Going from Static to Dynamic CGE Models

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Outline

1. Going from a static to a dynamic CGE model – the basics
2. A simple 2x2 recursive-dynamic model
3. Exercise: Introduction of a stylized climate policy
4. Other elements of dynamics included in EPPA
5. Tomorrow: introduction of an advanced technology backstop

Why dynamics ?

We want to capture the **dynamic structure of the economy**:

- Population, labor productivity, the capital stock and resource depletion change over time
- Activity in one period affects the availability of capital and resources in future periods
- Different regions or sectors may grow at different rates
- Penetration of new technologies takes time
- The impact of policies evolves over time

Dynamic modeling

Role of expectations in economic decision-making:

- **Recursive Dynamic CGE**
  - Myopic agents
  - Model is solved period after period *sequentially*

- **Forward-looking Dynamic CGE**
  - Each agent maximizes its inter-temporal utility or the present value of profits based on both current and expected future prices
  - All periods are solved *simultaneously*

We focus here on recursive-dynamic decision-making, i.e. we will consider a sequence of static models.

Key features of the dynamic process in the EPPA model

The following features of the EPPA capture the **dynamic characteristics** of the economy and energy system:

1 - Population growth
2 - Labor productivity growth
3 - Energy efficiency improvements
4 - Investments and capital accumulation
5 - Fossil fuel resource depletion
6 - Availability of advanced "backstop" energy supply technologies

In the model: 1-3 are "exogenous"; 4-6 are "endogenous"

Investment and capital accumulation (1)

We need to add to the model:

1 – an activity that "**supplies**" an investment good
2 - "**demand**" for investment

Investment supply:

Consider a closed economy model where savings (S) equal investment (I).

Assume a constant marginal propensity to save (s), i.e. a constant fraction of income (M) is allocated to savings:

$$I = S = s\,\frac{M}{P_I}$$

Investment and capital accumulation (2)

The capital stock (*KS*) accumulates according to:

$$KS_{t+1} = I_t + (1 - \delta)\, KS_t$$

Where δ is the depreciation rate of capital.

In the model, we do not track capital stocks but capital earnings (*K*), where:

$$K_t = \rho\, KS_t$$

ρ is the rate of return on capital.

Capital earnings thus increase according to:

$$K_{t+1} = \rho\, I_t + (1 - \delta)\, K_t$$

A simple 2 by 2 recursive-dynamic model

We now consider a simple illustrative recursive dynamic CGE model.

- Most EPPA versions are recursive dynamic

- **Today:** introduce a simple climate policy
- **Tomorrow:** introduce a backstop technology

- Model is in **2x2RD.gms**

2x2RD.gms - Recursive dynamics – model structure

```
$TITLE  Two-by-Two recursive dynamic CGE
..
$MODEL:M21
$SECTORS:
        X   ! Activity level of sector X
…
M21.ITERLIM = 0;
$INCLUDE M21.GEN
SOLVE M21 USING MCP;

SETS t /2010*2030/;

LOOP(t,

M21.iterlim = 1000;
$INCLUDE M21.GEN
SOLVE M21 USING MCP;

* report of time-specific parameters
OUT(t,"sec_X") = OX.L+eps;
..
* update labor and capital endowments
K = K*(1-delta)+ror*20*INV.L;
L = L*(1 + grate);
)
```

Define the static MPSGE model

Check benchmark calibration

Define number of time periods

For each time period,

1. Solve model
2. Report time-dependent results
3. Update capital and labor endowments

2x2RD.gms – The static model

The static model:

- All sectors are constant-return-to-scale (CRS)

- 2 sectors: X and Y
- 2 factors: L (labor) and K (capital), which move freely between sectors
  - X is relatively capital-intensive
  - Y is relatively labor-intensive
  - The production of X emits CO2, the production of Y does not

```
$PROD:X s:0          b:1
        O:PX           Q:100
        I:PL           Q:25        b:
        I:PK           Q:75        b:
        I:PC$policy    Q:25
```

```
$PROD:Y s:1
        O:PY           Q:100
        I:PL           Q:75
        I:PK           Q:25
```

2x2RD.gms - Investment

We add an "Investment" sector in the static model by declaring a new production activity and a new commodity:

```
$SECTORS:
     INV          ! Activity level of sector INV

$COMMODITIES:
     PINV         ! Price index of commodity INV

$PROD:INV
O:PINV       Q:20
I:PX         Q:20

$PROD:W s:0  s1(s):1
O:PW         Q:200
I:PX         Q:80      s1:
I:PY         Q:100     s1:
I:PINV       Q:20
```

Investment is a fixed share of consumption

Static model

- The Social Accounting Matrix (SAM) in the base year

Sector that "produces" investment

Sector that "produces" utility

	X	Y	INV	W	CONS
PX	100		-20	-80	
PY		100		-100	
PINV			20	-20	
PW				200	-200
PL	-25	-75			100
PK	-75	-25			100

Zero-profit condition for X : MC-MR >= 0 ; Q >= 0 ; (MC-MR)*Q = 0 ;

Market clearing condition for X : S-D >= 0 ; P >= 0 ; (S-D)*P = 0 ;

Income balance condition : Income = Expenditure

2x2RD.gms - Dynamics

Dynamics: the drivers of economic growth

- Population and labor productivity growth, which combined are assumed to have a growth rate of 1% (*grate*)
- Capital accumulation, subject to a depreciation rate of 1% (*delta*)

```
* labor and capital income at benchmark
L       = 100;
K       = 100;
* depreciation rate and rate of return on capital
delta   = 0.01;
ror     = 0.1;
* labor productivity and population growth rate
grate   = 0.01;
-- IN LOOP AFTER SOLVE:
* update labor and capital endowments
L = L*(1 + grate);
K = K*(1 - delta)+ror*20*INV.L;
```

Steady-state model

- The identities behind the SAM hold for the next period

	X	Y	INV	W	CONS
PX	100		-20	-80	
PY		100		-100	
PINV			20	-20	
PW				200	-200
PL	-25	-75			100
PK	-75	-25			100

```
K(2)  = K(1)*(1-0.01)+0.1*INV(1)  =  100*0.99+2  =  101
L(2)  = L(1)*(1+0.01)             =  101
```

	X	Y	INV	W	CONS
PX	101.00		-20.20	-80.80	
PY		101.00		-101.00	
PINV			20.20	-20.20	
PW				202.00	-202
PL	-25.25	-75.75			101
PK	-75.75	-25.25			101

Output

Reporting variables in MPSGE code:

```
$REPORT:
        V:OW          O:PW          PROD:W
        V:OX          O:PX          PROD:X
        V:OZ          O:PX          PROD:Z
        V:OY          O:PY          PROD:Y
        V:OINV        O:PINV        PROD:INV
```

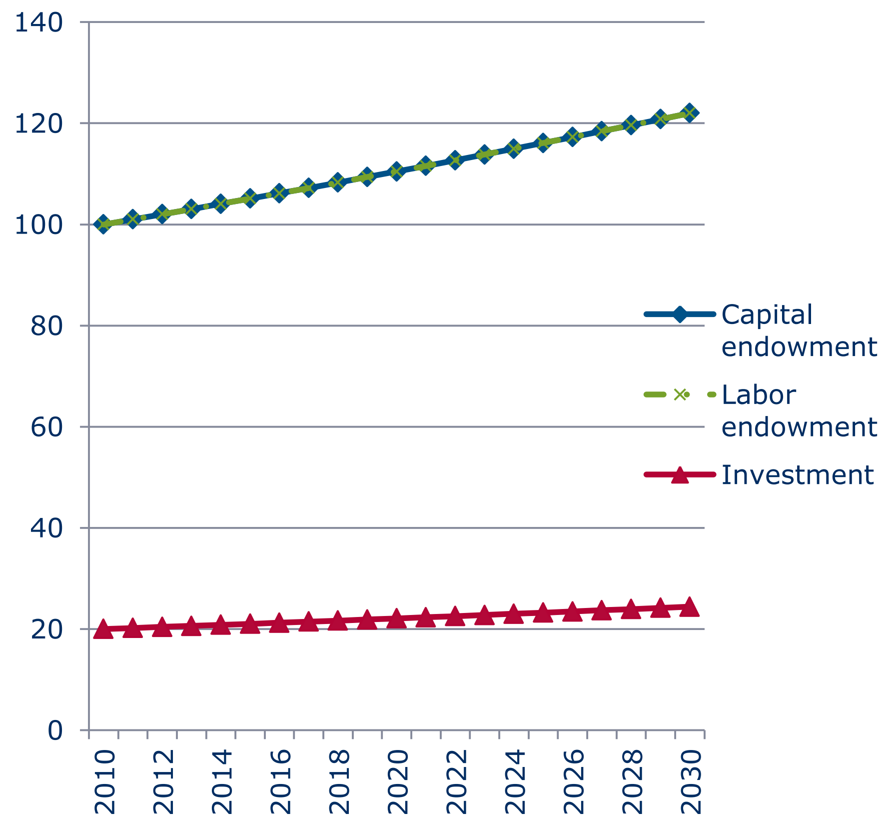
Track evolution of variables over time:

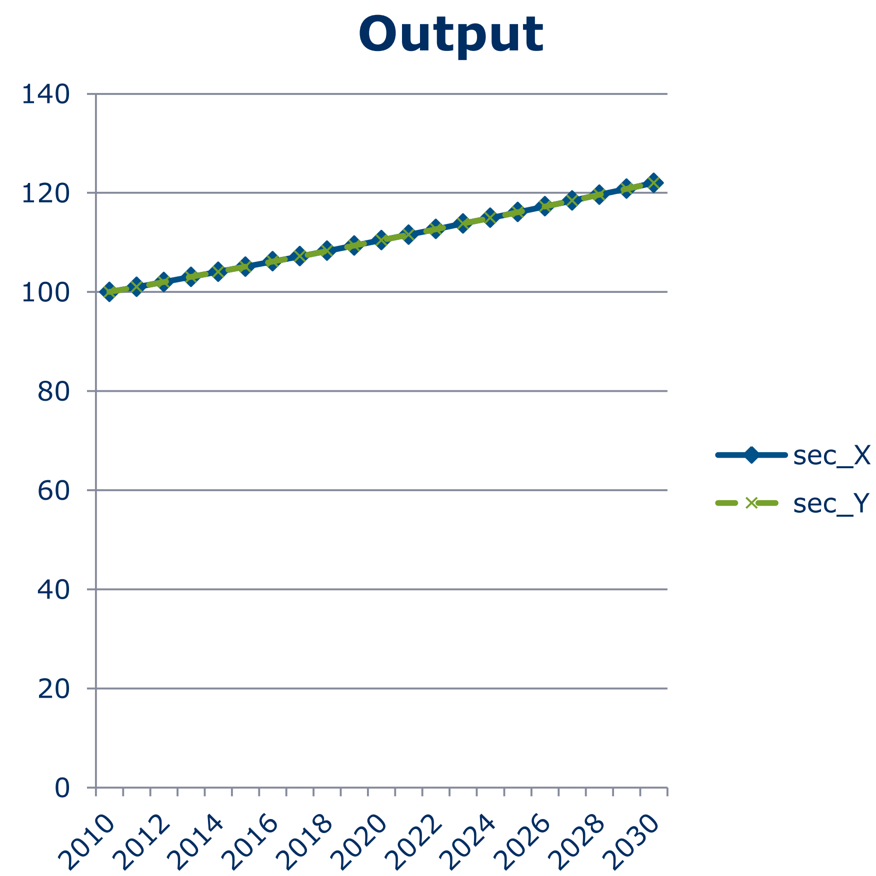
```
OUT(t,"sec_X") = OX.L+eps;
OUT(t,"sec_Z") = OZ.L+eps;
OUT(t,"sec_Y") = OY.L+eps;
CLIMbyt(t)     = CLIM+eps;
PCbyt(t)       = PC.L+eps;
PLbyt(t)       = PL.L+eps;
PKbyt(t)       = PK.L+eps;
Wbyt(t)        = OW.L+eps;
kbyt(t)        = K;
```

These parameters are dumped to **output.gdx**

Some results: steady state

- At steady-state, absent policy, factor endowments, production and investment all grow at 1% per year



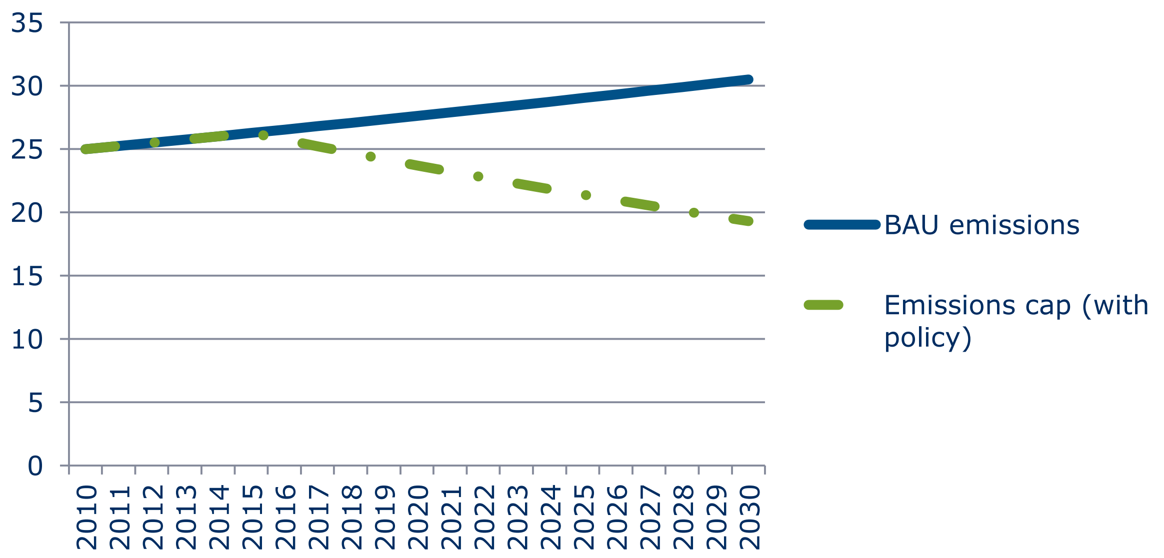


Introducing a simple climate policy

- CO2 emissions are priced in a cap-and-trade-like policy
- Policy enters from 2016 onward and reduces emissions by 3% annually relative to Business-as-Usual (BAU)

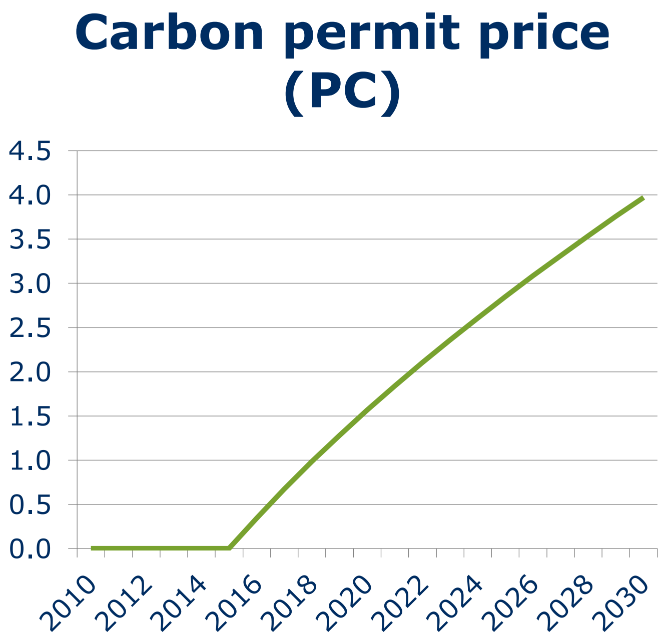
```
policy = yes$(t.val ge 2016);
•  reduce emissions by 3 % per year starting in 2016 (relative to BAU
   growth)

CLIM$policy    = CLIM*0.97;
```

} CLIM acts as a cap on total emissions

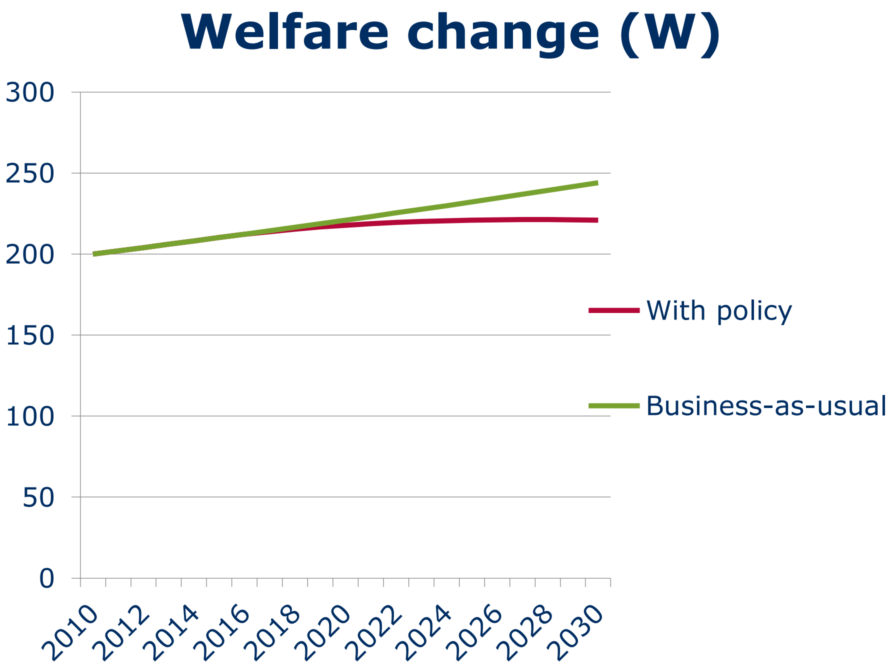


Impact of policy

- Gradually increasing carbon permit price
- Welfare (consumption) decreases



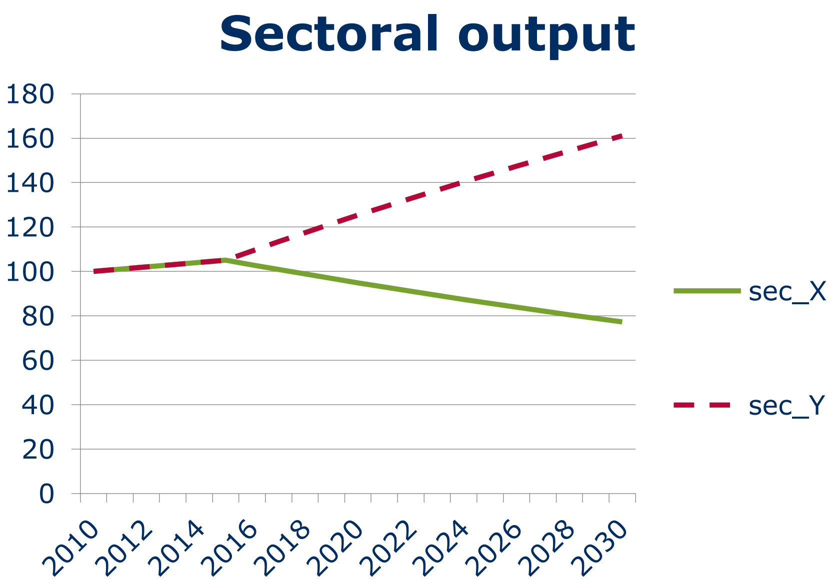
`Pcbyt` parameter



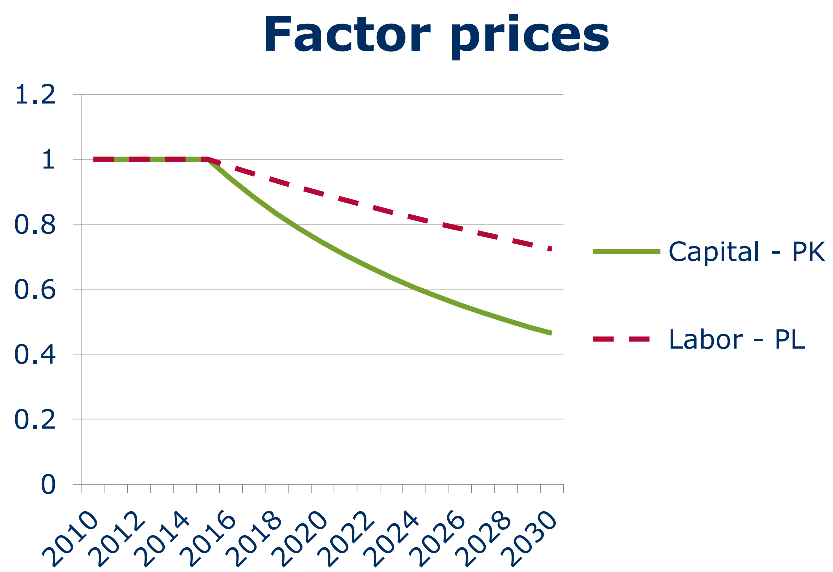
`Wbyt` parameter

Impact of policy

- Output of X relative to Y decreases
- Relative price of capital falls



`Out` parameter



`PLbyt` and `PKbyt` parameters

Dynamic model exercises (2x2rd.gms)

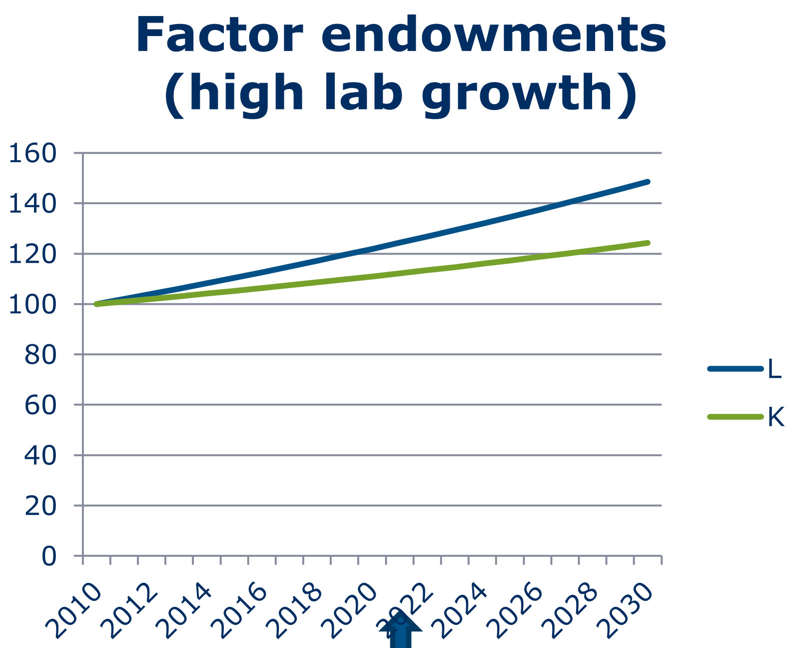
1. Implement the carbon policy starting in 2016 and replicate the results just shown.
2. Double the labor productivity growth rate, with and without policy. What happens?
3. Gradually reduce the CO_2 intensity of the X sector (AEEI – autonomous energy efficiency improvement) by 3% per year starting in 2023 - What happens to the CO_2 permit price ? To output ?

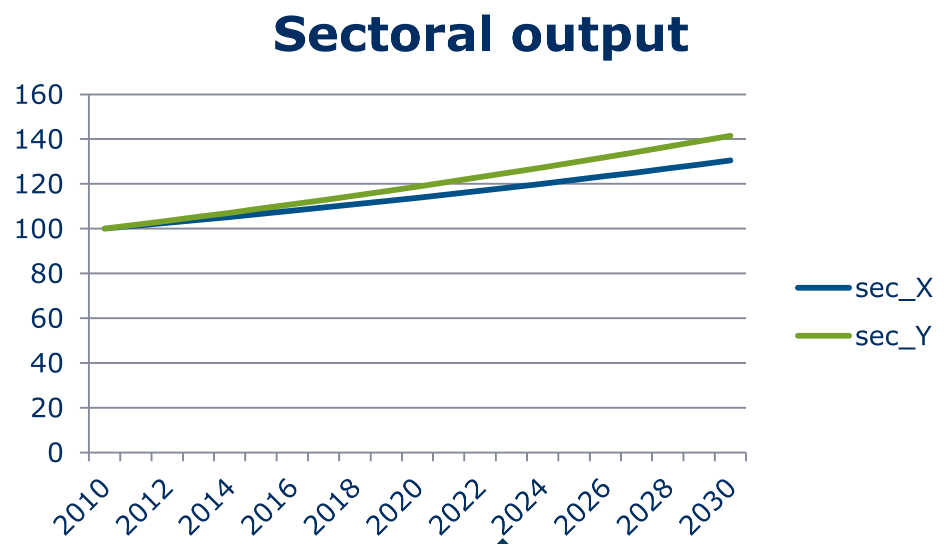
Dynamic model exercises (2x2rd.gms)

2. Double the labor productivity growth rate, with and without policy. What happens?

grate = 0.02;

No policy case:





Unbalanced growth

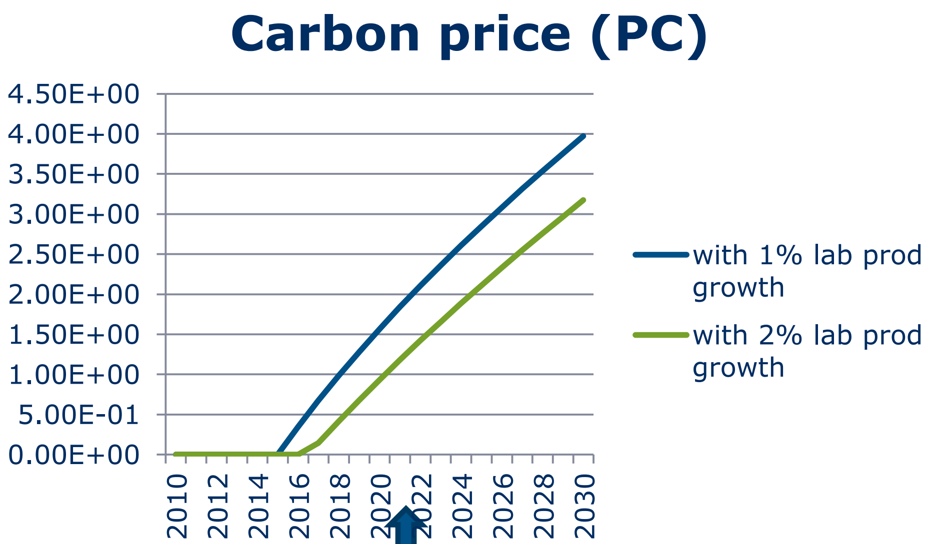
Output of both sectors increases, but higher growth of Y

Dynamic model exercises (2x2rd.gms)

2. Double the labor productivity growth rate, with and without policy. What happens?

grate = 0.02;

With policy



Less pressure on carbon cap

Dynamic model exercises (2x2rd.gms)

3. Gradually reduce the CO_2 intensity of the X sector (AEEI – autonomous energy efficiency improvement) by 1% per year starting in 2023 – what happens to the CO_2 permit price ? To output?

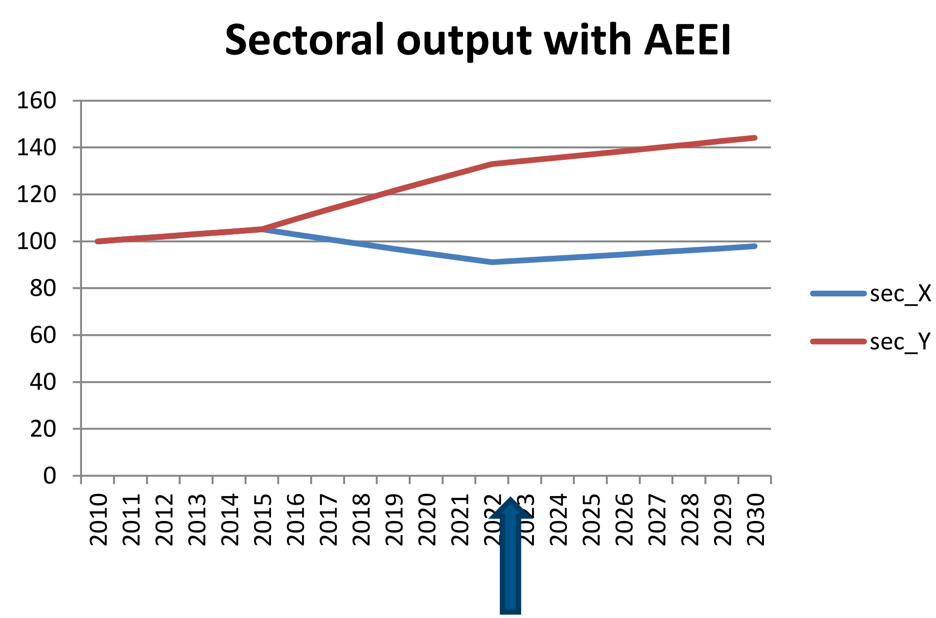
```
parameter aeei /1/;

..  In static model:

$PROD:X s:0          b:1
        O:PX         Q:100
        I:PL         Q:25       b:
        I:PK         Q:75       b:
        I:PC$policy  Q:(25*aeei)

 .. In loop:

aeei$(t.val ge 2023) = aeei / 1.03;
```

See 2x2RD_AEEI.gms

GLOBAL CHANGE

Dynamic model exercises (2x2rd.gms)

3. Gradually reduce the CO2 intensity of the X sector (AEEI – autonomous energy efficiency improvement) by 1% per year starting in 2023 – what happens to the CO2 permit price ? To output?



Reduces carbon price

But also increases output of X

More elements of dynamics present in EPPA

1 . Vintaging of the capital stock

- Only a proportion of the capital stock is mobile across sectors and some capital is "frozen" into existing production techniques.

2. Resource depletion

- The EPPA model incorporates empirical estimates of fossil fuel reserves by region
- Increased fossil fuel production reduces the amount of resources available in future periods

3. Consumption patterns evolve as income grows (non-homothetic preferences)

4. Backstop technologies: will be covered tomorrow!