ESCWA

United Nations Economic and Social Commission for Western Asia

Linking CGE model to pollution emission

What is a single country CGE model

What is a CGE model

Walrasian general equilibrium prevails when supply and demand are equalized across all of the interconnected markets in the economy.

CGE models are simulations that combine the abstract general equilibrium structure of Arrow and Debreu with realistic economic data to solve numerically.

CGE models are a standard tool of empirical analysis, and are widely used to analyze the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or contain menus

of different tax, subsidy, quota or transfer instruments.

CGE Standard Model Elements

- Input Output Economics & SAMs
- Behavioral Relationships/ Agents
  - Supply
  - Demand
  - Trade
- Government
- Pricing
- Policy – tax equivalents
- Closure
  - Accounting identities
  - Endogenous/exogenous variables
  - Macroeconomic assumptions
  - Exchange rate determination
- Solution
  - Equilibrium
  - Linearization
  - Percent change variables

CGE Standard Model Elements

- Calibration/Benchmarking
- Aggregation
  - Agents
  - Goods/Sectors
- Experiments
  - Welfare Measures
  - Projections
  - What if
- Extensions
  - Imperfect Competition, IRS
  - Product Differentiation
  - Dynamics
- Results Comparisons

Input-Output economics & SAMs

- Production= Intermediates + Value Added
- Production= Intermediate demand + Final Demand
- +
- Macroeconomic accounting identities to capture income flows, tax incidence, trade and payments, and savings-investment balances
- = > SAMs capture `circular flow' of income and expenditure

Input-Output economics & SAMs

- A social accounting matrix to benchmark (calibrate) a model and to represent relevant accounting identities.

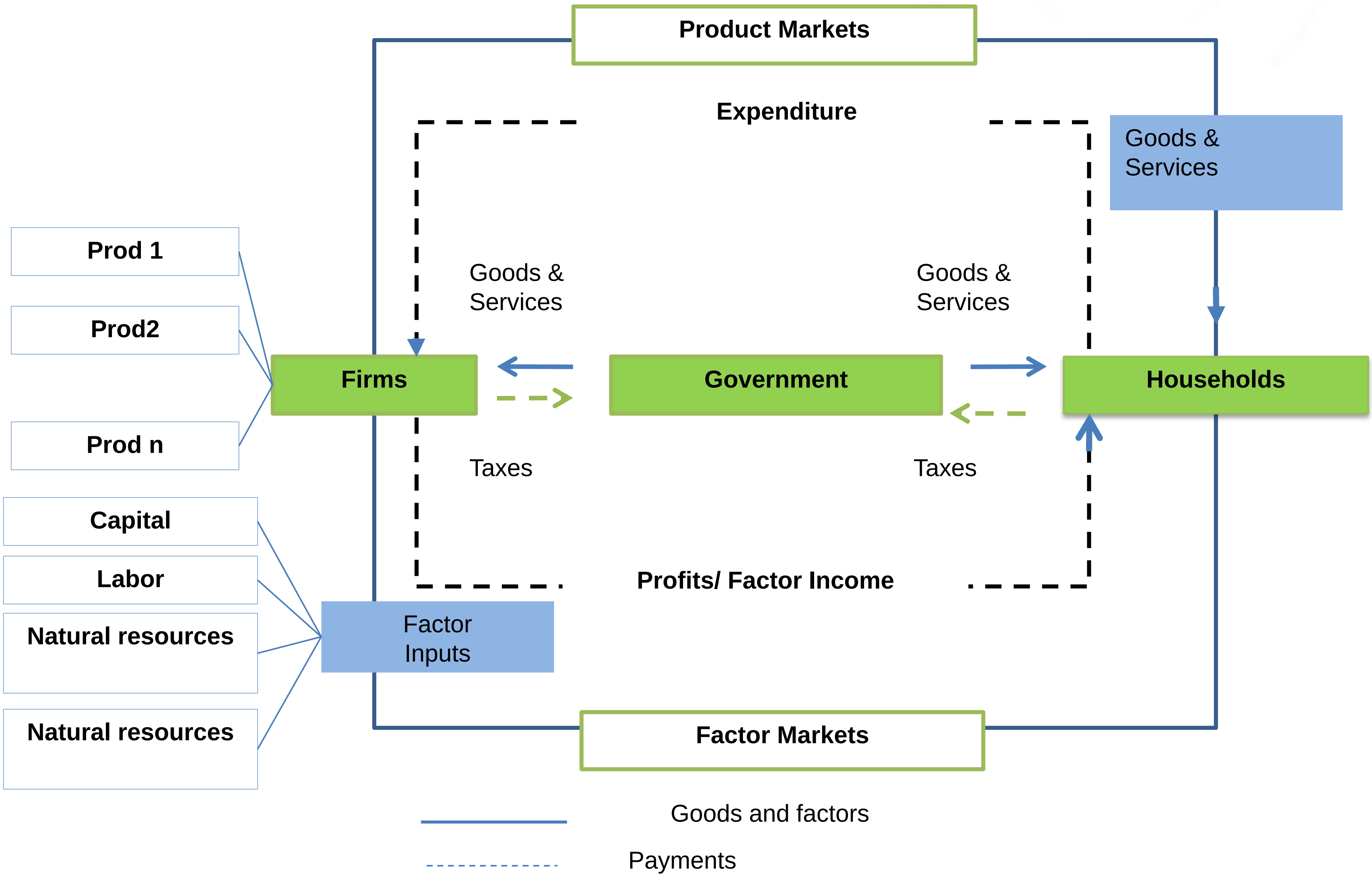
- SAMs capture equilibrium conditions
- Walras' law applies

Decision Making and Institutions

- Linkages in SAMs are accounted for by modelling the decision-making process of the firm, the consumer, as well as other economic agents and institutions: production and demand structure
- Trade results from that decision-making processes and their interaction with institutions:
- Production- Exports + Imports=Consumption

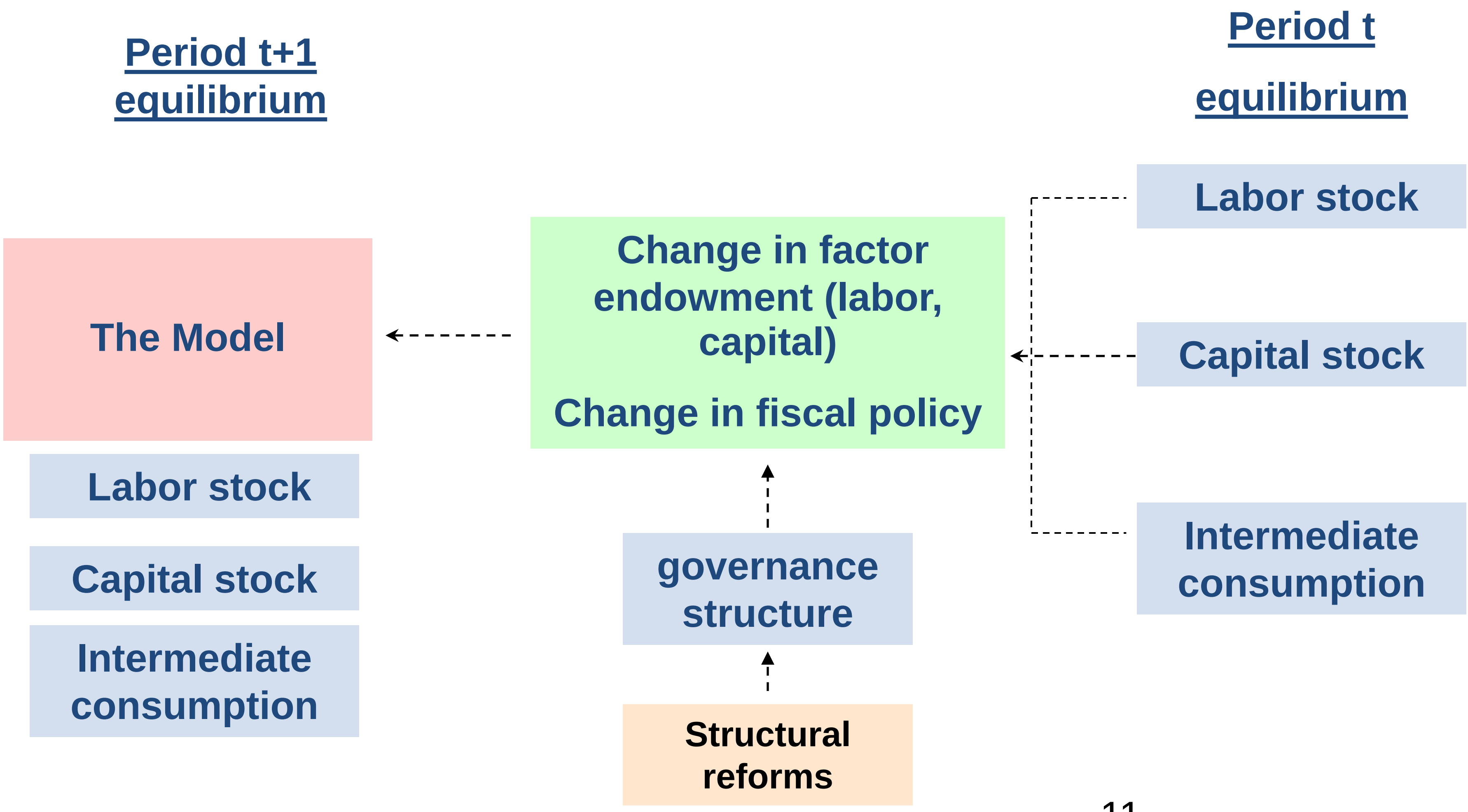
Closing the Model

- Need to define a numéraire (walras law allows to “drop” one market)
- Assumption about the adjustment mechanism in factor and commodity markets
- Macro closure
  - Macro accounting balance (gvt expenditure and deficit; aggregate saving and investment; balance of trade and -real- exchange rate)
  - Macro adjustment mechanism (exogenously determined)


Product Markets
Expenditure
Goods & Services
Prod 1
Prod2
Prod n
Goods & Services
Goods & Services
Firms
Government
Households
Taxes
Taxes
Capital
Labor
Natural resources
Natural resources
Profits/ Factor Income
Factor Inputs
Factor Markets
Goods and factors
Payments

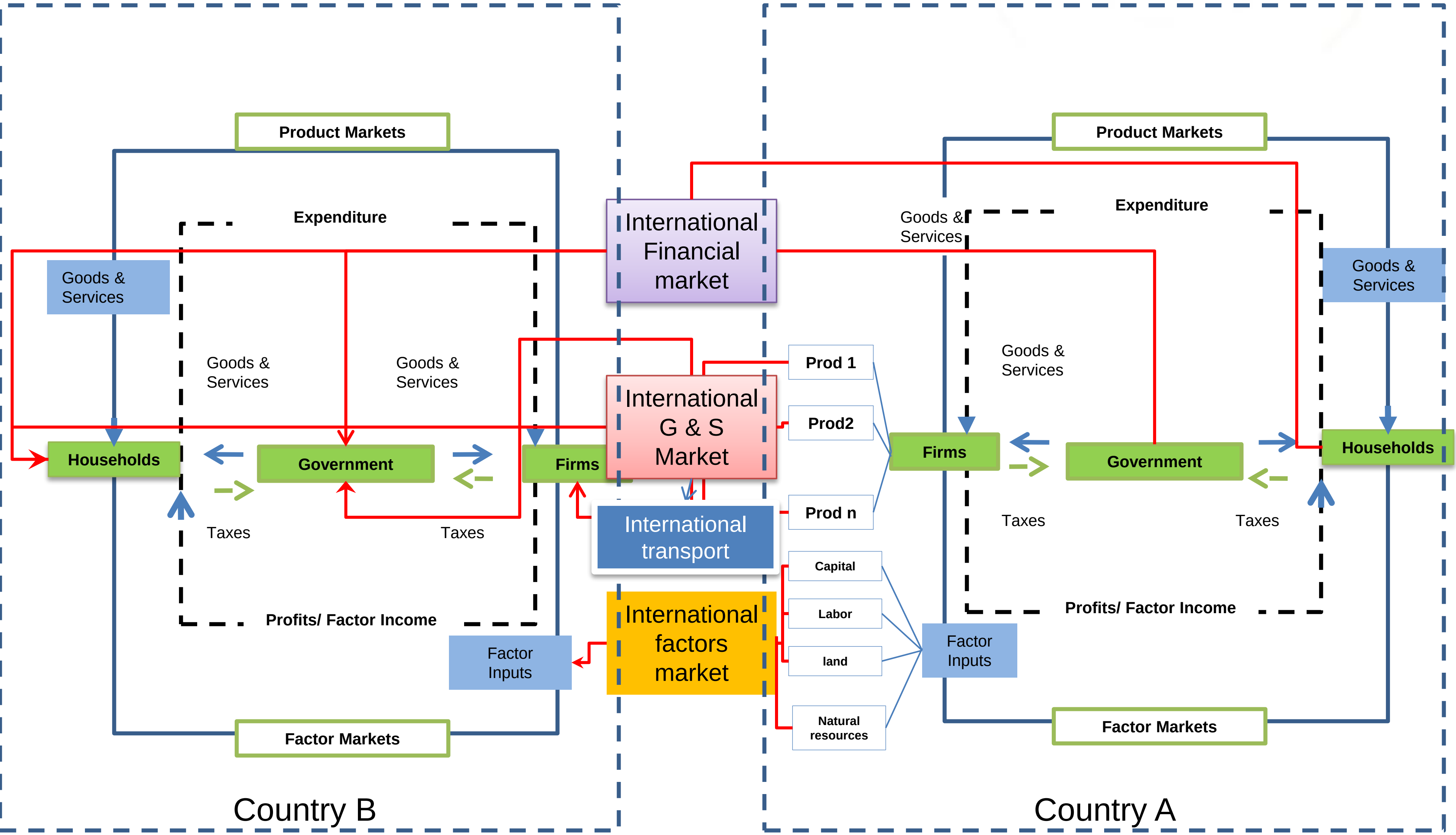
CGE Dynamic Models

- Recursive:



Mirage **Global** CGE model

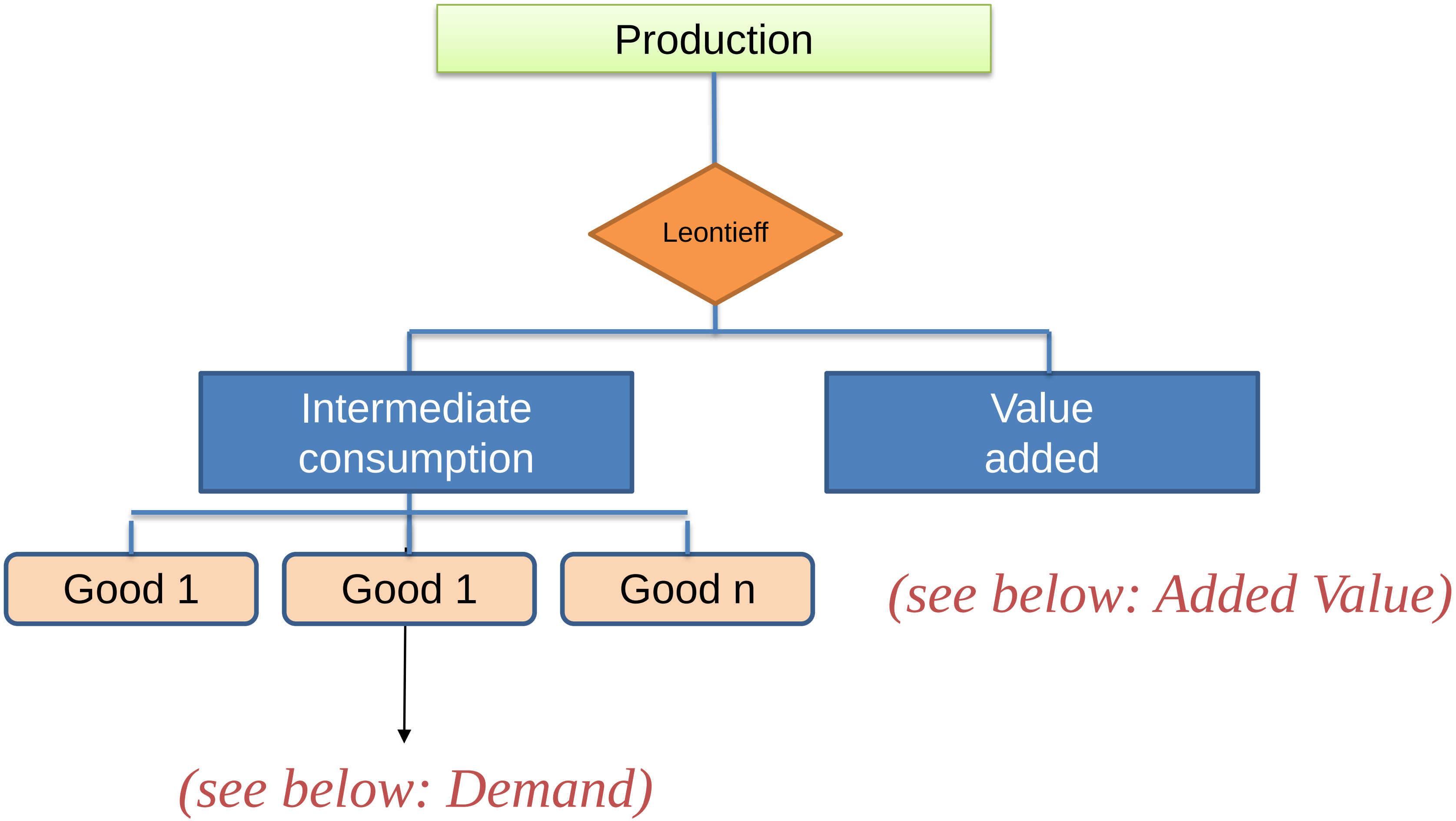
What is a Global CGE model: A 2 countries model



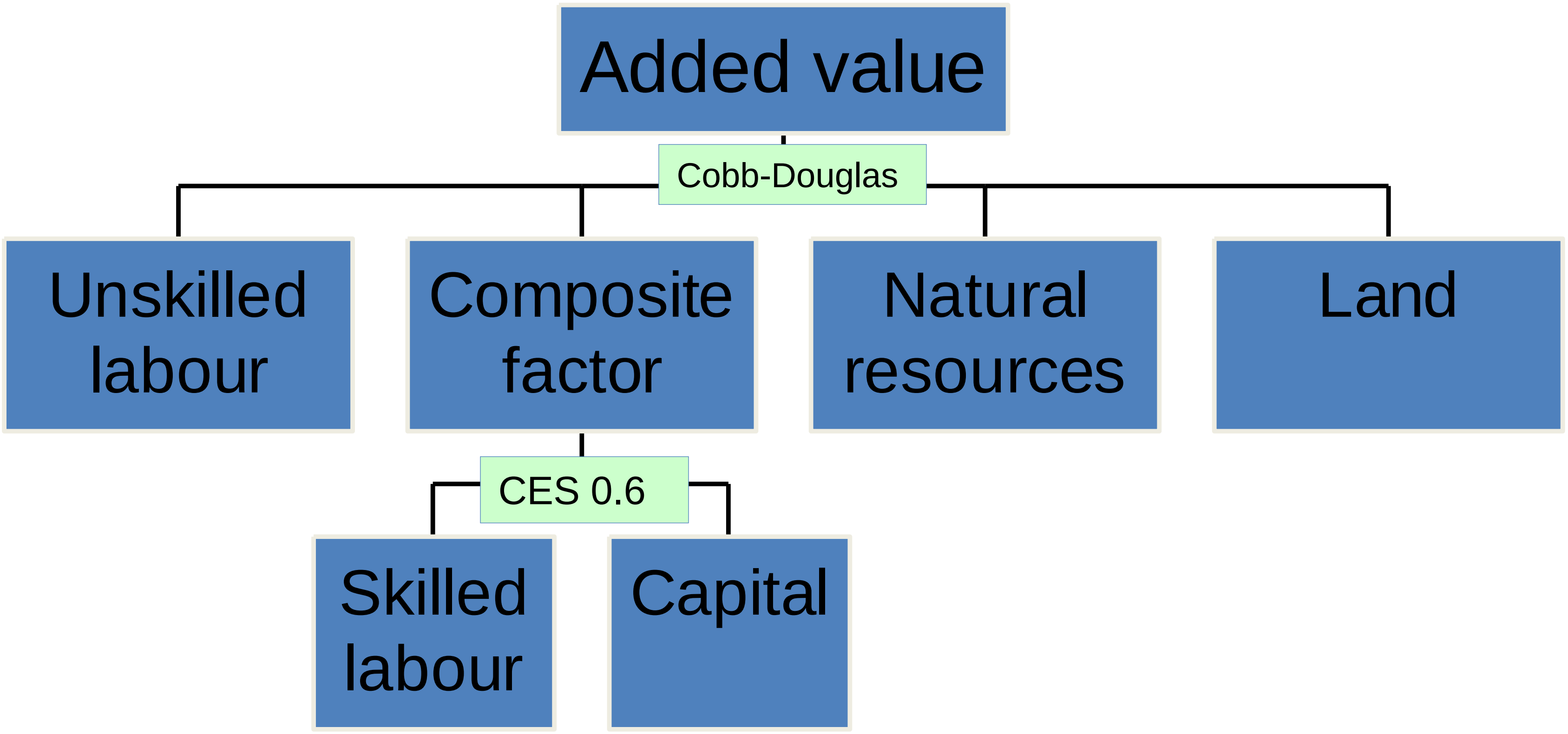
Data

- MIRAGE calibration is computed based on data of a base year supposed to typify the long run equilibrium.
- GTAP 8 data (year 2007): this database features production, trade flow and tax data in 2007.
- An adjustable regional and sectoral disaggregation.
- Trade restrictions from MAcMap — ‘Market ACcess Maps’ (year 2001) & the CTS database
- Aggregator: BACI (from COMTRADE)
- Internal support: GTAP, OECD, national sources

Supply (1)


Production
Leontieff
Intermediate consumption
Value added
Good 1
Good 1
Good n
(see below: Added Value)
(see below: Demand)

Supply (2)


Added value
Cobb-Douglas
Unskilled labour
Composite factor
Natural resources
Land
CES 0.6
Skilled labour
Capital

Production factors

- Skilled labour, Unskilled labour are perfectly mobile among sectors.Relative (Skilled/unskilled) endowment fixed, absolute endowment grow at exogenous rate
- Land is imperfectly mobile among sectors. Land supply endogenous: depends on land return. Elasticity of supply varies across countries.
- Natural resources are specific and constant.
- Capital is sector-specific and accumulative. Financial capital is not mobile among regions. Capital is mobile across regions through FDI.

Demand

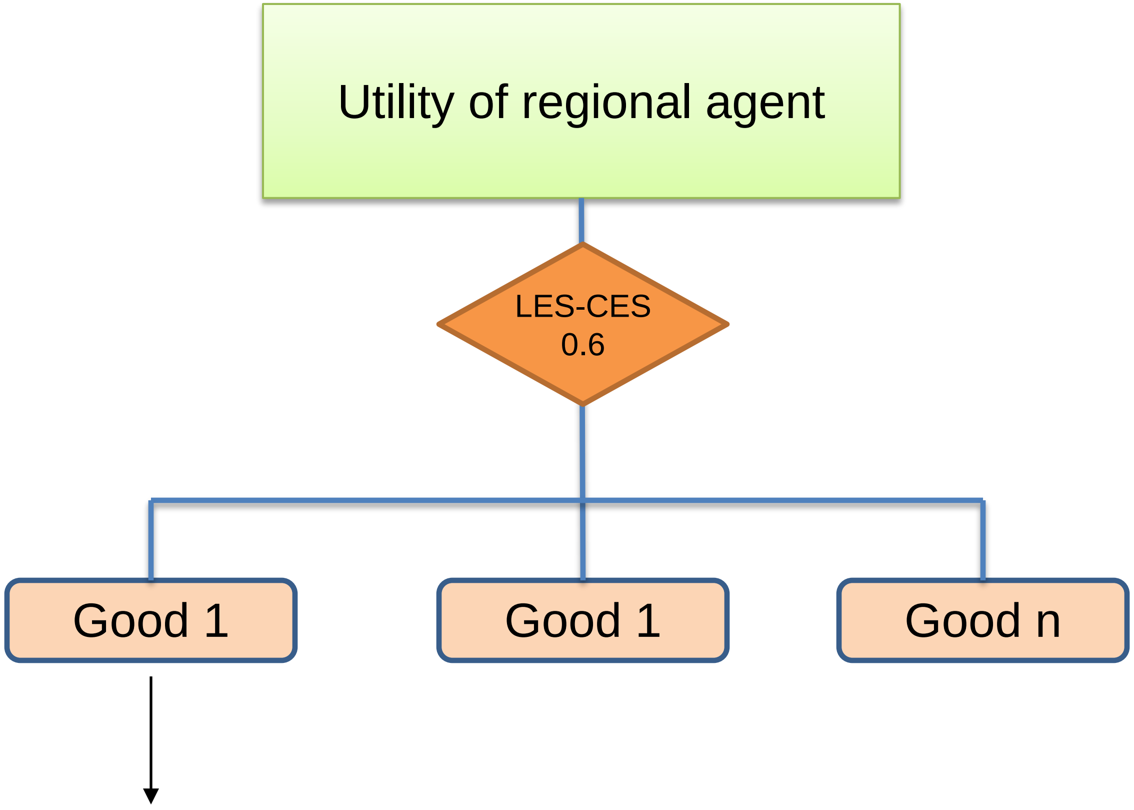
- 3 types of demand: final consumption, intermediate consumption and capital good.
- Goods are distinguished by origin with several levels:

  - differentiation according to quality;

  - differentiation local vs. foreign;

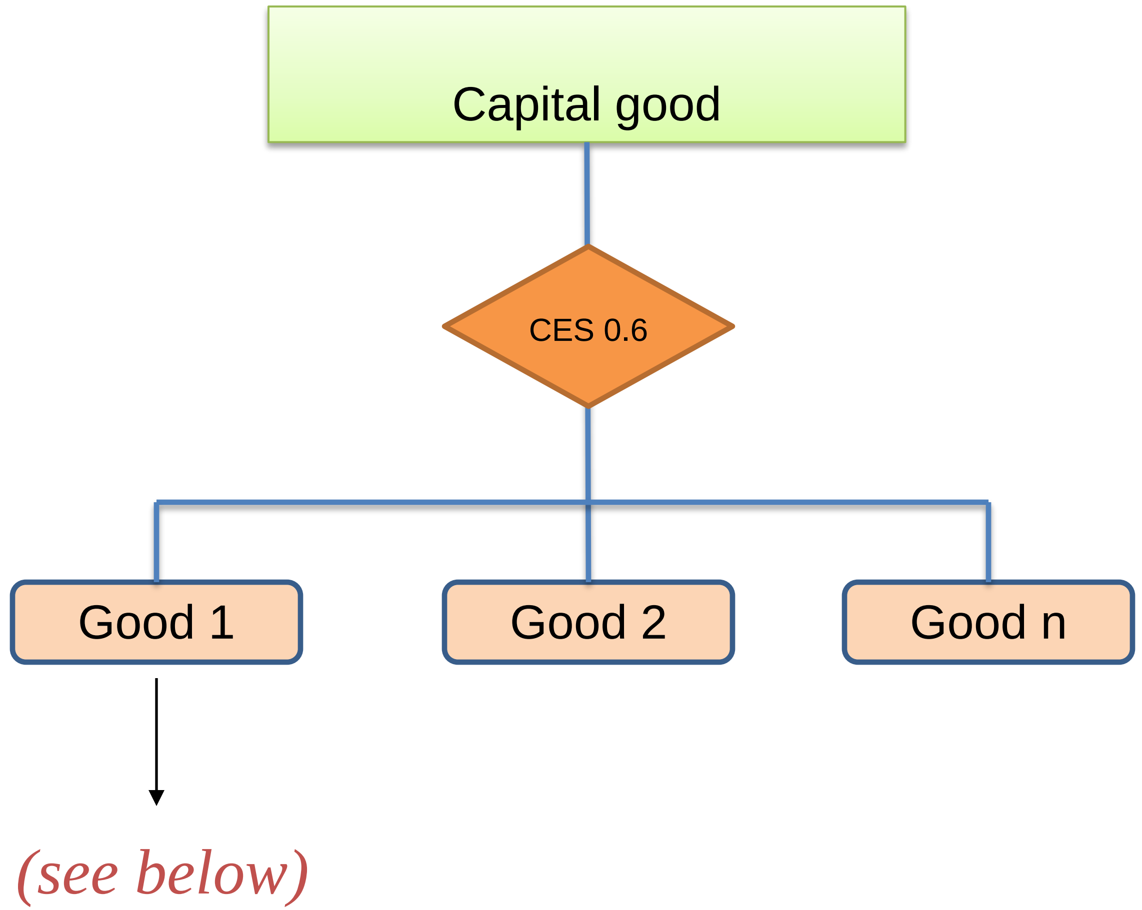
  - differentiation by regions within each quality zone.

Final demand

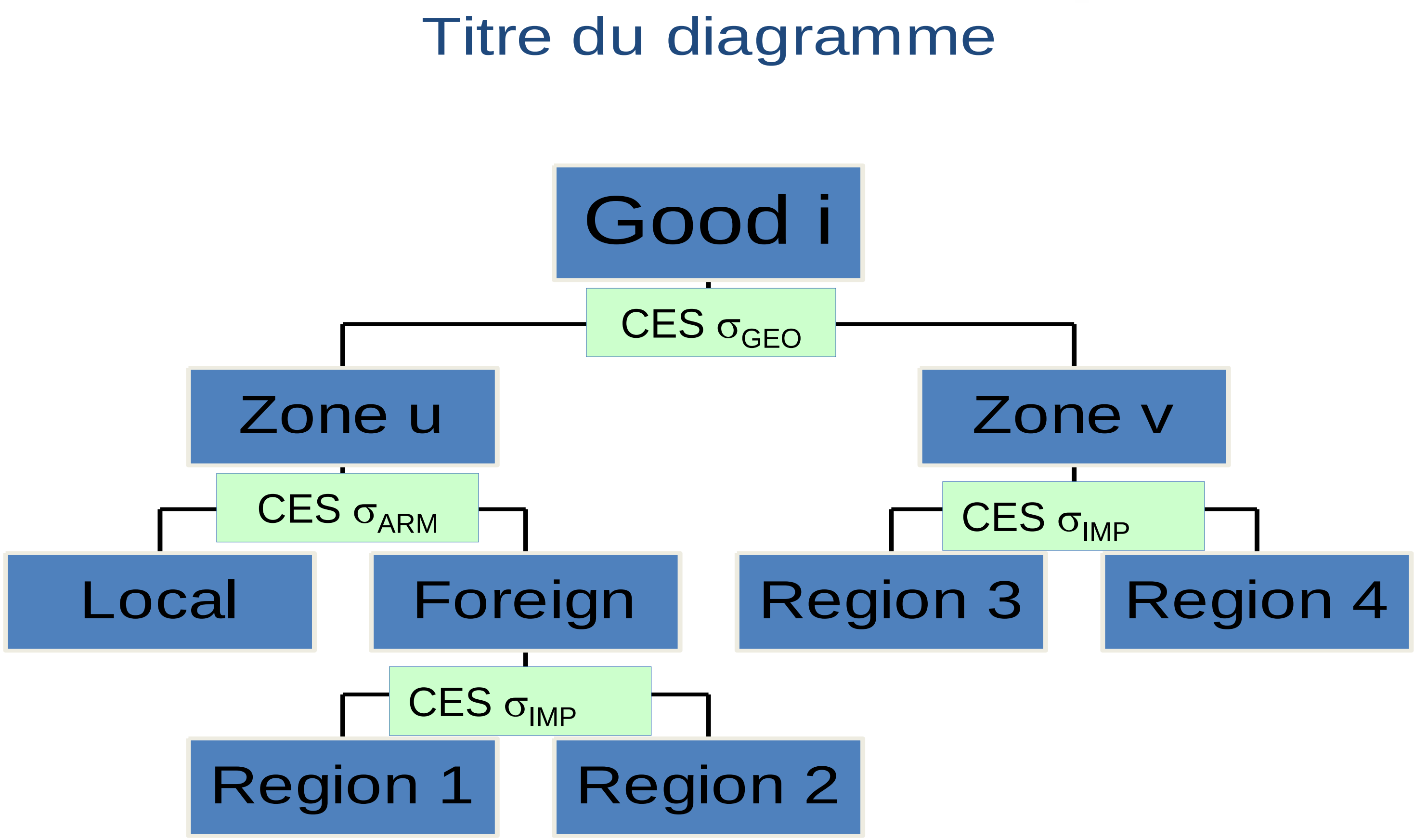


(see below)

Capital good



Choice of goods among production location



Where $\sigma GEO = (\sigma ARM - 1) / 2^{1/2} + 1$ and $\sigma_{ARM} = (\sigma_{IMP} - 1) / 2^{1/2} + 1$

Capital and investment

- Installed capital is assumed to be immobile and sector-specific.
- Accordingly, the rate of return to capital may vary across sectors and regions
- Domestic and foreign investments are the only adjustment device for capital stocks
- Portfolio allocation strategy
- Because the existence of a risk, which is not explicitly modelled, substitution between the different assets is not perfect.
- A single formulation is used for setting both domestic and foreign investment.

Financial closure

- The saving rate is constant. Savings finance local investment and FDI-out.

- External credit to the regional agent is exogenous.

- So the Current account balance varies according to the difference between the FDI-in and FDI-out

Current account = FDI $_{in}$ – FDI $_{out}$ + *External credit exogenous*

Sequential Dynamics

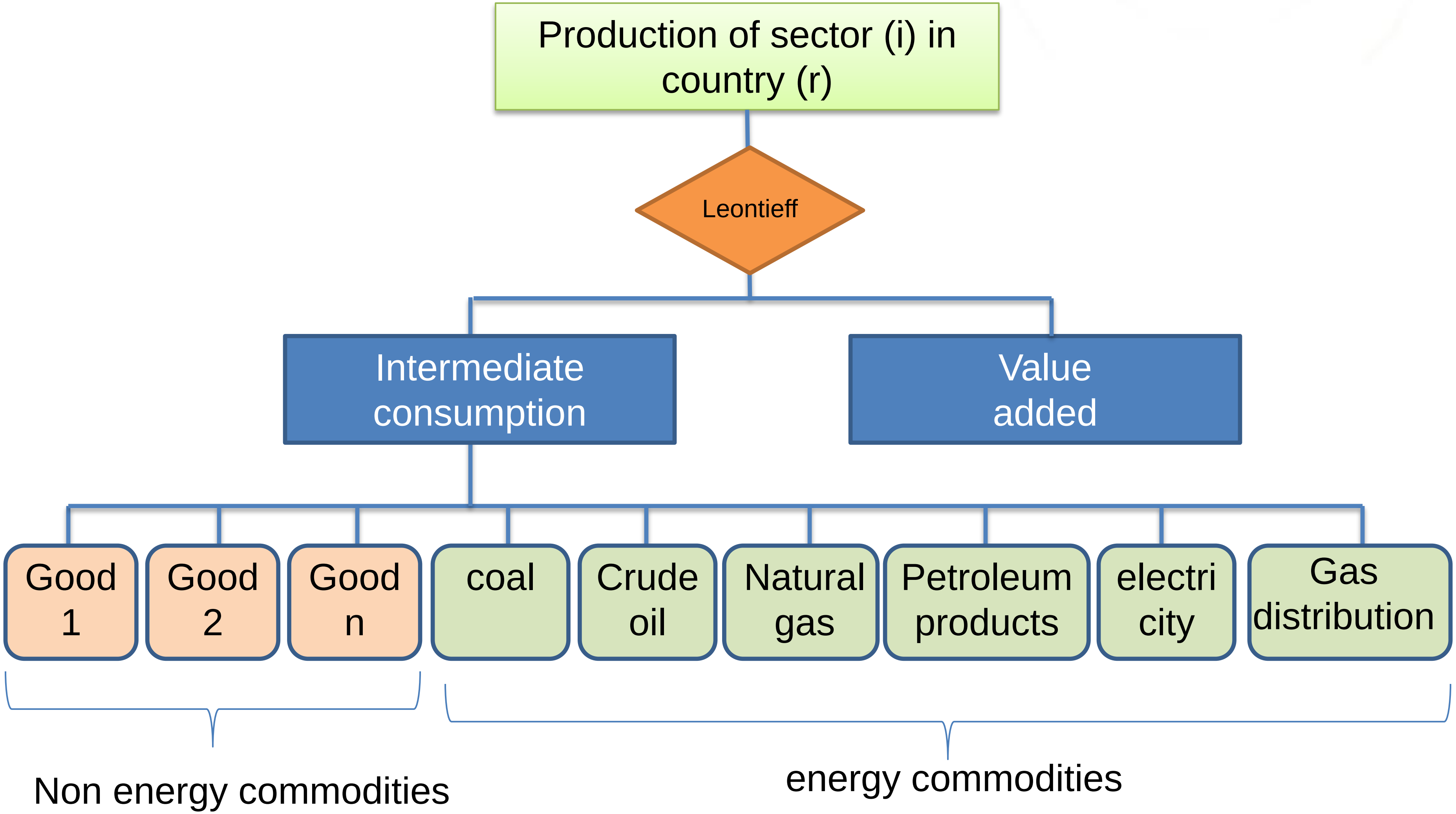
- Dynamics is a succession of static equilibrium states.
- Some parameters and exogenous variables change from one period to the next:
  - factor stocks
  - economic policy.
- Capital evolves endogenously through investment

Dynamic baseline

- **Labour force** supply based on demographic forecast by the World Bank
- Rate of population aged between 15 and 65 used for skilled and unskilled labour
- **GDP growth** forecast provided by the World Bank until 2015
- The 2015 GDP growth rate used for the following years when necessary
- Labour force growth is exogenous
- GDP growth is taken as exogenous in the baseline, while the growth of Total Factor Productivity (TFP) is endogenous
- In the simulations TFP growth becomes exogenous and the GDP variable is freed

How to introduce CO_2 emission in Mirage

Taking into consideration energy consumption in the production function



CO2 emission

- In each country r the CO2 emission in each sector I using energy commodity j is given by the following matrix

	Sector 1	Sector 2	Sector n
Coal	CO2(coal,1,r)	CO2(coal,2,r)	CO2(coal,n,r)
Crude oil	CO2(Crude oil ,1,r)	CO2(Crude oil ,2,r)	CO2(Crude oil ,n,r)
Natural gas	CO2(Natural gas ,1,r)	CO2(Natural gas ,2,r)	CO2(Natural gas ,n,r)
Petroleum products	CO2(Petroleum products,1,r)	CO2(Petroleum products,2,r)	CO2(Petroleum products,n,r)
electricity	CO2(electricity ,1,r)	CO2(electricity ,2,r)	CO2(electricity ,n,r)
Gas distribution	CO2(Gas distribution,1,r)	CO2(Gas distribution,2,r)	CO2(Gas distribution,n,r)

In MIRAGE and GTAP

$$CO2_{ijr} = \left(FC_{ijr} \times CC_i \times (1 - CST_{ijr}) \times EF_i \times FOC_i \times \left(\frac{44}{12}\right)\right)/1000,$$

$$i \in EGY\_COMM,\ j \in ALLSEC,\ r \in REG. \quad (1)$$

Set EGY_COMM contains six energy commodities by the GTAP sector classification: coal (ecoa), crude oil (eoil), natural gas (egas), petroleum products (ep_c), electricity (eely), and gas distribution (egdt);

set ALLSECT contains all producers (set TRAD_COMM) and private households; and

set REG contains all 113 regions of the GTAP version 7 data base classification.

Coefficients are defined as follows:

$CO2_{ijr}$: CO_2 emissions (giga gram, or Gg) from energy commodity i used by sector j of region r;

FC_{ijr}: fuel consumption (1000 tons of oil equivalent, or 1000 toe) of energy commodity i by sector j of region r;

CC_i: conversion coefficient (tera joule per 1000 toe) of energy commodity i;

CST_{ijr}: ratio of carbon stored of energy commodity i used by sector j of region r;

EF_i: emission factor (tones Carbon per tera joule, or tC/TJ) of energy commodity i; and

FOC_i: fraction of carbon oxidized of energy commodity i.

Values of coefficients

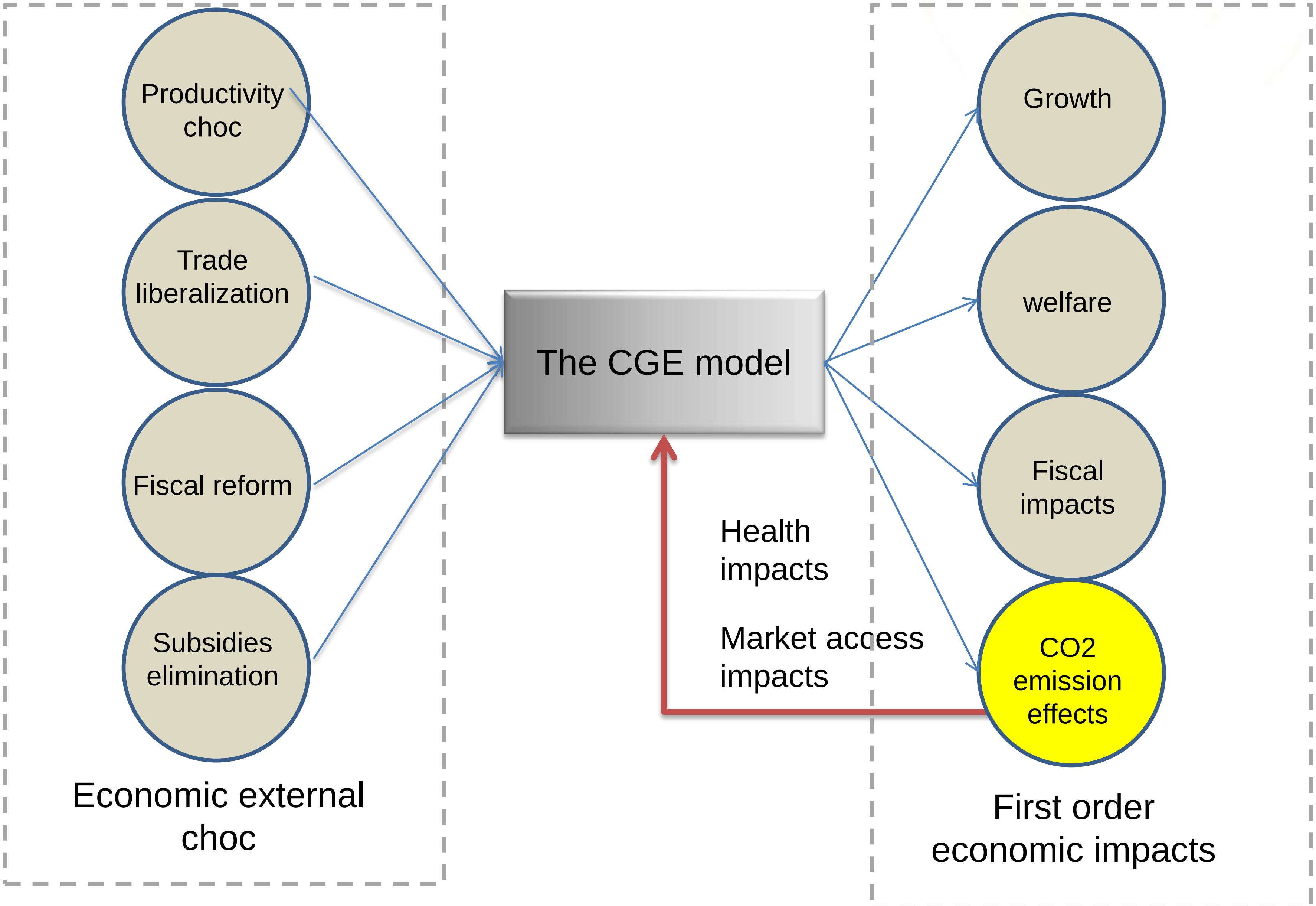
Energy commodities	Conversion Coefficient (CC)	Emission Factor (EF)	Fraction of Carbon Oxydized (FOC)
Unit:	(TJ/1000toe)	(ton Carbon/TJ)	
Coal	41.868	25.80	0.980
Crude oil	41.868	20.00	0.990
Natural gas	41.868	15.30	0.950
Petroleum products*	44.50	19.00	0.990
Gas**	47.31	17.20	0.995

* We use an approximate for all petroleum products.

** Mainly Liquefied Petroleum Gas (LPG).

Note: values of coefficients are obtained from the "Greenhouse Gas Inventory Reference Manual" of IEA (1997).

Assessing the CO2 impacts of an economic policy



Application: Local Air Pollution and Public Health in Tunisia: Assessing the Ancillary Health Benefits of Pollution Abatement Policy

INTRODUCTION AND OBJECTIVES

There has been an explosion of interest in the potential benefits of pollution abatement to offset some of the costs of reducing gas emissions.
While the list of such effects is long and the benefits from each are large, pollution will yield far better deal when these benefits are captured
Until quite recently, literature on direct and ancillary benefits, came from developed countries, especially the US and Europe.
In the Arab region, no empirical analysis tried to estimate ancillary benefits of pollution abatement policies.

INTRODUCTION AND OBJECTIVES

What interest do developing countries have in limiting the growth of their greenhouse gas (GHG) emissions or other pollutants?

The primary benefits for individual countries of GHG abatement remain highly uncertain, and, in any case, long term in nature. The costs, on the other hand, are near-term. However, the benefits of reducing emissions of many pollutants, also associated with energy consumption, is immediate.

Four categories of effects of pollution abatement policies have been identified: Health, ecological, economic, and social.

In addition to considering the full range of sources of benefits, it is also vital to consider costs

METHODOLOGICAL CONSIDERATIONS

Making estimates of ancillary benefits involves carefully following the chain linking a specific policy measure to changes in emissions levels to changes in ambient pollutant concentration to changed human (or animal or plant or material) exposure to environmental/health effects and finally to monetized welfare changes

Each link in this chain involves difficult measurement/estimation problems

Links in Chain from Policy Measure to Welfare Change

Policy change (e.g. pollution tax) →
Emissions reduction →
Lower ambient concentration →
Reduced exposure →
Improved health →
Welfare gains.

METHODOLOGY

- The standard CGE model has been extended to incorporate additional features for the analysis of ancillary benefits of pollution abatement policy. The main changes are the following:

- 1. Energy types (production functions and final demands)
- 2. Modeling emissions

- 3. Modeling the links between emissions, ambient concentration and exposure

- 3. Modeling health effects

- 4. Modeling Pollution Abatement tax

- 5. Modeling welfare change with reduced health damages

I. METHODOLOGY (4)

- Additional data used for the CGE model:
- 1. Sectoral emission intensities for production
- 2. Sectoral emission intensities for consumption
- 3. Monetary Values Estimates of Unit Changes in various health endpoints

Sectoral emission intensities for production – 2006 (metric tons per millions TD)

	Agri	Chemicals	Textiles	Other Manufacturing	Non Manufacturing Industries	Services
TOXAIR	9,5	180,7	56,3	37,8	33,7	6
TOXWAT	18,8	464,1	11,7	73,9	45,6	12,4
TOXSOL	17,8	562,2	11,5	159,2	235,5	16,8
BIOAIR	28,2	515,1	12,9	395,8	670,5	28,9
BIOWAT	0,3	25,8	0,3	16,6	32,2	1,1
BIOSOL	294,1	10374,6	171	7198,7	13188,9	505,9
SO2	17,9	493,2	11,4	64,7	39,8	11,5
NO2	11	298,1	77	37,3	18,9	6,8
CO	6,8	209,7	4,5	48,5	52,8	5,5
VOC	16	318,5	7,3	46,1	32,8	7,6
PART	3	82,4	1,9	12	5,8	1,9
BOD	7,9	17,4	0,2	13,8	21,8	0,8
TSS	9,5	966,4	10	621,5	1198,7	41,8
Output%	7,7	4,1	7,9	24,3	16,9	39,1
Exp/Output	7,3	47,3	85,7	34,7	15,7	7,8
Imp/Demand	30,7	191,9	159,1	104,1	156,3	131,9

Sectoral emission intensities for consumption – 2006 (metric tons per millions TD)

	AgriFood	Chemicals	Textiles	Other Manufacturing	Non Manufacturing Industries	Services
TOXAIR	0	301,2	0	23,9	0	0
TOXWAT	0	856,6	0	10	0	0
TOXSOL	0	752,8	0	42,5	0	0
BIOAIR	0	0	0	214,5	0	0
BIOWAT	0	0	0	4,9	0	0
BIOSOL	0	0	0	2929,6	0	0
SO2	0	925,4	0	4,7	0	0
NO2	0	567,8	0	2	0	0
CO	0	335,9	0	7,5	0	0
VOC	0	586,3	0	4,1	0	0
PART	0	155,9	0	0,7	0	0
BOD	0	0	0	3,3	0	0
TSS	0	0	0	180,7	0	0
Cons %	10	3	4	11	12	60

Source and distribution of GHG emissions by type of gas in 2008 in Tunisia (in Kilo Tone equivalent of CO_2 ($KTCO_2$))

GHG	CO_2	CH_4	N_2O	Nox	VOC	CO
Energetic combustion	24 224	277	143	87	60	425
Energy industries	8 891	13	24	12	1	16
Manufactured industries	4 936	5	8	13	0	1
Transport	6 399	13	23	48	37	195
Other services	1 152	5	3	2	0	4
Residential	1 805	239	47	6	21	208
Agriculture	1 041	3	38	6	1	2
Fugitive emission	1 252	1 907	12	0	172	0
Total	25 476	2 184	155	87	232	425

Source: Authors' compilations using data from ANME (2010).

Major Air Pollutants, Their Sources and Their Environmental Impacts

Pollutant	Major Sources	Transformations in Atmosphere	Major End-Points	Nature of Effects
Particulates	Fossil fuel combustion (exc. Natural gas) construction, natural dust (small proportion inhalable) Coal and diesel fuel combustion		(i) Health (ii) Materials	a) Mortality b) Morbidity: respiratory and cardiovascular complications c) Soiling a) Mortality
Sulphur dioxide (SO2) and sulphate aerosols (SO4)	Fuel combustion	SO2 transported, transformed into and suspended/deposited as SO4	(i) Health (ii) Soils, forests, aquatic ecosystems	b)Morbidity: respiratory illness Acidification Respiratory problems
Nitrogen oxides (NOX) and nitrates (NO2 and HNO3)		Precursor to acid rain; Constituent in formation of photochemical smog and of tropospheric O3	i) Health ii) Visibility	Reduced enjoyment Reduced amenity value
Volatile organic compounds (VOCs)	Fuel combustion	Constituent in formation of photochemical smog	i) Visibility	Cancer Acute respiratory distress at high concentrations (asthma)
Ozone (O3)		Formed from oxidation of NOX in the presence of sunlight and reactive VOCs	ii) Health Health	a)Adults: hypertension; stroke b) Children: Reduced IQ a) Asphyxiation b) Stillbirth
Lead (Pb)	Gasoline		Health	
Carbon monoxide (CO)	Fuel combustion, including biomass		Health	

Air Quality Standards in Tunisia

	Average type	Exceeding authorisation	Limiting value (related to health)	Guide value (related to welfare)
CO	8 hours	2 times/30 days	9 ppm- 10 mg/m^3	9 ppm- 10 mg/m^3
	1 hour	2 times/30 days	35 ppm- 40 mg/m^3	26 ppm- 30 mg/m^3
NO_2	Annual average	-	0.106 ppm- 200 mg/m^3	0.08 ppm- 150 mg/m^3
	1 hour	1 time/30 days	0.35 ppm- 660 mg/m^3	0.212 ppm- 400 mg/m^3
O_3	1 hour	2 times/30 days	0.12 ppm- 235 mg/m^3	0.077-0.102 ppm- 150 to 200 µg/m^3
Suspended particulate (PM 10)	Annual average	-	80 µg/m^3	40 to 60 µg/m^3
	24 hours	1 time/ 12 months	260 µg/m^3	120 µg/m^3
SO_2	Annual average	-	0.03 ppm- 80 µg/m^3	0.019 ppm- 50 µg/m^3
	24 hours	1 time/ 12 months	0.12 ppm- 365 µg/m^3	0.041 ppm- 125 µg/m^3
	3hours	1 time/ 12 months	0.5 ppm- 1300 µg/m^3	-
Pb	Annual average	-	2 µg/m^3	0.5 to 1 µg/m^3
H_2S	1 hour	1 time/ 12 months	200 µg/m^3	-

Source: ANPE (2008).

Solid Particulate concentration in selected Tunisian cities PM10 (2004-2008) in (µg/m³)

PM10	2004		2005		2006		2007		2008	
	Av/year	24 h	Av/year	24 h	Av/year	24 h	Av/year	24 h	Av/year	24 h
Bab Saâdoun	85	526	82	195	88	316	91	328	77	190
Bizerte	83	466	91	249	98	711	80	248	67	216
Sfax city	-	-	-	197	87	318	87	240	90	335
Ben Arous	-	-	-	-	78	141	81	279	74	183
Sousse	-	-	-	105	54	181	57	172	55	143
Sfax south suburban	-	-	180	117	94	582	90	264	89	326

Monetary Values Estimates of Unit Changes in various health endpoints

	Equivalent estimate for Tunisia, 2020	Units
Value of statistical life (VSL)	1.6	$million/death avoided
Respiratory hospital admission (RHA)	4488.2	$/event
Emergency room visit (ERV)	126.9	$/event
Restricted activity day (RAD)	36.5	$/day
Minor restricted activity day (MIRAD)	15.4	$/day
Clinic visit for LRI in children	122.3	$/visit
Chronic bronchitis in adults	151085.5	$/case
Asthma attack	21.3	$/attack day
Respiratory symptom day	4.3	$/day
Child respiratory symptom day	3.4	$/day
Adult chest discomfort case	4.3	$/event
Eye irritation	4.3	$/event day
Headache episode (avg. Of mild and severe)	17.3	$/event day
IG decrement	1880.6	$/point lose
Hypertension in adult males	442.6	$/case
Non-fatal heart attack	33726.3	$/event

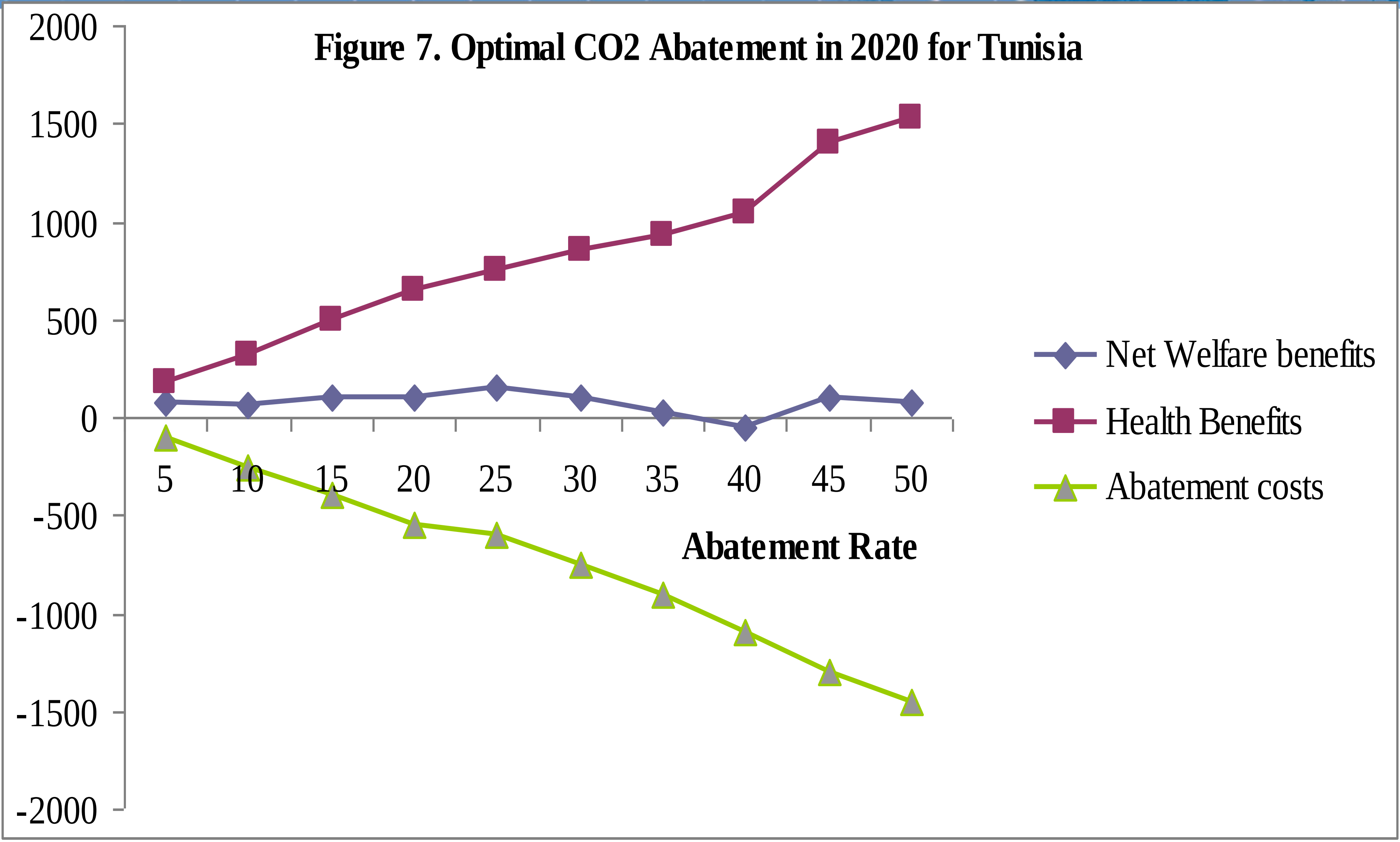


Figure 7. Optimal CO2 Abatement in 2020 for Tunisia
2000
1500
1000
500
0
-500
-1000
-1500
-2000
5
10
15
20
25
30
35
40
45
50
Abatement Rate
Net Welfare benefits
Health Benefits
Abatement costs

- The welfare changes is measured by equivalent variation, including ancillary benefits, which is approximated by the value of changes in mortality and morbidity.
- It suggests an “optimal” abatement rate in 2020 of around 25% of CO2 reduction compared with the baseline 2020 emissions.
- However, the “no regrets” abatement rate is 35% where welfare changes reach a neutral level. Implementation of an abatement rate exceeding 35% will negatively affects the economy where the welfare change became negative showing a lose rather than a gain.
- Of the total ancillary health benefits, mortality benefits constitute about 20%.
- Benefits from avoided IQ (Intelligence Quotient) loss in children under seven contributes to 40%. The remainder benefits come from reduced incidence of disease (30%) and reduced pollution-related symptoms (10%)

RESULTS

- The most important finding is the small aggregate cost of CO abatement policy in terms of foregone real average growth rate of GDP between 2010-2020 which can be explained by:

  -These policies seem to affect productive resources (capital and labor) which move from the contracting (extraction, chemicals and other manufacturing) to the expanding sectors which are the less polluting activities (agri-food, textiles, non manufacturing and services) . This the composition effect.

  - The second is related to the substitution possibilities among inputs, where we observe an increase in the use of less polluting inputs compared to more polluting ones.

  - The third reason is related to the distribution schema of the new taxes revenue generated by the green taxes. This additional revenue is distributed by the government to households, which in other terms reduce the adjustment costs related to the impact of pollution abatement policy on household welfare.