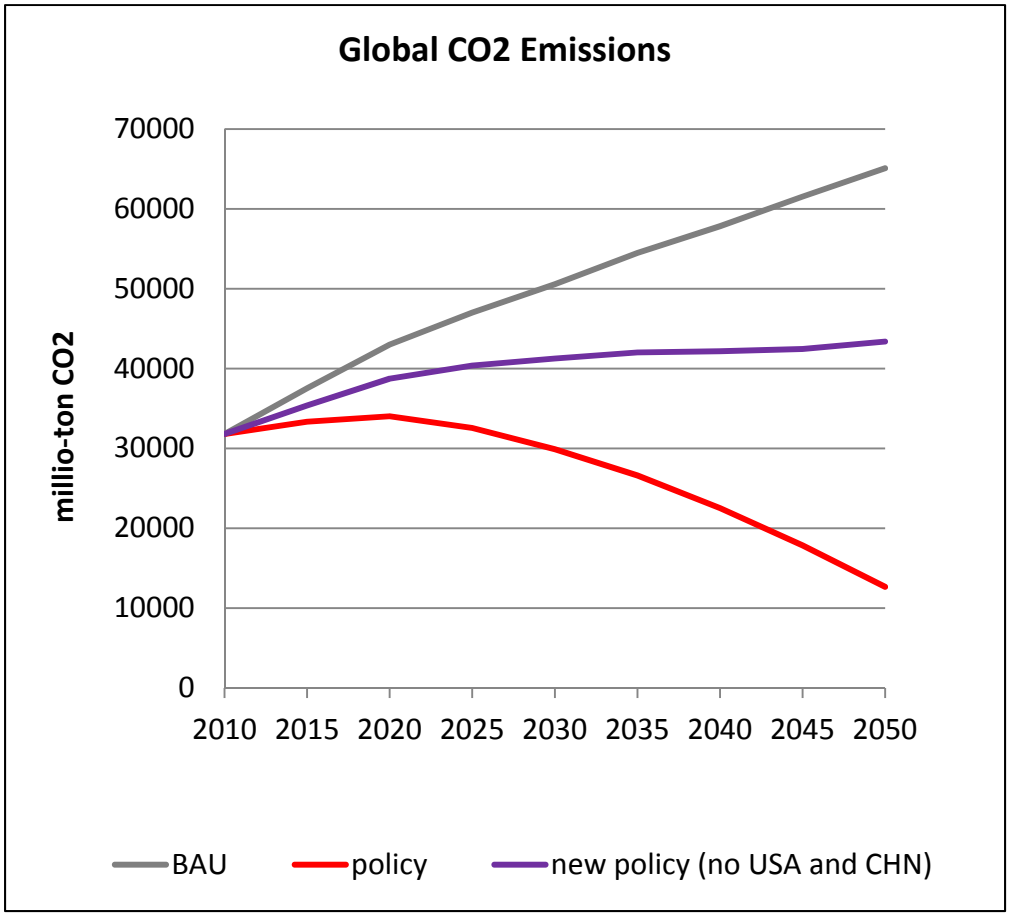
- Inside policy.cas, we have:
  - available("cafe","usa",t) = yes$(t.val ge 2010); (also appears in BAU)
  - co2cf(r,t)$(t.val ge 2015) = yes;
  - cflagf(r,t)$(t.val ge 2015) = yes;
  - table ert(t,r): Emissions relative to BAU levels



Structure

- Exercise 3
  - Save policy.cas as a new case file named “newpolicy.cas”
  - Implement the same carbon policy for all regions except China and US (consider the case where no carbon policies are imposed on these two countries).
  - Run the case newpolicy.cas up to 2050
  - Compared the CO2 emissions levels with those from v-ref.cas and policy.cas

Structure


Global CO2 Emissions
millio-ton CO2
70000
60000
50000
40000
30000
20000
10000
0
2010
2015
2020
2025
2030
2035
2040
2045
2050
BAU
policy
new policy (no USA and CHN)

Structure

- A CGE model has N equations with N endogenous variables
  - With one more constraint, there must be an additional “freed” variable
  - If the CO2 emission is exogenous, then CO2 price must be endogenous
  - If the CO2 price is exogenous, then CO2 emission must be endogenous

Guidelines

- Why do we need these guidelines
  - Let others understand our code, settings, data source, etc.
  - Avoid “GIGO”: know how to explain model results
  - Crucial for future model development and maintenance
- What are the guidelines for working on EPPA
  - Back up the last version
  - Follow the existing model structure
    - ✓ Where are parameters declared?
    - ✓ Where are sets declared?
    - ✓ How are variables created?
    - ✓ ALWAYS bring all key controls to the case file!
  - Keep the code clean and readable
  - Put comments explaining changes
  - Documentation

Guidelines

The same production structure (the above one has valued added taxes) with different expressions

```
* set elec = {elec}
$prod:d(g,r)$xp0(r,g)$elec(g)  s:sigg("sf6",g,r) u:sigu(g) b(u):0.6 a(b):0  ee(a):selas(r,g,"e_kl")   va(ee):selas(r,g,"l_k")

        o:pd(g,r)$(not x(g))                                          q:xp0(r,g)                                    a:ra(r) t:td(r,g)
        o:phom(g,r)$x(g)                                              q:xp0(r,g)                                    a:ra(r) t:td(r,g)
        i:pa(ne,r)                                                    q:(xdp0(r,ne,g)+xmp0(r,ne,g)) p:pi0(ne,g,r)   a:ra(r) t:ti(ne,g,r)      a:
        i:pl(r)                                                       q:labd(r,g)                   p:pf0("lab",g,r) a:ra(r) t:tf("lab",g,r)   va:
        i:pk(r)                                                       q:kapd(r,g)                   p:pf0("cap",g,r) a:ra(r) t:tf("cap",g,r)   va:
        i:pen(g,r)                                                    q:(ene(g,r)*aeei(r,g))                                                   ee:
        i:pf(g,r)                                                     q:ffactd(r,g)                                                            b:
        i:pghg(ghg,r)$((not ss(g,r))$ghglim(ghg,r)$(not wghgk))       q:oghg(ghg,g,r) p:(1/gu(ghg))
        i:pghgw(ghg)$(ghglim(ghg,r)$wghgk)                            q:oghg(ghg,g,r) p:(1/gu(ghg))
        i:sghg(ghg,g,r)$(ghglimg(ghg,g,r)$oghg(ghg,g,r))              q:oghg(ghg,g,r) p:(1/gu(ghg))
        i:purb(urb,r)$urblim(urb,r)                                   q:ourb(urb,g,r) p:(1/gu(urb))                                            u:
        i:pren(r)$srenc(r)                                            q:(phi(r)*xp0(r,g))
```

```
* ELEC
$PROD:D(G,R)$XP0(R,G)$elec(g)  s:sigg("sf6",g,r) u:sigu(g) b(u):0.6 a(b):0  ee(a):SELAS(R,G,"E_KL")
+                                        va(ee):SELAS(R,G,"L_K")
        O:PD(G,R)$(NOT X(G)) Q:XP0(R,G)       A:RA(R) T:TD(R,G)
        O:PHOM(G,R)$X(G)     Q:XP0(R,G)       A:RA(R) T:TD(R,G)
        I:PGHG(GHG,R)$(GHGK(R)$ghglim(ghg,r)$(not ss(g,r)))     Q:OGHG(GHG,g,r) P:0.001
        I:PGHG_gwp(GHG,R)$(ghg_gwp$ghg_gp(ghg,r)$(not ss(g,r))) Q:OGHG(GHG,g,r) P:0.001
        I:PGHGw(GHG)$(ghgkw(r)$wghgk)         Q:OGHG(GHG,g,r)    P:0.001
        I:PGHGw_gwp(GHG)$(ghg_gwc(r)$ghg_gwp$ghg_gw(ghg))        Q:OGHG(GHG,g,r)        P:0.001
        I:SGHG(GHG,G,R)$(SGHGK(R)$ss(g,r))      Q:OGHG(GHG,g,r) P:0.001
        I:PURB(URB,R)$urbn(urb,r)       Q:OURB(URB,g,r) P:0 u:
        I:PA(NE,R)           Q:(XDP0(R,NE,G)+XMP0(R,NE,G)) P:PI0(NE,G,R)
+                                                 A:RA(R) T:TI(NE,G,R)  a:
        I:PL(R)              Q:LABD(R,G)      va:
        I:PK(R)              Q:KAPD(R,G)      va:
        I:PEN(G,R)           Q:(ENE(G,R)*ELEKADJ(G,R))          ee:
        I:PF(G,R)            Q:FFACTD(R,G)    b:
        I:PREN(R)$SRENC(R)      Q:(PHI(R)*XP0(R,G))
```

Guidelines

- How can we add a new backstop technology into EPPA
  - Study the engineering data
    - ✓ Cost markup relative to the current technology?
    - ✓ Input-output structure?
    - ✓ How fast might the technology grow once economic (fixed factor setting)?
    - ✓ Cost function structure?
    - ✓ Substitution/transformation elasticities?
    - ✓ Is the vintage backstop necessary?
  - Add the technology into the model
    - ✓ Check the model structure figures!
    - ✓ Declare the new technology? (eppaset.gms; eppacore.gms)
    - ✓ Implement the cost function by MPSGE? (eppacore.gms)
    - ✓ Declare the input/output coefficients? (eppaparm.gms)
    - ✓ Specify the substitution elasticity? (eppaback.gms)
    - ✓ Specify the fixed factor? (eppaloop.gms, eppacore.gms)
    - ✓ Save the technology's output/input for each period? (eppaloop.gms)
    - ✓ Any related emissions? (eppaemis.gms)
    - ✓ Report writing? (report.gms)
  - Make sure the model solves up to 2100

Applications

- Uncertainty modeling forum
- JP Report for EPPA6
- Uncertainty analysis
- Power sector
- Refined oil sector
- Land-use change

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