Introduction to EPPA

The structure of EPPA6

Y.-H. Henry Chen

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   - Replicating the reference run
   - Creating the policy run
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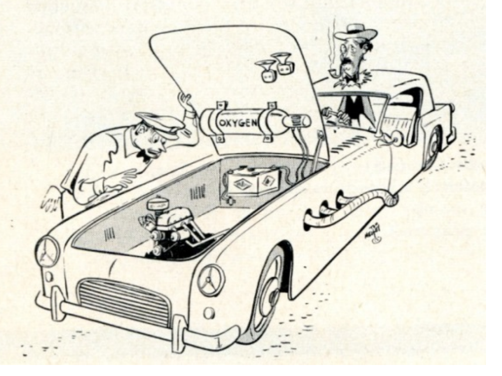
   - A small uncertainty analysis
4. Guidelines

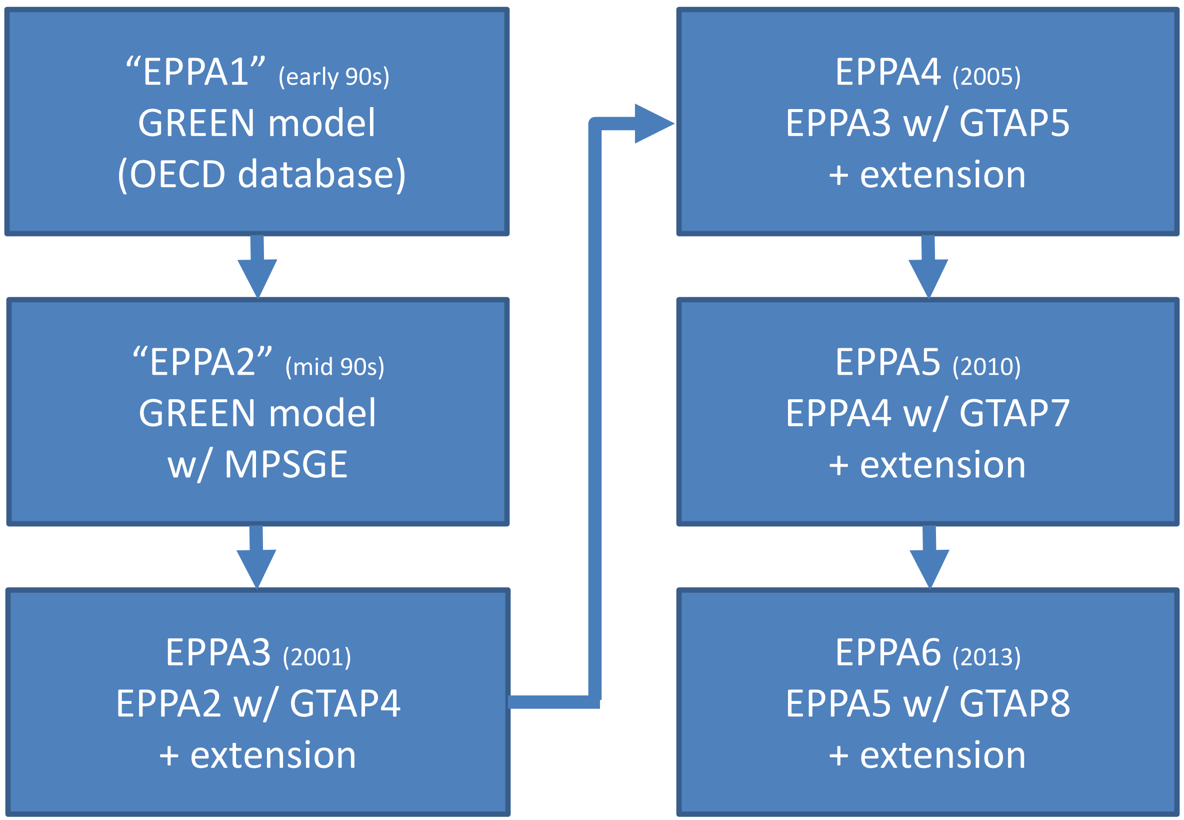


Introduction

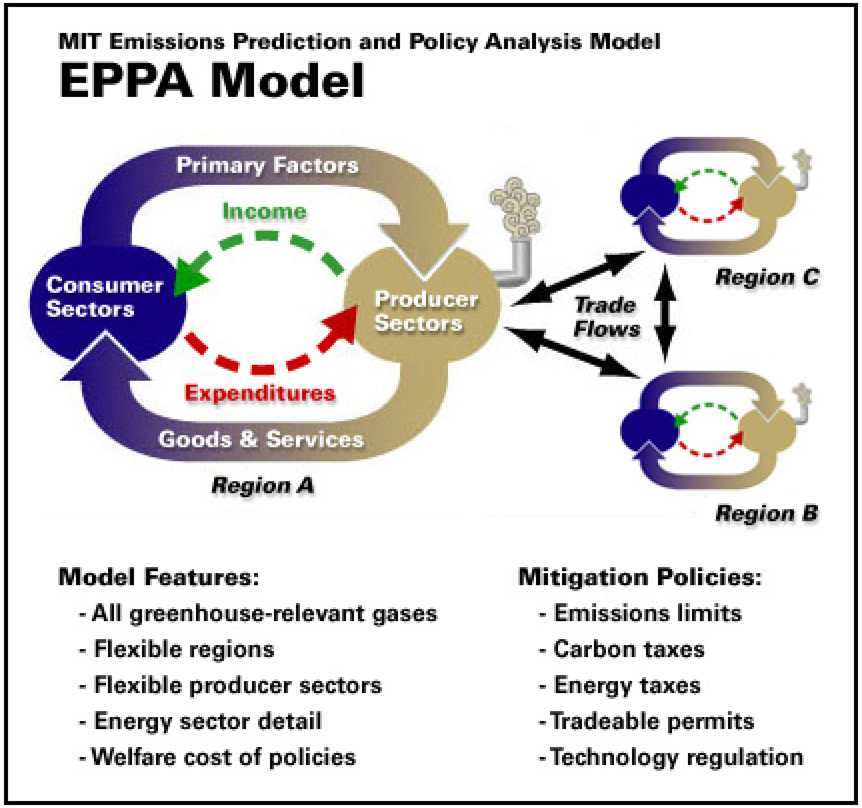
- EPPA is the human system module of IGSM
- A recursive dynamic CGE of the world economy
- Multi-region, multi-sector, multi-resource model
- Data: economics, energy use, GHGs emissions, engineering data, etc.

Introduction

- History of EPPA



Introduction



- Public released version is EPPA4, current versions are EPPA6 and EPPA5.
- Based on EPPA5 or EPPA4, 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

- Use the version control system Github for EPPA6 development
- EPPA6-L
  - ***Light version***; basis for other versions
  - Github branch name: master
- EPPA6-LUC
  - ***Main version***; with land-use change details
  - Github branch name: luc-new
- EPPA6-ROIL
  - ***Refined oil version***; with refined sectors details
  - Github branch name: dramberg

Introduction

- GTAP8:
  - 129 regions; 57 sectors; 5 primary factors
- Energy consumption:
  - IEA data (Narayanan et al., 2012)
- Emissions:
  - CO_2 from IEA (2012), Boden et al. (2010), Riahi et al. (2007)
  - Other GHGs and Non-GHGs from EDGAR v.4.2 (European Commission, 2013)
- Backstop cost structure:
  - Relevant engineering data (Paltsev et al., 2010)
- Elasticity data:
  - Substitution elasticities: Cossa (2004)
  - Income elasticities: Reimer and Hertel (2004); USDA (2013)

Introduction

Regions in EPPA:

EPPA6			EPPA5
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

Introduction

Agriculture
- crop
- livestock
- forest

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

Energy Supply
- coal
- crude oil
- refined oil
- gas
- electricity
  - fossil
    - coal
    - gas
    - oil-fired
  - nuclear
  - hydro
  - advanced nuclear
  - IGCC w/ CCS
  - NGCC
  - NGCC w/ CCS
  - wind
  - bio-elec
  - wind-bio
  - wind-gas
  - solar
- 1st gen biofuels
- 2nd gen biofuels
- oil shale
- synthetic gas from coal
- hydrogen

Introduction

	Pulverized Coal built in 1980	New Pulverized Coal	NGCC	NGCC with CCS	IGCC with CCS	Advanced Nuclear (EIA Numbers)	Wind	Biomass	Solar Thermal	Solar PV	Wind Plus Biomass Backup	Wind Plus NGCC Backup
"Overnight" Capital Cost ($/KW)	1775	2196	956	1909	3731	3774	1942	3803	5070	6097	5745	2899
Total Capital Requirement ($/KW)	2059	2548	1033	2138	4477	5284	2098	4411	5476	6584	6205	3131
Capital Recovery Charge Rate (%)	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%	10.6%
Fixed O&M ($/KW)	27.81	27.81	11.82	20.11	46.58	90.93	30.61	65.03	57.30	11.79	95.64	42.42
Variable O&M ($/KWh)	0.005	0.005	0.002	0.003	0.004	0.001	0.000	0.007	0.000	0.000	0.007	0.002
Project Life (years)	20	20	20	20	20	20	20	20	20	20	20	20
Capacity Factor (%)	85%	85%	85%	80%	80%	85%	35%	80%	35%	26%	42%	42%
(Capacity Factor Wind)											35%	35%
(Capacity Factor Biomass/NGCC)											7%	7%
Operating Hours	7446	7446	7446	7008	7008	7446	3066	7008	3066	2278	3679	3679
Capital Recovery Required ($/KWh)	0.0292	0.0362	0.0147	0.0322	0.0675	0.0750	0.0723	0.0665	0.1887	0.3055	0.1782	0.0899
Fixed O&M Recovery Required ($/KWh)	0.0037	0.0037	0.0016	0.0029	0.0066	0.0122	0.0100	0.0093	0.0187	0.0052	0.0260	0.0115
Heat Rate (BTU/KWh)	8740	8740	6333	7493	8307	10488	0	7765	0	0	7765	6333
Fuel Cost ($/MMBTU)	3.15	3.15	8.18	8.18	3.15	0.50	0.00	2.61	0.00	0.00	2.61	8.18
Fraction Biomass/NGCC (%)											8.8%	8.2%
Fuel Cost ($/KWh)	0.03	0.03	0.05	0.06	0.03	0.01	0.00	0.02	0.00	0.00	0.00	0.00
Levelized Cost of Electricity ($/KWh)	0.07	0.07	0.07	0.10	0.11	0.09	0.08	0.10	0.21	0.31	0.21	0.11
Transmission and Distribution ($/KWh)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Cost of Electricity ($/KWh)	0.09	0.09	0.09	0.12	0.13	0.11	0.10	0.12	0.23	0.33	0.24	0.14
Markup Over New Pulverized Coal	0.92	1.00	0.98	1.34	1.43	1.23	1.11	1.33	2.47	3.59	2.64	1.50
Markup Over Coal built in 1980	1.00	1.08	1.06	1.44	1.55	1.33	1.20	1.44	2.67	3.89	2.85	1.62

Introduction

Table 5. Substitution Elasticities in EPPA6-L

Type of substitution elasticity	Notation	Value
between domestic and imported goods	sdm	1.0–3.0
between imported goods	smm	0.5–5.0
between energy and non-energy (labor-capital bundle) inputs	e_kl	0.6–1.0
between labor and capital	l_k	1.0
between electricity and fossil energy bundle for the aggregated energy	noe_el	0.5
between fossil energy inputs for the fossil energy bundle	esube	1.0
between conventional fossil generations	enesta	1.5
between natural resource and other inputs	esup	0.3–0.5

Source: Cossa (2004)

Table 6. Income Elasticity for Agricultural and Food Products

	CROP	LIVE	FOOD		CROP	LIVE	FOOD
USA	0.08	0.65	0.67	CHN	0.65	1.01	0.88
CAN	0.13	0.61	0.62	IND	0.58	1.11	0.88
MEX	0.50	0.71	0.70	BRA	0.58	0.78	0.75
JPN	0.18	0.60	0.61	AFR	0.63	1.05	0.89
ANZ	0.22	0.59	0.60	MES	0.63	0.83	0.80
EUR	0.16	0.60	0.61	LAM	0.63	0.82	0.79
ROE	0.63	0.82	0.79	REA	0.54	1.16	0.87
RUS	0.56	0.76	0.74	KOR	0.30	0.61	0.61
ASI	0.64	0.86	0.81	IDZ	0.67	1.00	0.88

Source: Reimer and Hertel (2004); with adjustments for changes in prices and income levels

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

Market clearing condition for domestic production

zero profit condition for domestic production

Settings

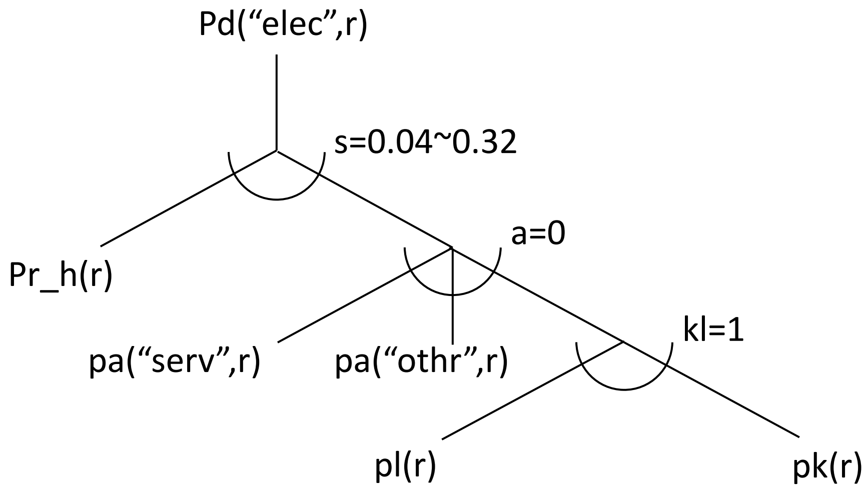
income balance for the representative agent

	d	n_e	h_e	inv	yt	htrn	eid	eid_ghg	efd_ghg	tefd_ghg	edf	tedf	a	m	z	w	govt	ra
pd	XP0	N_E0	H_E0		VST								D0	WTFLOW				
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	XDI0+ XMI0		TOI; TSE; PURTRN	EUSEP				HEUSEF	TEUSEF	A0		XDC+ XMC		XDG0+ XMG0	
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
pg																	G0	-GRG
pcarb	OUTCO2						EIND*ε				HEFD*ε	TEFD*ε						CARBLIM
TAX	TD;TI;TF	TD;TI;TF	TD;TI;TF			TP								TX; TM	TP		TG	GRG

Settings

{example: elec: hydro power}

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

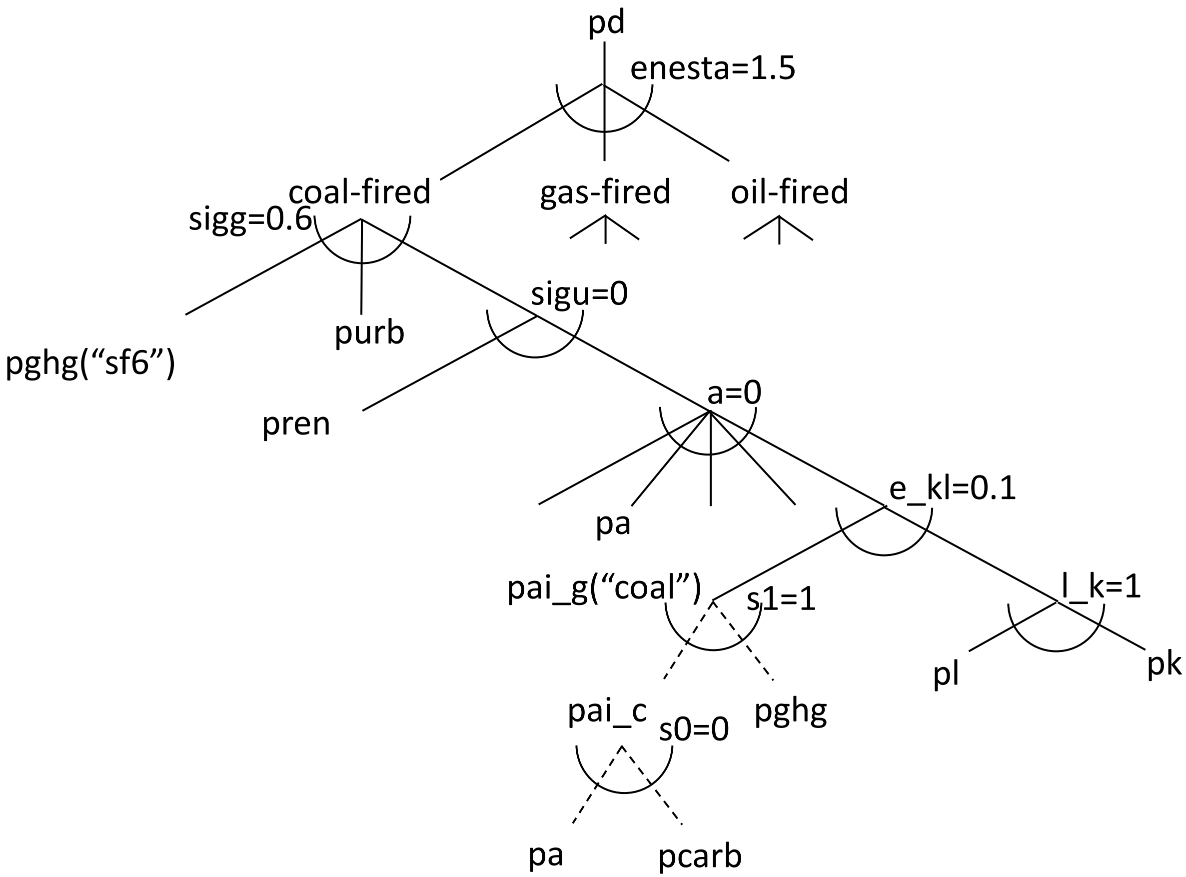



```
* hydro electric generation
$prod:h_e(r)$h_e0(r)    s:hsigma(r)  a:0 kl(a):1.0
   o:pd("elec",r)  q:h_e0(r)                             a:ra(r) t:td(r,"elec")
   i:pl(r)         q:h_l0(r)   p:pf0("lab","elec",r)     a:ra(r) t:tf("lab","elec",r)    kl:
   i:pk(r)         q:h_k0(r)   p:pf0("cap","elec",r)     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: elec: fossil based generation}

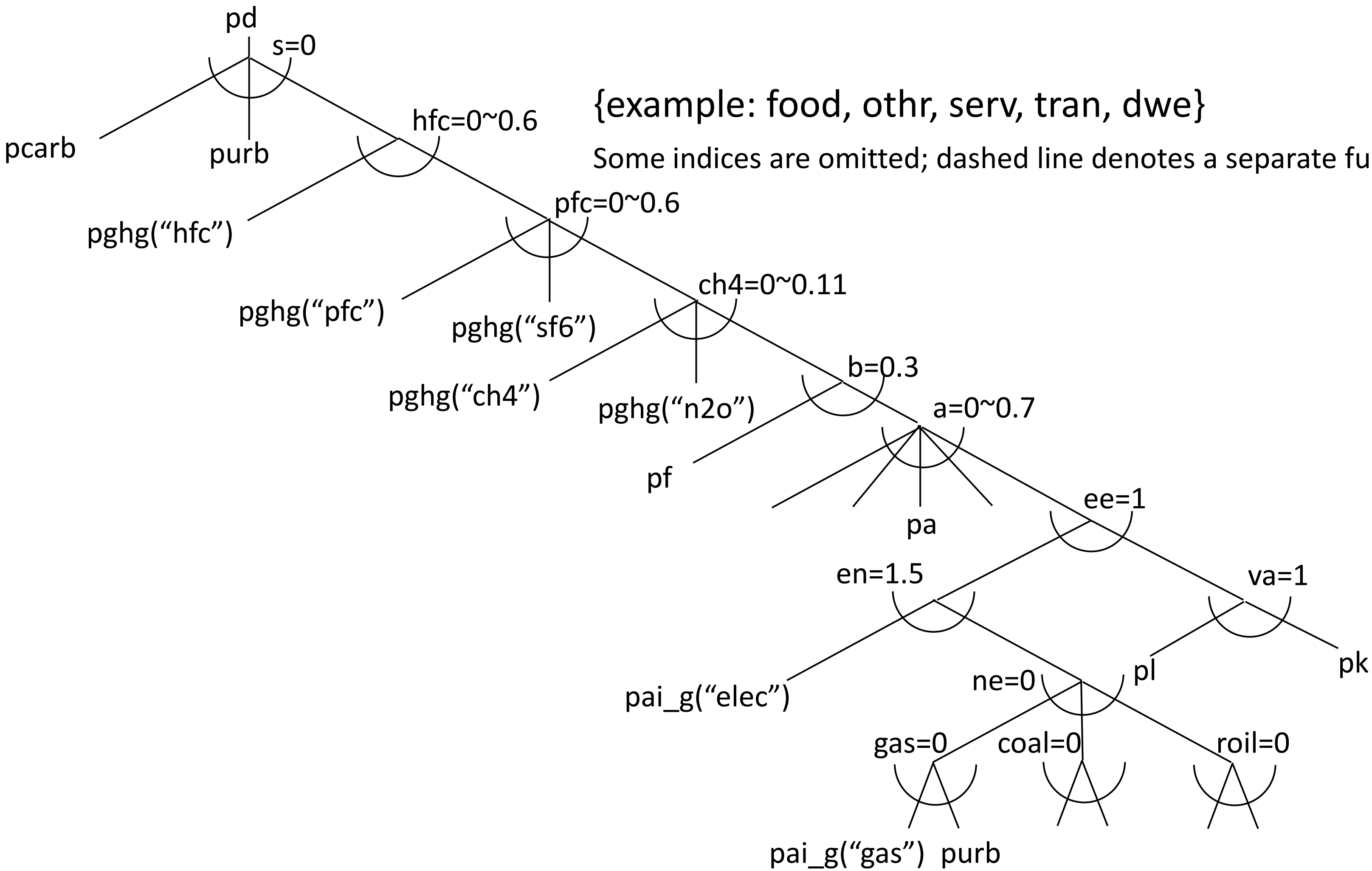
Some indices are omitted.



Settings

{example: food, othr, serv, tran, dwe}

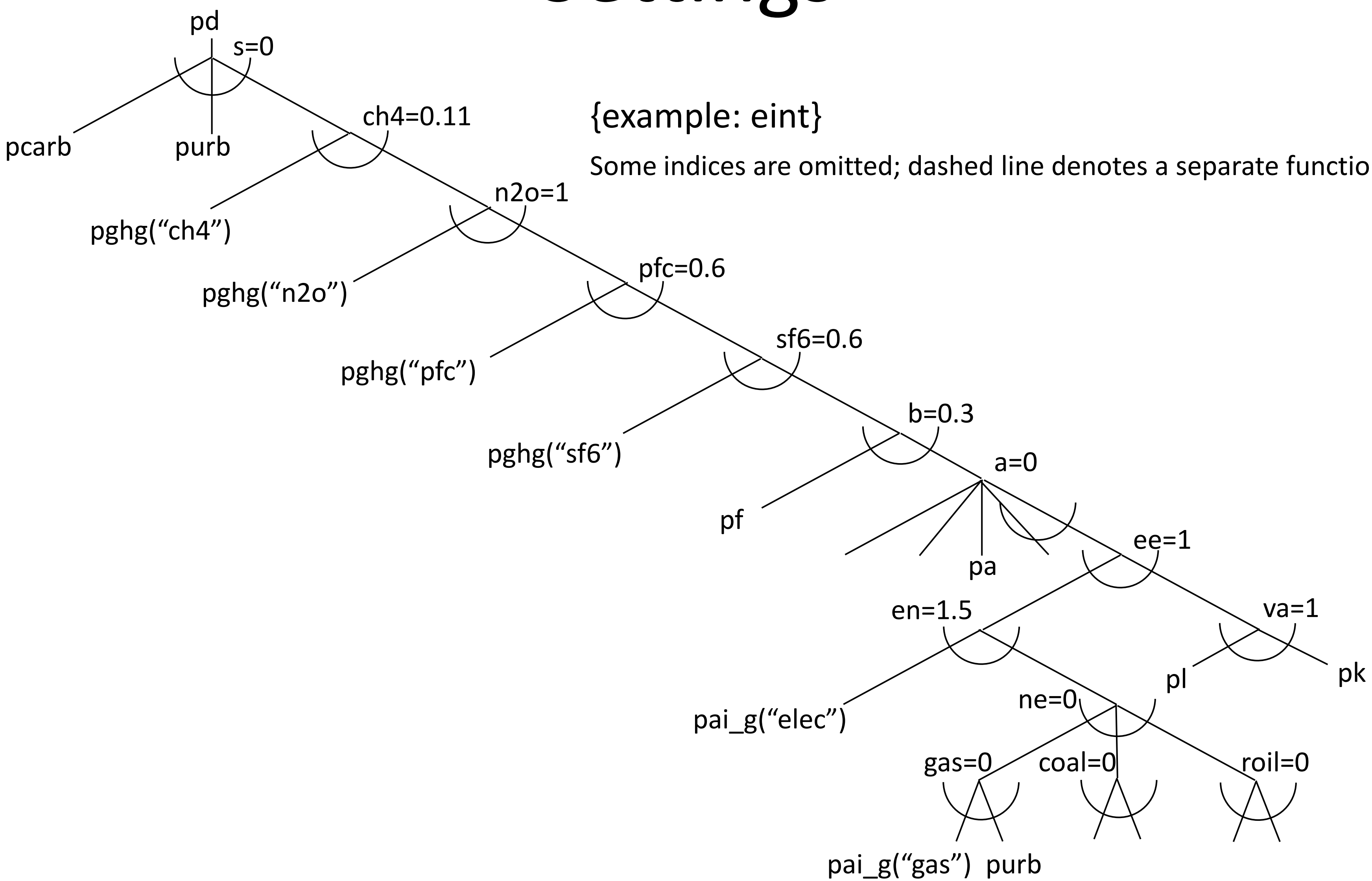
Some indices are omitted; dashed line denotes a separate function.



Settings

{example: eint}

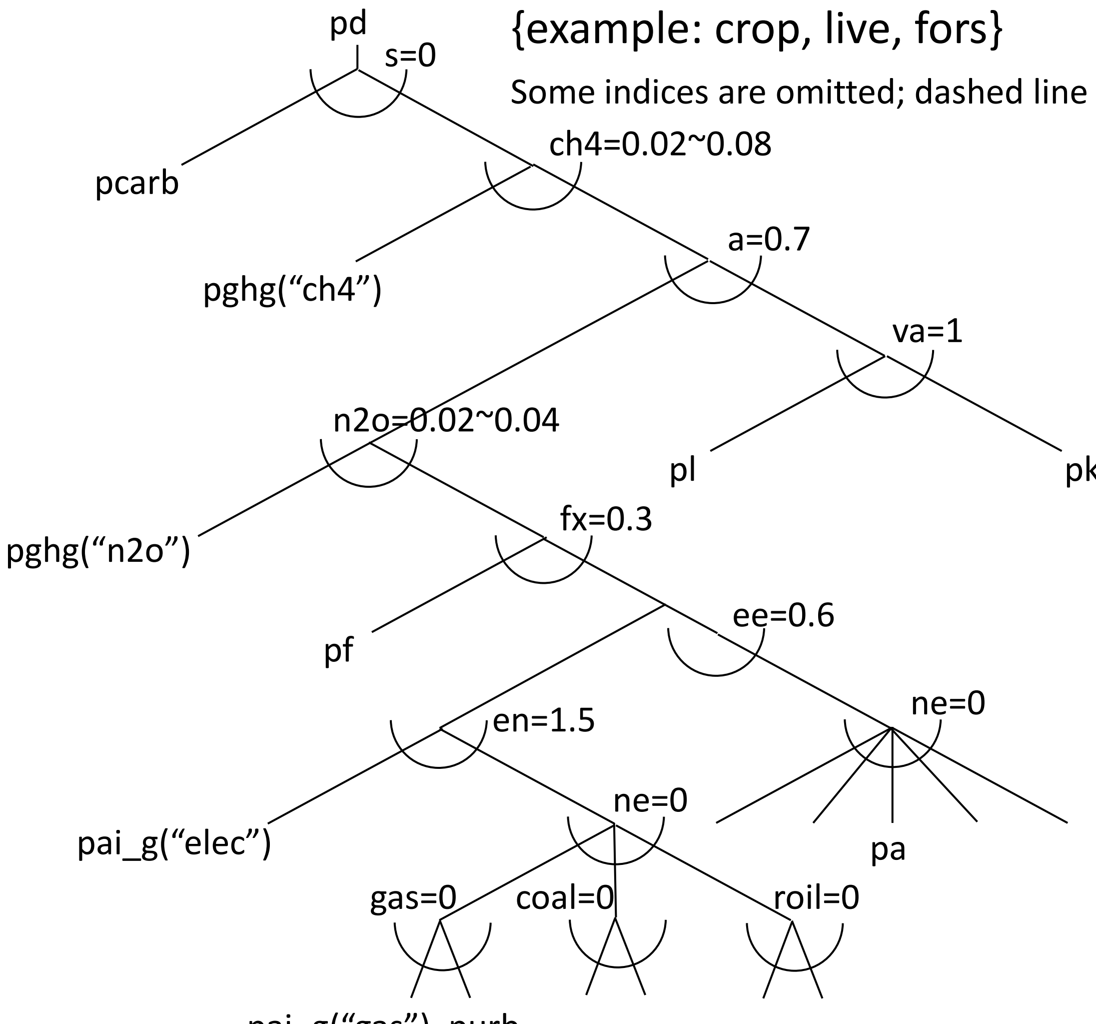
Some indices are omitted; dashed line denotes a separate function.



Settings

{example: crop, live, fors}

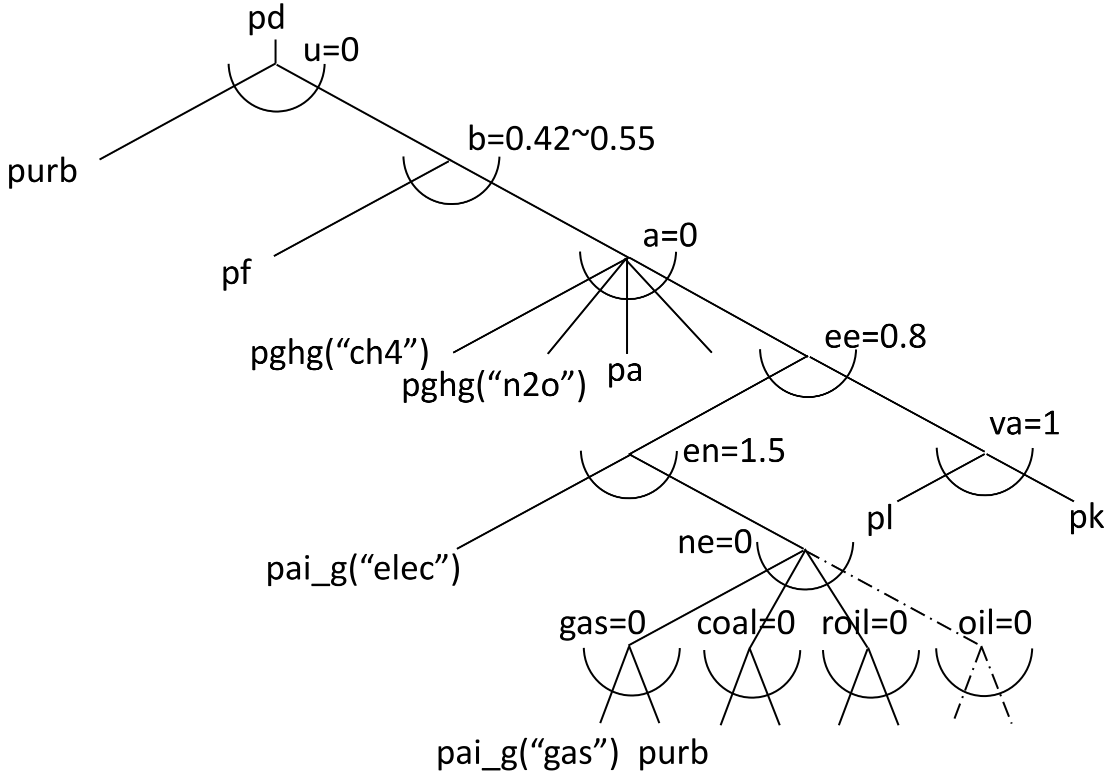
Some indices are omitted; dashed line denotes a separate function.



Settings

{example: coal, oil, roil, gas}

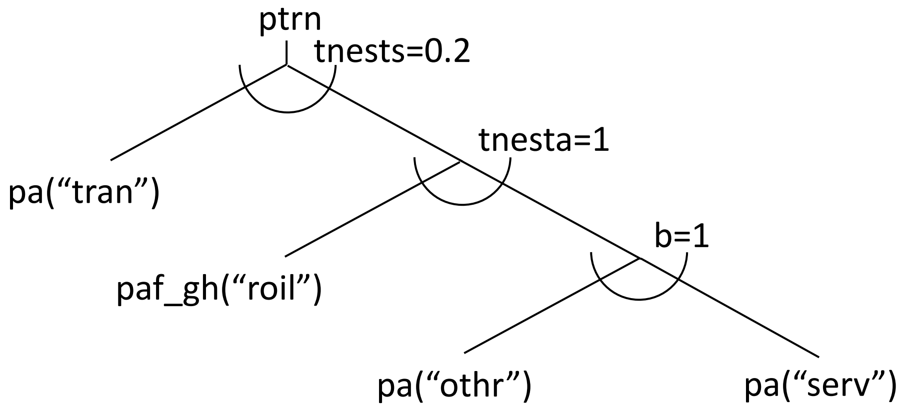
Some indices are omitted; dashed line denotes a separate function.



Settings

{example: household transportation}

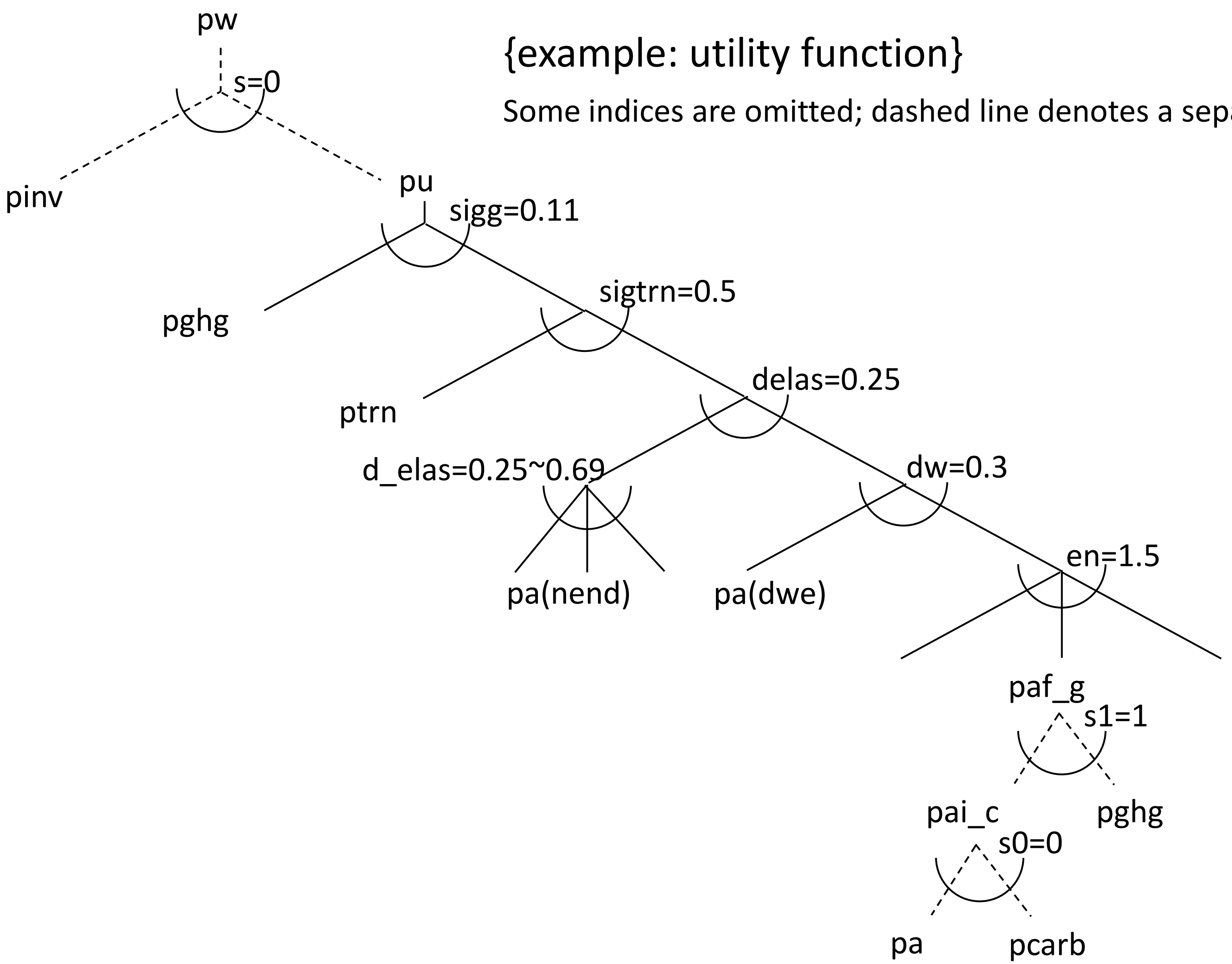
Some indices are omitted; dashed line denotes a separate function.



Settings

{example: utility function}

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



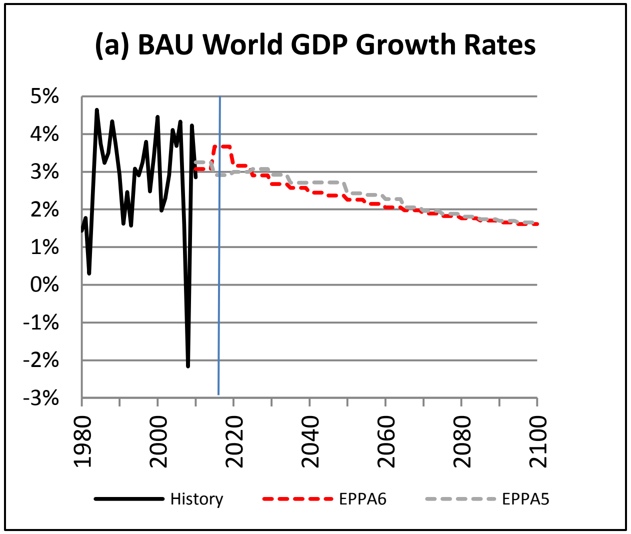
Settings

- Dynamics: exogenously specified:
  - Business-as-usual (BAU) GDP growth
  - Population growth
  - Factor-augmented productivity growths
  - Hick’s neutral productivity (calibrated to match the GDP growth)
  - Income elasticity for crop, livestock and food consumption
  - Autonomous energy efficiency improvement (AEEI)
  - Fossil fuel endowments
  - Fixed factor supply (how fast the cost of a new technology drops)

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

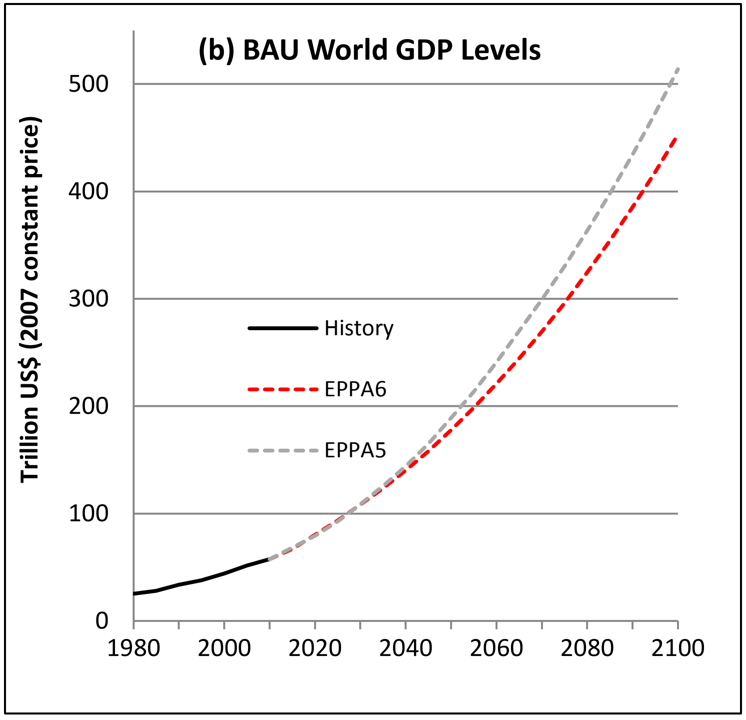
Settings

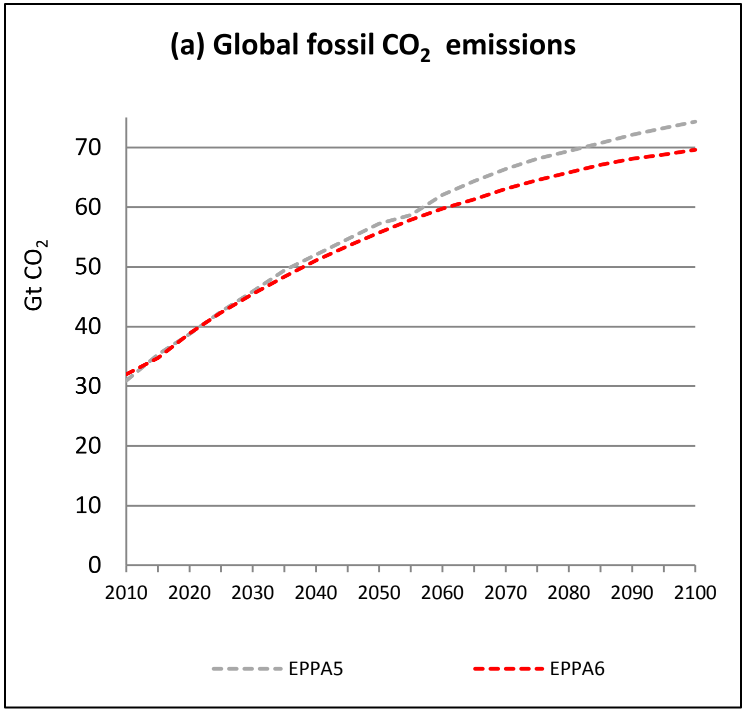
- GDP projection:
  - Up to 2018: World Economic Outlook (IMF, 2013)
  - Beyond 2018: Paltsev et al. (2010), World Bank (2013), United Nations (2012), Gordon (2012), Empresa de Pesquisa Energética (EPE) (2007).



Settings

- GDP and emissions projections:





Settings

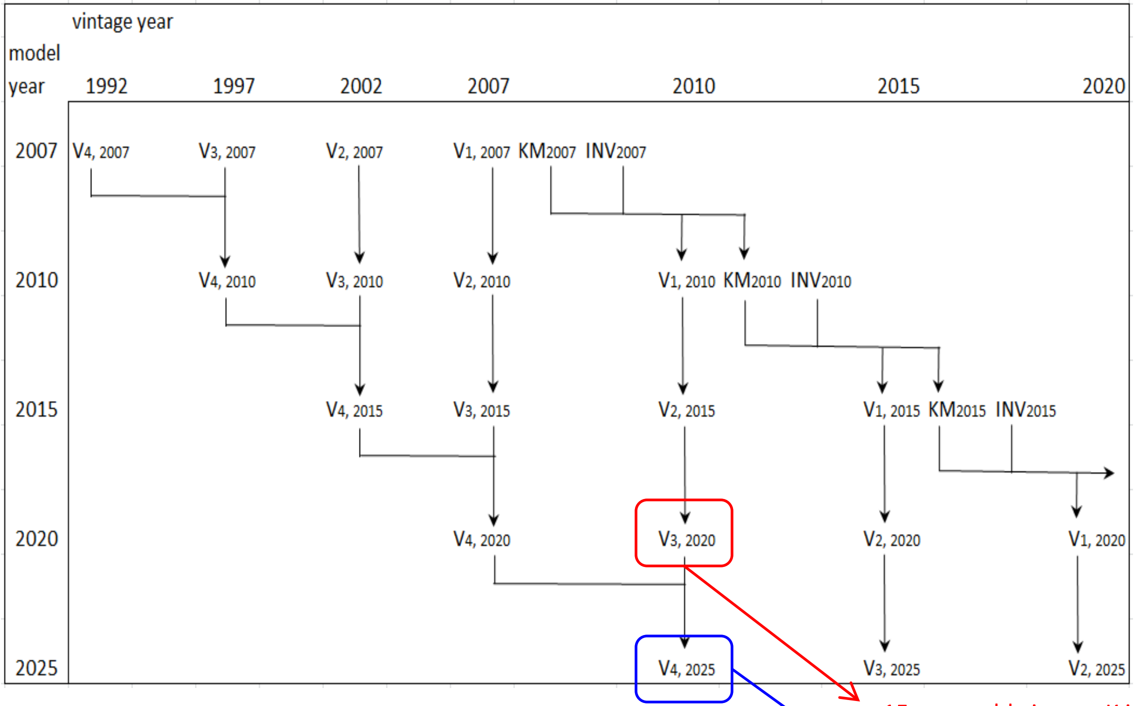
- On top of the given factor-augmented productivity growths:
  - The model will calibrate the regional Hick's neutral productivity growth, so for each region, the future BAU GDP matches the projection.
  - After setting GDP growth paths, the adjustment is done automatically during the BAU run.

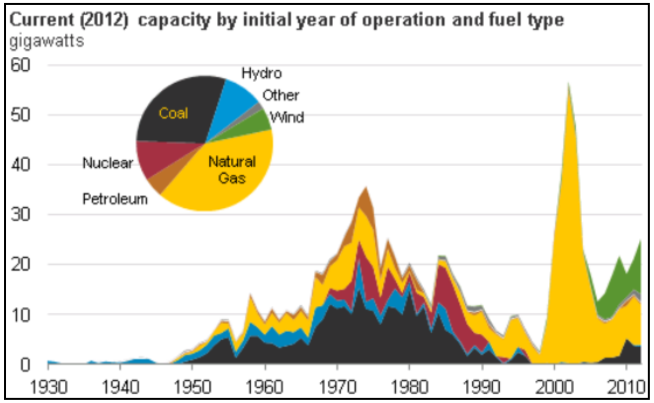
Settings

- 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:
  - $u = U(c_1 - c_1^*, c_2 - c_2^*, \dots, c_N - c_N^*)$
  - Income elasticity of good i is $\eta_i = \left(\frac{c_i - c_i^*}{c_i}\right) / \left(\frac{w - \sum_{i=1}^{N} c_i^*}{w}\right)$
  - Apply Engel's aggregation, we have $c_i^* = (1 - \eta_i)c_i$
  - c_i^* could be calibrated by a given η_i

Settings

- Capital Accumulation:
  - Malleable and vintage capital stocks
  - In EPPA6, vintage capital stock can survive beyond 20 years subject to depreciation
- Roles of decades-old vintage capital:
  - Example: coal-fired power plants in the U.S.





15 years old vintage K in 2020 (model year) formed in 2010 (vintage year)

20+ years old vintage K in 2025 formed in 2010 and earlier

Settings

- Capital stock accumulation in EPPA6:

  - Malleable capital (Non-sector-specific):

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

  - Vintage/nonmalleable capital (Sector-specific)

    $$V_{1,t} = \theta(1-\delta)^5 KM_{t-1}$$

    $$V_{2,t+1} = V_{1,t}$$

    $$V_{3,t+2} = V_{2,t+1}$$

    $$V_{4,t+3} = V_{3,t+2} + (1-\delta)^5 V_{4,t+2}$$

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

- When a backstop technology is operated, the rent to the limited fixed factor supply reflects the "nth plant story."

If backstop output $bout_{bt,t} = 0$*, fixed factor supply is linked to the output of competing technology:*

$$bbres_{bt,r,t} = inish_{bt,r} \cdot outt_{g,r}$$

If backstop output $bout_{bt,t} > 0$*, fixed factor supply grows as backstop output increases over time:*

$$bbres_{bt,r,t+1} = \alpha \cdot \left[bout_{bt,t} - (1-\delta)^5 \cdot bout_{bt,t-1}\right] + \beta \cdot \left[bout_{bt,t}^2 - (1-\delta)^5 \cdot bout_{bt,t-1}^2\right] + bbres_{bt,r,t} \cdot (1-\delta)^5$$

The fixed factor supply may become non-binding, or it may decline due to a reduced backstop output. A reduced backstop output results in the decline of technology specific input (fixed factor).

Settings

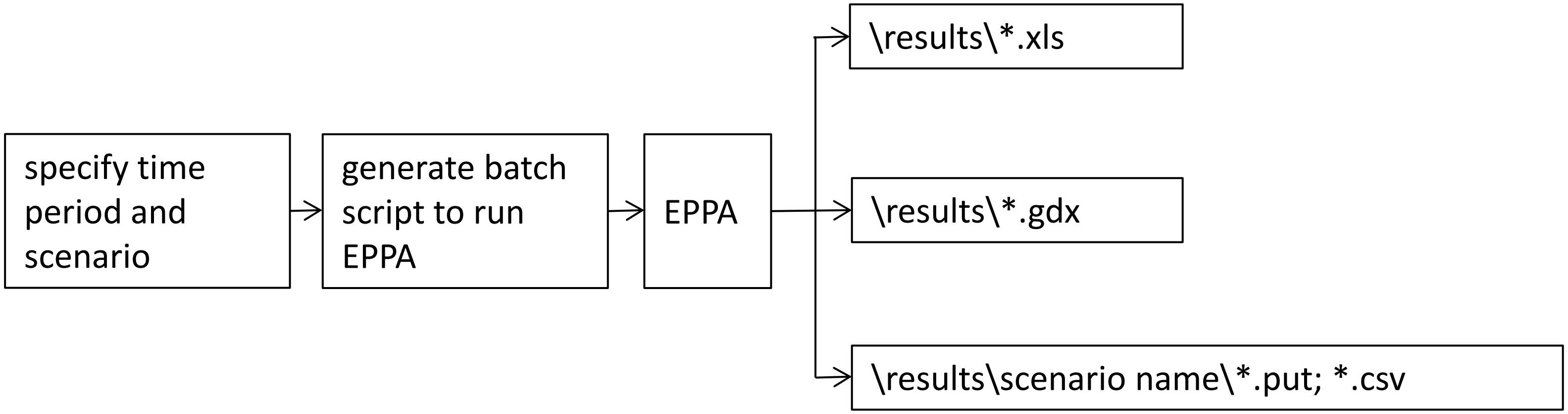
- Earlier EPPAs lump net income of primary factors and value-added tax together
- In EPPA6, value-added taxes are considered explicitly
- Easier to study tax reform/double dividend issues

Settings

25-Sep-2014	10:26:08a	<DIR>	.	
25-Sep-2014	10:26:08a	<DIR>	..	
24-Sep-2014	9:50:24p	<DIR>	active	⇒ run.gms; commandfile.bat; case files
24-Sep-2014	9:54:14p	<DIR>	core	⇒ static model, dynamic settings, etc.
18-Sep-2014	3:58:20p	<DIR>	data	⇒ economics, energy, GHGs, populations, etc.
25-Sep-2014	10:25:36a	<DIR>	gdxaggr	⇒ summary of solve status
25-Sep-2014	11:29:04a	<DIR>	logs	⇒ complete solve status
25-Sep-2014	11:28:56a	<DIR>	lst	⇒ definition of parameters, sets, etc.
18-Sep-2014	3:58:22p	<DIR>	parameters	⇒ files to restart the model after period one
25-Sep-2014	11:29:16a	<DIR>	restart	⇒ model output
25-Sep-2014	10:40:54a	<DIR>	results	⇒ files to speed up solution next time
24-Sep-2014	6:15:50p	<DIR>	savepoint	⇒ tools for EPPA
25-Sep-2014	10:30:16a	<DIR>	tools	⇒ uncertainty analysis
18-Sep-2014	3:58:22p	<DIR>	uncertainty	

Settings

- EPPA is run at 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)
- The policy case can be run alone afterward when the reference run exists and is unchanged.



Exercises

- The first step of running EPPA is to check the following files:
  - ChangeLog.md => what version we have, changes relative to the previous version
  - DEVELOPERS.md => guidelines for working on EPPA
  - README.md => license, requirements, etc.

```
   Directory of c:\temp\eppa6
18-Sep-2014   4:01:54p      <DIR>     .
18-Sep-2014   4:01:54p      <DIR>     ..
18-Sep-2014   4:35:02p      <DIR>     active
19-Sep-2014   2:23:40p      <DIR>     core
18-Sep-2014   3:58:20p      <DIR>     data
18-Sep-2014   4:37:28p      <DIR>     logs
18-Sep-2014   4:37:28p      <DIR>     lst
18-Sep-2014   3:58:22p      <DIR>     parameters
18-Sep-2014   4:38:24p      <DIR>     restart
19-Sep-2014   2:23:40p      <DIR>     results
18-Sep-2014   4:01:54p      <DIR>     savepoint
18-Sep-2014   3:58:22p      <DIR>     uncertainty
18-Sep-2014   3:58:18p          222   .gitignore
18-Sep-2014   3:58:18p        9,743   ChangeLog.md
18-Sep-2014   3:58:18p        1,894   DEVELOPERS.md
18-Sep-2014   3:58:18p        1,708   README.md
```

Exercises

- How to run EPPA on PC up to year 2020

1) To run the reference (BAU) case v-ref-cas, in \active\, type
   gams run *--csnm=v-ref --start=2007* ***--stop=2030***
   (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=2030***
   (this generates commandfile.bat for running policy.cas).
4) Type ***commandfile***, and this will run policy.

Exercises

- Exercise 1: Creating the reference run
  - run the reference case up to 2030
  - find the output files for the reference case

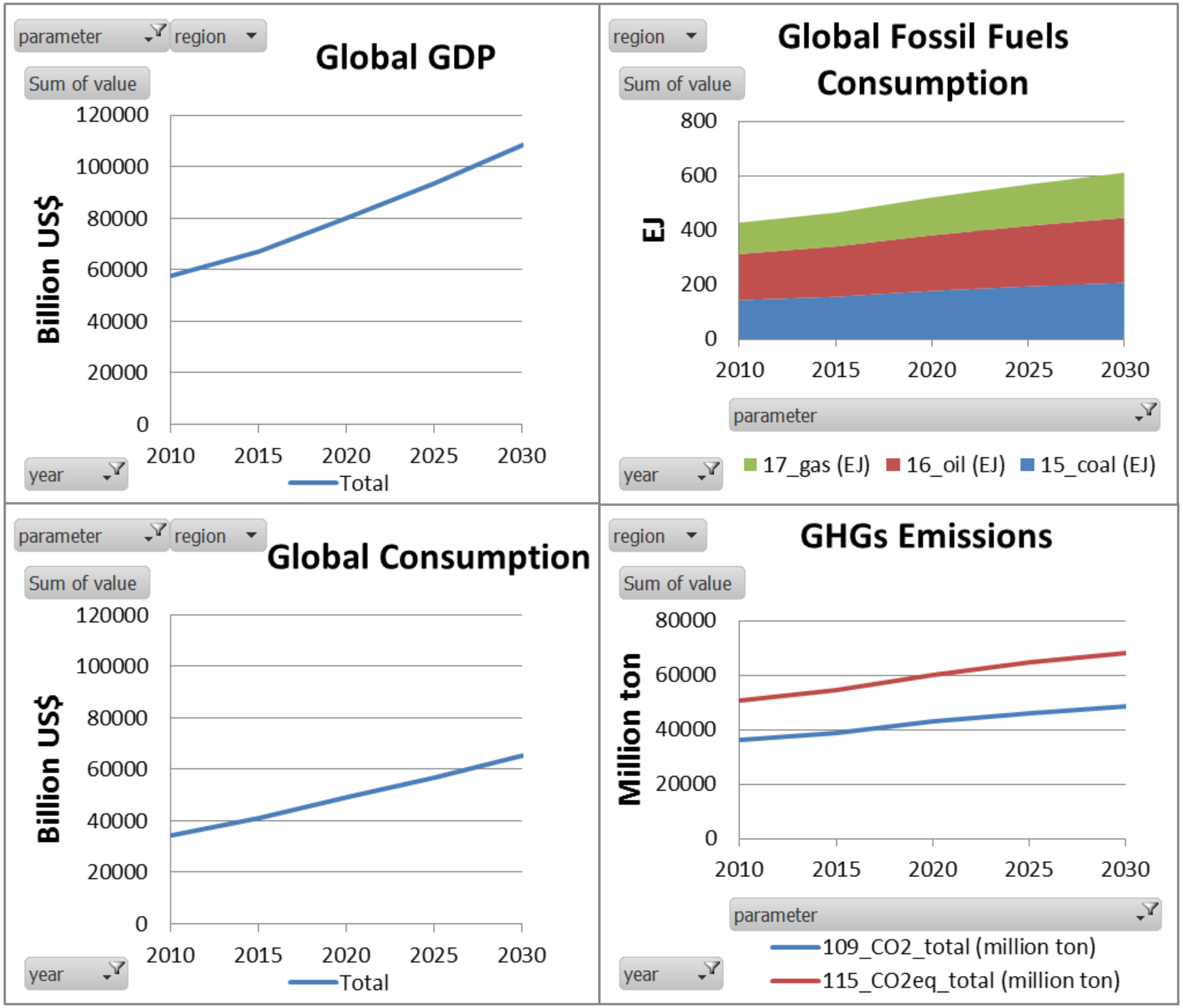
  - go to the model directory: \results\
  - gdx file: all_v-ref_p0_r0_gdpg-m_aeeg-m_sekl-m.gdx
  - excel file: out_v-ref_p0_r0_gdpg-m_aeeg-m_sekl-m.xls

reference base pop gr base prod gr median GDP gr median AEEI gr median AEEI gr

  - Find model projections for

  - global GDP
  - final consumptions
  - emissions
  - fossil fuels use

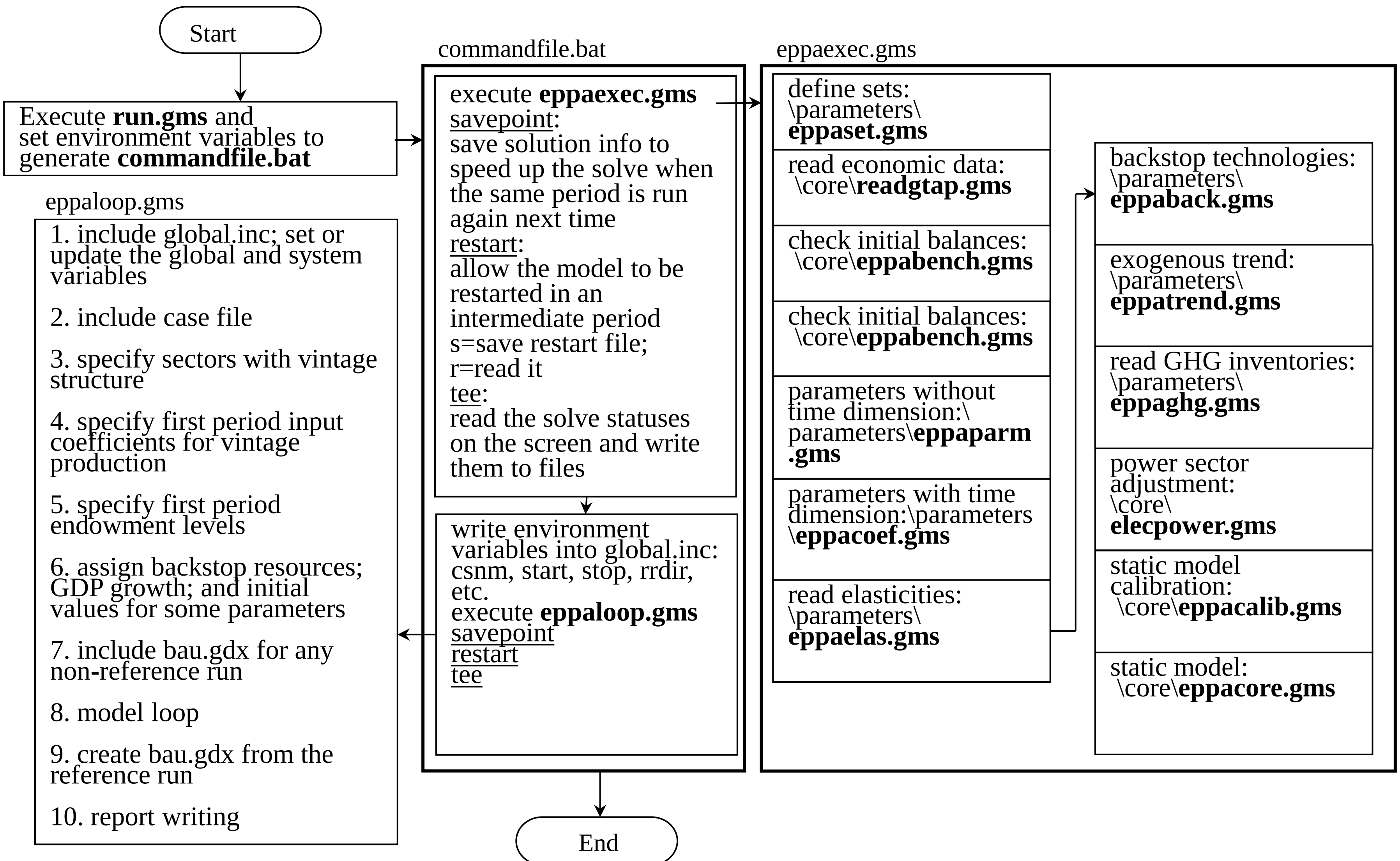
Exercises


parameter
region
Sum of value
Global GDP
Billion US$
120000
100000
80000
60000
40000
20000
0
2010
2015
2020
2025
2030
year
Total
region
Sum of value
Global Fossil Fuels Consumption
EJ
800
600
400
200
0
parameter
17_gas (EJ)
16_oil (EJ)
15_coal (EJ)
Global Consumption
GHGs Emissions
Million ton
109_CO2_total (million ton)
115_CO2eq_total (million ton)

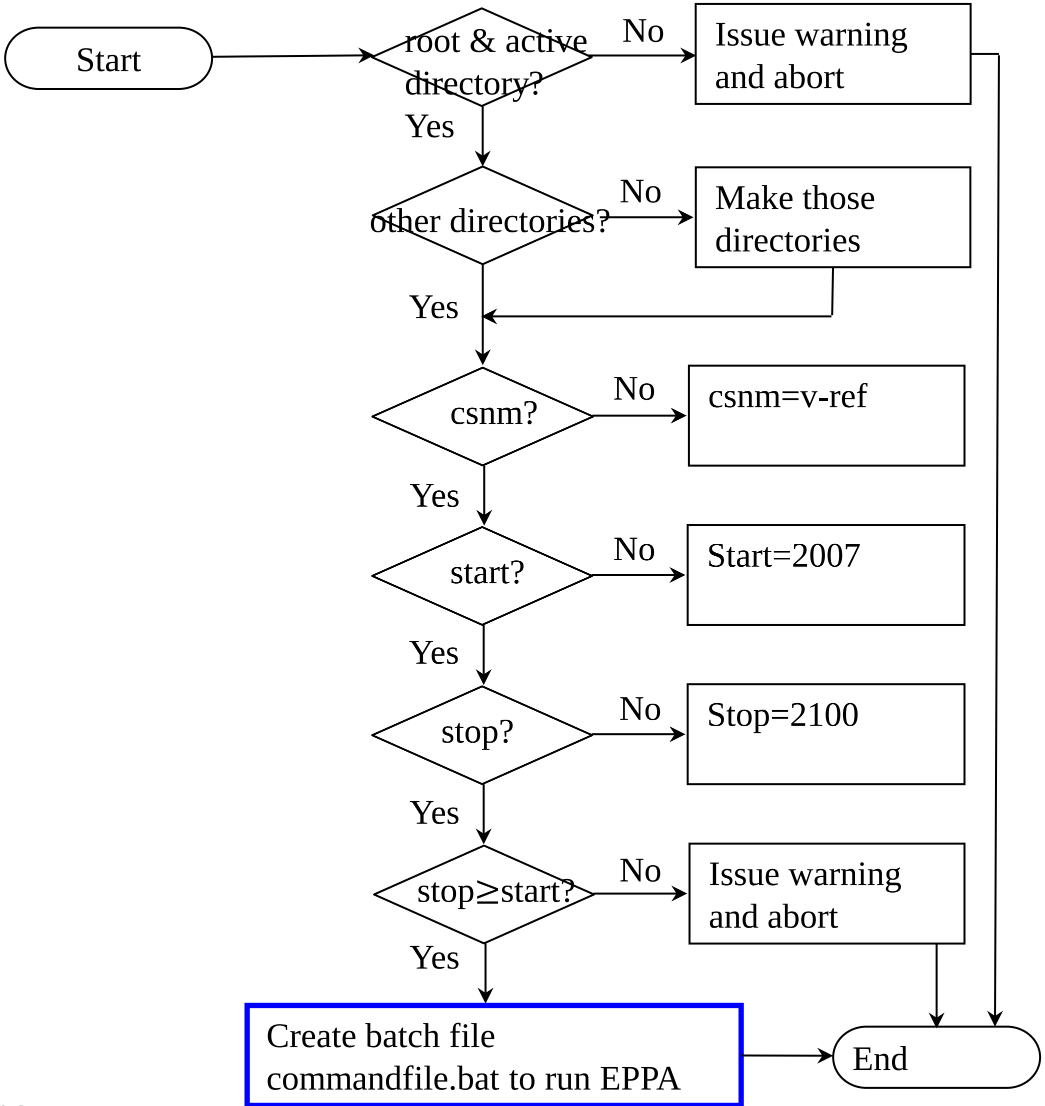
Exercises

- To become an advanced user or a model developer…
  - ChangLog.md; DEVELOPERS.md; README.md
  - Understand the model structure (this is crucial!)

Exercises

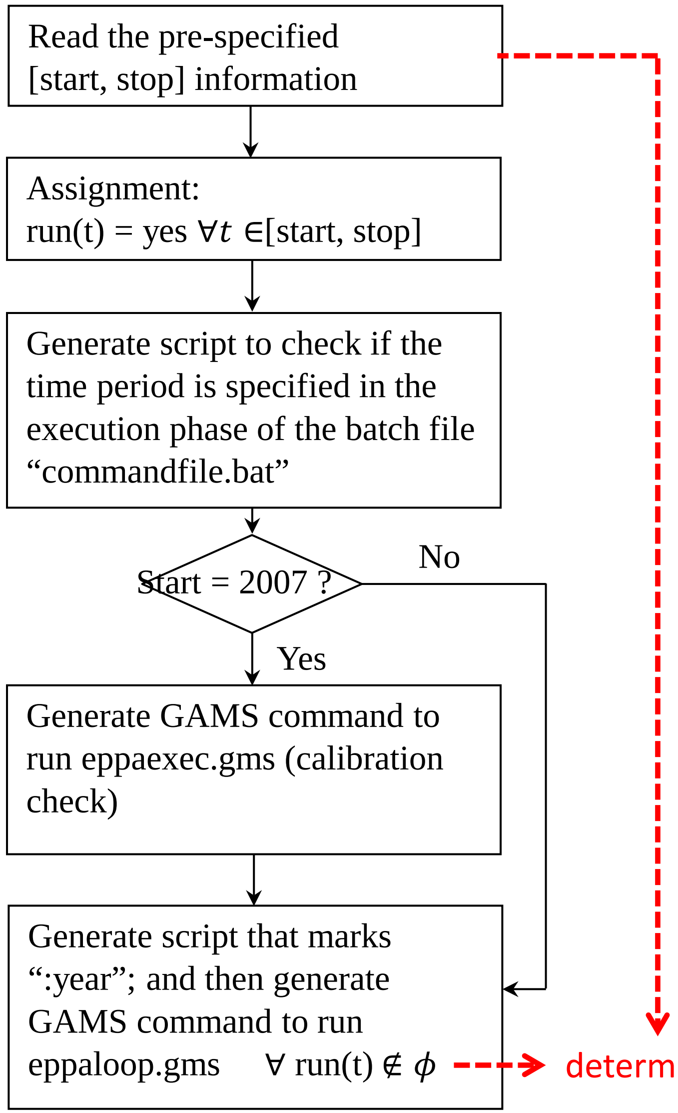

Start
Execute **run.gms** and set environment variables to generate **commandfile.bat**
eppaloop.gms
1. include global.inc; set or update the global and system variables
2. include case file
3. specify sectors with vintage structure
4. specify first period input coefficients for vintage production
5. specify first period endowment levels
6. assign backstop resources; GDP growth; and initial values for some parameters
7. include bau.gdx for any non-reference run
8. model loop
9. create bau.gdx from the reference run
10. report writing
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
End
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**
power sector adjustment: \core\ **elecpower.gms**
static model calibration: \core\ **eppacalib.gms**
static model: \core\ **eppacore.gms**

Exercises



run.gms

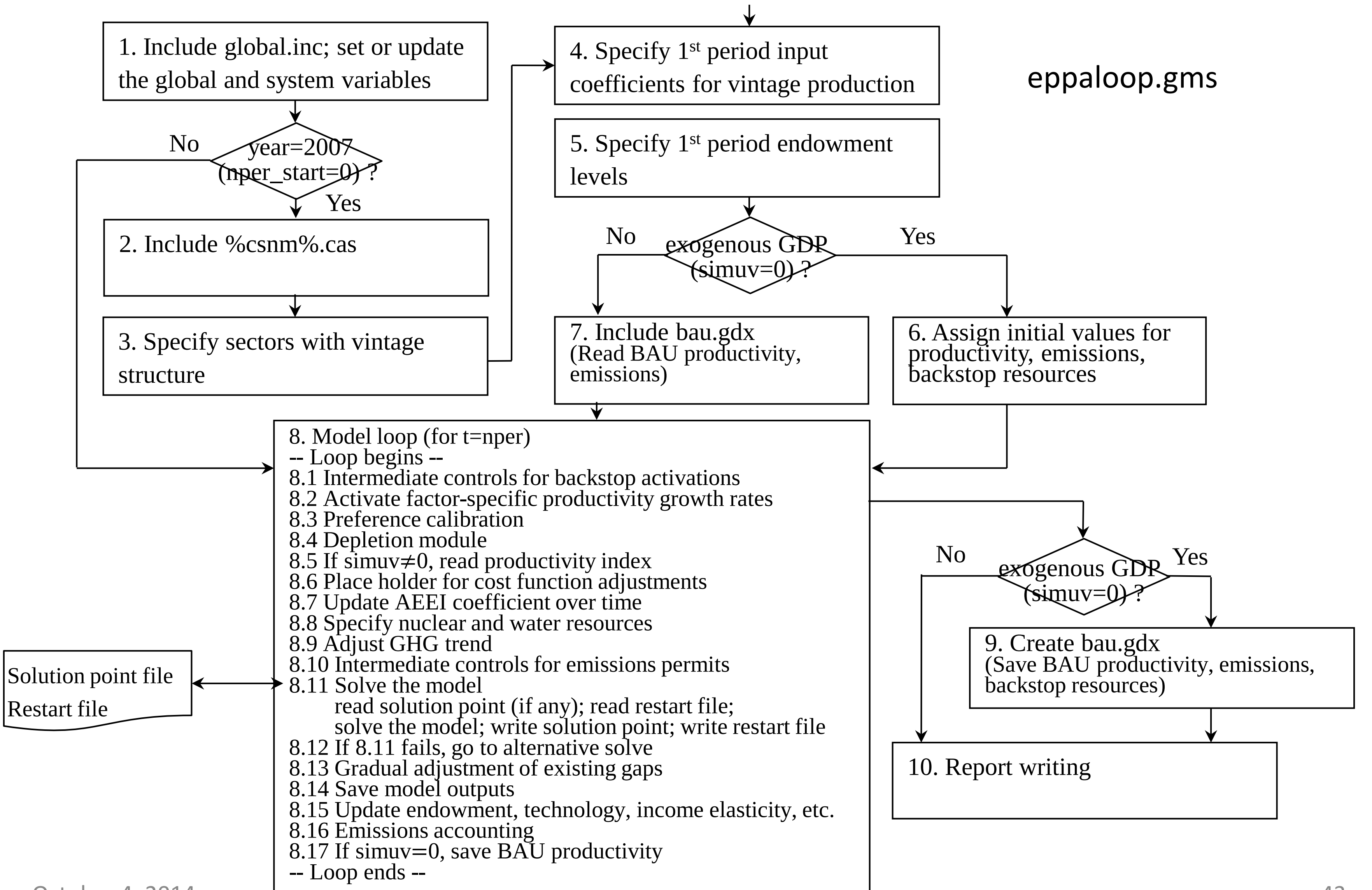
Exercises



Part of run.gms (blue box of the last slide): how commandfile.bat is created

determines how many periods will be run

Exercises


1. Include global.inc; set or update the global and system variables
year=2007 (nper_start=0) ?
No
Yes
2. Include %csnm%.cas
3. Specify sectors with vintage structure
4. Specify 1st period input coefficients for vintage production
eppaloop.gms
5. Specify 1st period endowment levels
exogenous GDP (simuv=0) ?
No
Yes
7. Include bau.gdx (Read BAU productivity, emissions)
6. Assign initial values for productivity, emissions, backstop resources
8. Model loop (for t=nper)
-- Loop begins --
8.1 Intermediate controls for backstop activations
8.2 Activate factor-specific productivity growth rates
8.3 Preference calibration
8.4 Depletion module
8.5 If simuv≠0, read productivity index
8.6 Place holder for cost function adjustments
8.7 Update AEEI coefficient over time
8.8 Specify nuclear and water resources
8.9 Adjust GHG trend
8.10 Intermediate controls for emissions permits
8.11 Solve the model
read solution point (if any); read restart file;
solve the model; write solution point; write restart file
8.12 If 8.11 fails, go to alternative solve
8.13 Gradual adjustment of existing gaps
8.14 Save model outputs
8.15 Update endowment, technology, income elasticity, etc.
8.16 Emissions accounting
8.17 If simuv=0, save BAU productivity
-- Loop ends --
Solution point file
Restart file
exogenous GDP (simuv=0) ?
No
Yes
9. Create bau.gdx (Save BAU productivity, emissions, backstop resources)
10. Report writing

Exercises

- 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

Exercises

- Exercise 2: Understanding the case files
  - Open v-ref.cas (case file for the reference scenario)
  - Where is the place for setting the availability of backstop technologies?
  - When a backstop technology becomes available (technically feasible), will it produce some output immediately (economically feasible)?
  - Any additional assumption?

Exercises

```
set     available(*,r,t)        Periods in which technologies or policies are available;

available("windbio",r,t)      = yes$(t.val ge 2010);
available("windgas",r,t)      = yes$(t.val ge 2010);
available("wind",r,t)         = yes$(t.val ge 2010);
available("bioelec",r,t)      = yes$(t.val ge 2015);
available("bio-oil",r,t)      = yes$(t.val ge 2015);
available("bio-fg",r,t)       = yes$(t.val ge 2007);
available("biotrade",r,t)     = yes$(t.val ge 2101);
available("solar",r,t)        = yes$(t.val ge 2010);
available("synf-oil",r,t)     = yes$(t.val ge 2015);
available("synf-gas",r,t)     = yes$(t.val ge 2015);
available("h2",r,t)           = yes$(t.val ge 2020);
available("windbio",r,t)      = yes$(t.val ge 2010);
available("windgas",r,t)      = yes$(t.val ge 2010);
available("ngcc",r,t)         = yes$(t.val ge 2015);
available("ngcap",r,t)        = yes$(t.val ge 2020);
available("igcap",r,t)        = yes$(t.val ge 2020);
available("adv-nucl",r,t)     = yes$(t.val ge 2020);
available("cafe","usa",t)     = yes$(t.val ge 2110);
available("limcoalf","usa",t) = yes$(t.val ge 2010);
available("limcoalf","eur",t) = yes$(t.val ge 2010);
available("coalmkup",r,t)     = yes$(t.val ge 2010);
```

Exercises

- Exercise 3: Replicating the reference run
  - Open baseline.cas (case file for the reference scenario)
  - Any differences between baseline.cas and v-ref.cas?
  - Run baseline.cas
  - Compare GDP results from baseline.cas and v-ref.cas

Exercises

```
* ..\active\v-ref.cas
$TITLE  EPPA6 --- Baseline scenario

* Use simuv to run exogenous BAU GDP: exogenous GDP = 0; endogenous GDP = 1

$setglobal simuv 0
simu = %simuv%;
```

```
* ..\active\baseline.cas
$TITLE  EPPA6 --- Baseline scenario

* Use simuv to run exogenous BAU GDP: exogenous GDP = 0; endogenous GDP = 1

$setglobal simuv 1
simu = %simuv%;
```

Exercises

- Remember that *v-ref.cas* is using a given GDP profile to calibrate TFP, while *baseline.cas* is treating the calibrated TFP as given and endogenously calculating GDP.
- With a higher level of numerical precision by taking more decimal points, you may find there are tiny differences between numbers from the two cases, but that is simply due to numerical reasons such as rounding errors, etc.

billion US$	Global GDP: v-ref.cas	Global GDP: baseline.cas
2010	57634.91	57634.91
2015	67036.90	67036.90
2020	80262.71	80262.70
2025	93768.04	93768.04
2030	108192.74	108192.74

Exercises

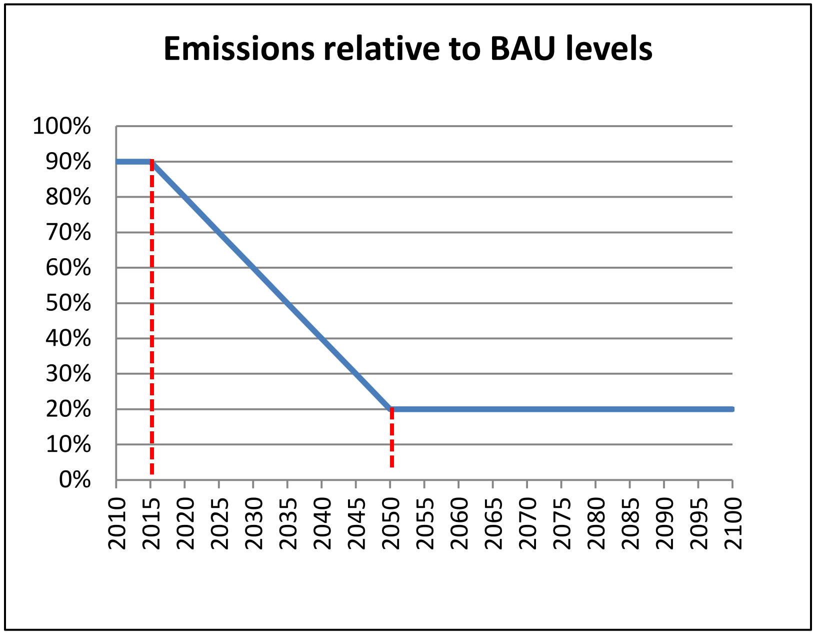
- Exercise 4: Creating the policy run
  - Open policy.cas (case file for the policy scenario)
  - Treating the calibrated TFP as given and endogenously calculating GDP
  - What kind of policy is imposed?
  - When will be the policy in place?
  - Run policy.cas up to 2030
  - What is the impacts on GDP, emissions, and energy use?

Exercises

```
* flag for CO2 policy on cement/eint emissions and (if applicable) deforestation emissions

cflagf(r,t)$(t.val ge 2015)      = yes;

* flag for non-tradable (national) CO2 permit: co2cf(r,t) controls the on and off for co2c(r) in eppaloop

co2cf(r,t)$(t.val ge 2015)       = yes;


* Emissions reduction relative to 2010 levels (target: 50% of 2000 levels for combustion CO2)
* Rigorously, for each GHGs and urban gases, their target tables need to be re-assigned

table ert(t,r) emissions ratio table

        usa     can     mex     jpn     anz     eur     roe     rus     asi     chn     ind
2010    1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
2015    0.900   0.900   0.900   0.900   0.900   0.900   0.900   0.900   0.900   0.900   0.900
2020    0.826   0.826   0.826   0.826   0.826   0.826   0.826   0.826   0.826   0.826   0.826
2025    0.752   0.752   0.752   0.752   0.752   0.752   0.752   0.752   0.752   0.752   0.752
2030    0.678   0.678   0.678   0.678   0.678   0.678   0.678   0.678   0.678   0.678   0.678
2035    0.604   0.604   0.604   0.604   0.604   0.604   0.604   0.604   0.604   0.604   0.604
2040    0.530   0.530   0.530   0.530   0.530   0.530   0.530   0.530   0.530   0.530   0.530
2045    0.456   0.456   0.456   0.456   0.456   0.456   0.456   0.456   0.456   0.456   0.456
2050    0.381   0.381   0.381   0.381   0.381   0.381   0.381   0.381   0.381   0.381   0.381
```

Exercises

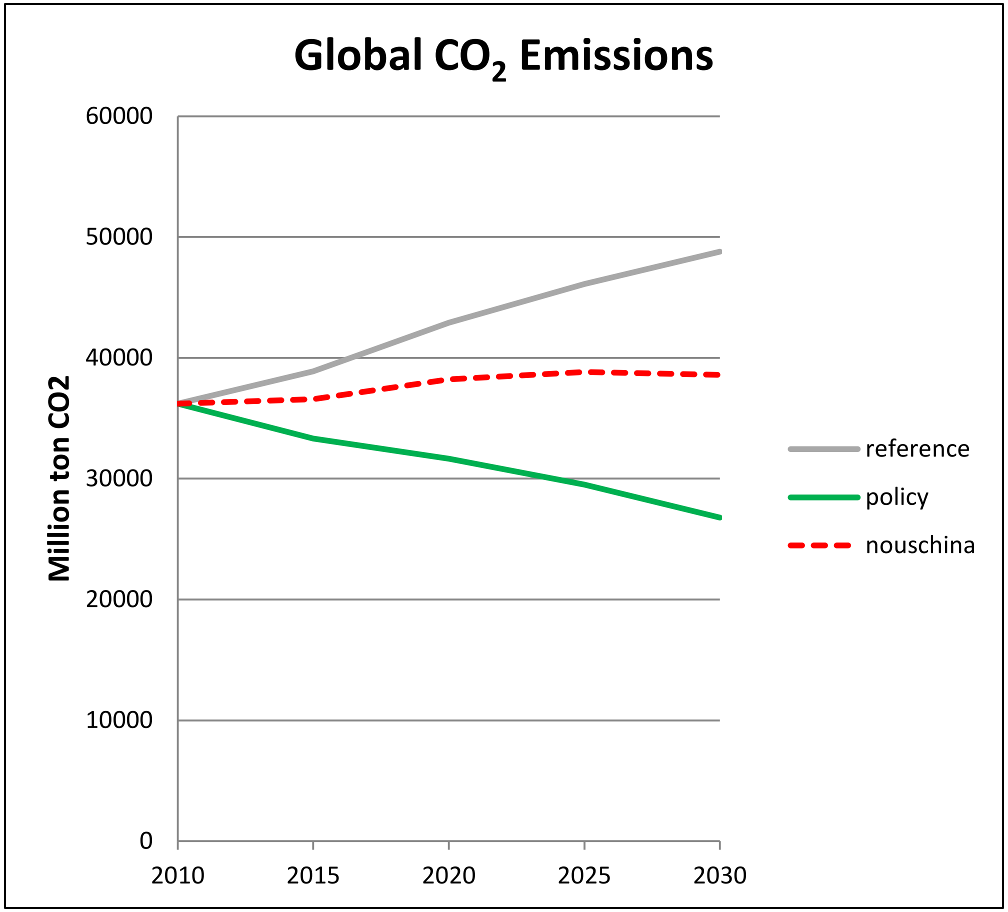
- Inside policy.cas, we have:
  - co2cf(r,t)$(t.val ge 2015) = yes;
  - cflagf(r,t)$(t.val ge 2015) = yes;
  - table ert(t,r): Emissions relative to BAU levels



Exercises

- Exercise 5: Roles of the US and China
  - Save policy.cas as a new case file named "nouschina.cas" to work on
  - Implement the same carbon policy on all regions except for China and US (Hint: flags for controlling the carbon policy implementation in these two regions need to be changed)
  - Run the case newpolicy.cas up to 2030
  - Compared the CO_2 emissions levels with those from baseline.cas and policy.cas

Exercises



Global CO_2 Emissions
Million ton CO2
60000
50000
40000
30000
20000
10000
0
2010
2015
2020
2025
2030
reference
policy
nouschina

Exercises

- Exercise 6: A small uncertainty analysis
  - Taking the US for instance and considering the time horizon up to 2030, if, starting from 2015, the annual US population growth is 1% higher (e.g. 1.4% -> 2.4%) or 1% lower (1.4% -> 0.4%) until 2030, compared to the original population growth profile, what would be the implications on the business-as-usual (reference) GDP growth and CO_2 emissions?
  - If the given CO_2 cap in the case file is only implemented in the U.S., what will be the CO_2 prices overtime under the above three population growth assumptions?
  - See hints in the next two slides before proceeding!

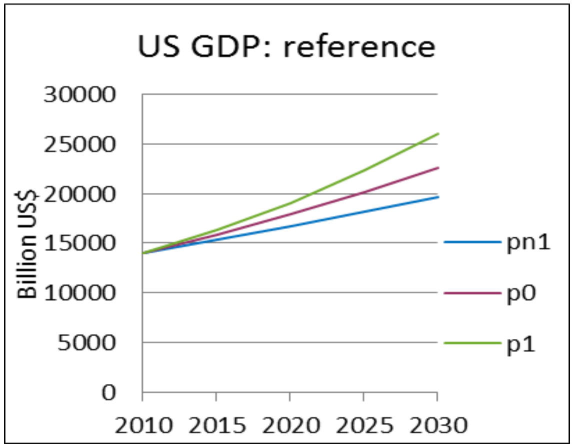
Exercises

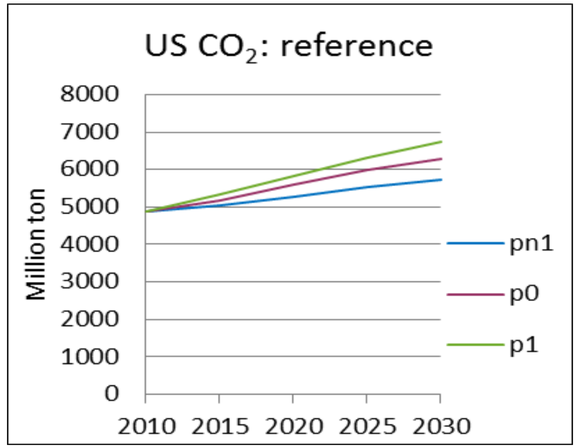
- Hint: I have put ±1% population growth parameterizations in each case file, i.e., a single case file can produce different population growth profiles.
- type ***gams run --csnm=baseline*** *--start=2007* ***--stop=2030*** ***--popg=p1*** to produce the "commandfile" for the reference case with "+1%" population growth profile
- type ***commandfile*** for running the model, and check the EXCEL and GDX outputs
- type ***gams run --csnm=baseline*** *--start=2007* ***--stop=2030*** ***--popg=pn1*** to produce the "commandfile" for the reference case with "-1%" population growth profile
- type ***commandfile*** for running the model, and check the EXCEL and GDX outputs
- Remember the reference case with benchmark population growth is produced in Exercise 3 (by default popg=p0)
- Save policy.cas as a new case file named "uspolicy.cas" to work on, revise the case file to implement a US-only carbon policy.
- One more thing we need to do before running the model: you need to revise the setting of labor(r)$(ord(t) gt 1) in subsection 8.15 of eppaloop.gms.

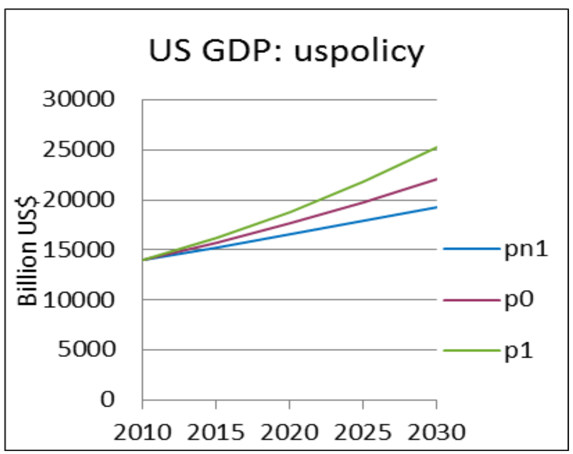
Exercises

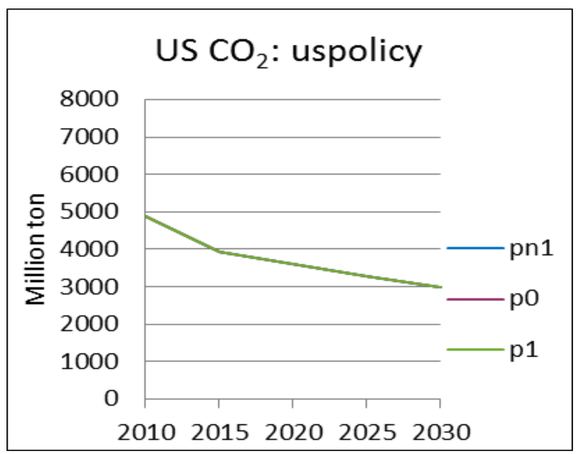
- Now, follow the same procedure in the previous slides, let us produce the respective commandfile for popg=pn1, popg=p0, and popg=p1
- You can extract data from 6 EXCEL files or 6 GDX files. But that could be cumbersome!
- I will show you a routine for merging the 6 GDX files into a single one in \tools\gdxaggr\

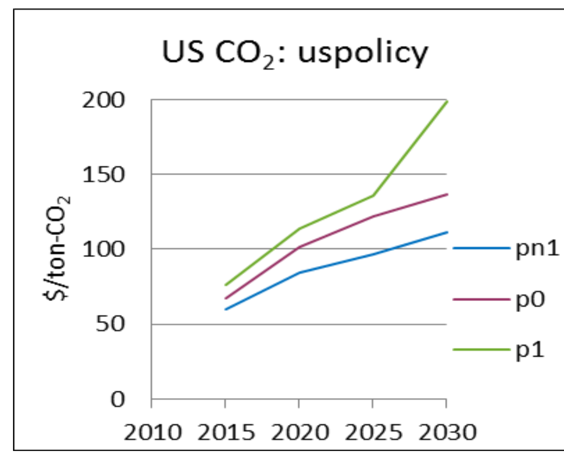
Exercises


US GDP: reference
Billion US$
30000
25000
20000
15000
10000
5000
0
2010 2015 2020 2025 2030
pn1
p0
p1


US CO_2: reference
Million ton
8000
7000
6000
5000
4000
3000
2000
1000
0
2010 2015 2020 2025 2030
pn1
p0
p1


US GDP: uspolicy
Billion US$
30000
25000
20000
15000
10000
5000
0
2010 2015 2020 2025 2030
pn1
p0
p1


US CO_2: uspolicy
Million ton
8000
7000
6000
5000
4000
3000
2000
1000
0
2010 2015 2020 2025 2030
pn1
p0
p1


US CO_2: uspolicy
\$/ton-CO_2
200
150
100
50
0
2010 2015 2020 2025 2030
pn1
p0
p1

Exercises

- A CGE model has N equations with N endogenous variables
  - With one more constraint, there must be an additional “freed” variable
  - If CO_2 emission is exogenous (emission cap is given), then CO_2 price must be endogenous
  - If CO_2 price is exogenous (carbon price is given), then CO_2 emission must be endogenous
  - In our previous examples, we implement emissions caps, which means CO_2 prices are endogenously determined
  - We may also set up CO_2 prices exogenously, and in that case, the emissions levels will 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 (required: ChangeLog.md; JP technical Report)

Guidelines

The same structure (the top one is even more sophisticated – it has valued added taxes) but…

```
* 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

Bibliography

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Thank You!

Appendix

Urban pollutants:
- CO
- VOC
- NOx
- SO2
- BC
- OC
- NH3

Non-CO2 GHGs:
- CH4
- N2O
- PFC
- SF6
- HFC

Appendix

- SO2 (Gg); 2007

	CROP	FORS	FOOD	EINT	ROIL	COAL	GAS	FD
AFR	11.55	3193.26	9.68	1291.58	437.88	3064.73	0.40	665.46
ANZ	5.15	134.90	13.72	1966.66	115.78	717.94	0.01	85.38
ASI	42.86	14.76	11.88	1129.43	1449.68	1902.28	0.02	228.06
BRA	53.94	21.81	40.32	903.57	272.90	337.64	0.01	98.89
CAN	1.59	6.36	73.23	863.57	367.38	807.69	0.02	301.54
CHN	3.67	2.54	53.57	10649.53	2249.12	21204.20	0.03	1941.69
EUR	6.83	1.49	208.35	1982.45	2583.11	5095.40	0.05	993.72
IDZ	56.72	111.77	23.74	908.60	460.44	1036.05	0.03	125.15
IND	68.61	3.28	9.29	2033.41	135.82	4885.87	0.01	853.58
JPN	0.16	0.37	55.25	848.58	544.65	707.35	0.00	724.60
KOR	0.08	0.00	15.09	439.17	470.94	433.30	0.00	129.66
LAM	30.61	63.11	17.70	2533.60	586.83	1918.04	0.06	204.67
MES	2.26	0.07	1.34	1539.21	738.41	4373.51	0.33	322.36
MEX	5.24	3.11	6.60	190.88	120.22	1139.70	0.03	189.42
REA	77.24	159.38	1.81	911.45	238.85	1220.96	0.02	303.50
ROE	12.25	11.36	7.53	2666.63	256.39	3597.96	0.10	347.76
RUS	6.36	0.19	26.07	2826.78	259.36	2132.51	0.54	717.73
USA	6.57	1.46	235.25	1354.64	908.12	7856.95	0.02	157.00

Appendix

so2_a(r, g)

- if g≠ "roil", "coal", "gas" => ourb("so2",g,r)
- if g= "roil", "coal", "gas"
  - curb00("so2",e,"fd",r)= $so2\_a(r,g) \cdot \frac{efd(e,r)}{\left[\sum_i eind(e,i,r) + efd(e,r)\right]}$
  - curb00("so2",e,g,r)= $so2\_a(r,g) \cdot \frac{eind(e,g,r)}{\left[\sum_i eind(e,i,r) + efd(e,r)\right]}$

so2_a(r, "fd") => ourb("so2","fd",r) => hhurb("so2",t,r) => household emissions with exogenous trends