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PREPARATORY LECTURE

CGE MODELS AND THEIR APPLICATION FOR CLIMATE POLICY ANALYSIS

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CGE Models and their Application for Climate Policy Analysis

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Topics of this Lecture

(1) CGE models – understanding the basic ideas

- Philosophy/theory
- Simple example of a CGE model
- Applications
- Model extensions
- Advantages/disadvantages

(2) CGE models in climate policy analysis

- History of CGE models for climate policy analysis
- Overview over existing models
- Crucial differences
- Application: Kyoto & Leakage effect

General Equilibrium (GE) Models

- Walrasian general equilibrium structure (formalized in the 1950's by Kenneth Arrow, Gerard Debreu & others)
- Based on neoclassical assumptions
- Market for each commodity (goods & intermediates)
- Consumers maximize utility s.t. to their budget constraint defined by their initial endowments => demand side
- Producers maximize profits taking the equilibrium input and output prices as given => supply side
- In equilibrium market prices are such that
  - demand equals supply in all input and output markets
  - In constant returns to scale case (normal assumption) there is zero profit

Computable GE (CGE) Models

Markusen (2002) CGE modeling is a way around the difficulties of theoretical models, such that the concept of GE actually becomes useful for analyzing real economies and real problems.

Bolnick 1989: A CGE model is "computable" in that an explicit numerical solution is computed. Values for all endogenous variables in the model are calculated from equations describing the economy, given numerical values for the parameters and the exogenous variables (such as policy variables and the initial capital stock). CGE models are simulation models.

Solving CGE Models

- Instead of formulation as optimization problem, derive demand and supply functions
- GE is reduced to finding the solution to a square system of n equations and n unknowns
- Numerical solutions using algorithms that are based on fixed point theorems, Newton approach or extensions
- Today: Powerful software, e.g. GAMS

Steps in CGE Modeling

1. Specify dimensions of the model
2. Chose functional forms for production, transformation, and utility functions; specification of side constraints
3. Construct consistent data set.
4. Calibration – parameters chosen such that functional form consistent with data (data are a model solution)
5. Replication – see if model reproduces the input data
6. Counter-factual experiments

Steps in CGE Modeling: 1. Specify Structure of the Model

- Number of goods & factors; consumers; countries

Simple Example of a CGE model

- 2 sectors (goods): X and Y
- Fixed supply of 2 production factors: L and K that can move between sectors
- 1 representative consumer with income I
- P_L, P_K, P_X, P_Y
- $X = X(L_X, K_X)$, $Y = Y(L_Y, K_Y)$
- $L^* = L_X + L_Y$, $K^* = K_X + K_Y$
- $U = U(X,Y)$, $I = p_L L^* + p_K K^* = p_X X + p_Y Y$

Simple Example of a CGE Model

- Derive unit cost $cx = cx(p_L, p_K)$, $cy = cy(p_L, p_K)$ & expenditure functions $e = e(p_X, p_Y)$ from producer/consumer maximization
- Use Shepard's Lemma to derive producer's demand for capital and labor per unit output and consumer's demand for X and Y per unit of utility
- 9 unknowns: X, Y, U, I, p_X, p_Y, p_K, p_L, p_U
- 9 Equations:
  - Non-positive profits for X, Y and U
  - Supply greater than demand for X, Y, L, K and U
  - Income balance

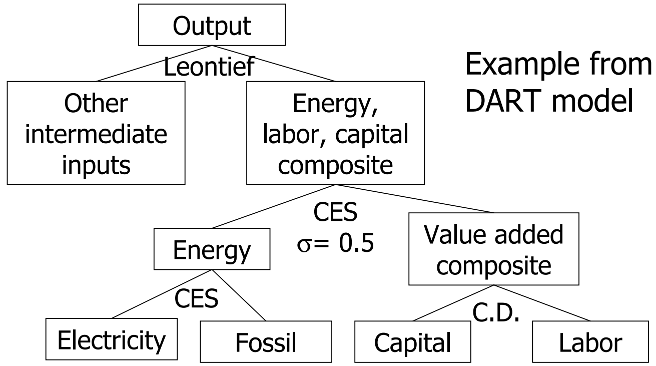
Steps in CGE Modeling: 2. Choosing Functional Forms

- Choose a functional form for the utility/production functions resp. the expenditure and the cost functions.
- Includes choice of outputs and inputs for each activity and specification of initially slack activities
- Functional form needs to be consistent with theory and analytically tractable.
- ➢ In practice use of "convenient" forms: Cobb-Douglas (C.D.) & constant elasticity of substitution (CES)

C.D.	$\prod_i X_i^{\alpha_i}$	$\sum_i \alpha_i \equiv 1$	α_i = expenditure share in demand function
CES	$[\sum_i \alpha_i^{1/\sigma} X_i^{(\sigma-1)/\sigma}]^{(\sigma/(1-\sigma))}$	$\sum_i \alpha_i^{1/\sigma} \equiv 1$	σ = elast. of subst. in utility between goods i,j

Choosing Functional Forms

- In applied models: hierarchical (or nested) CES functions.
- Benefit: greatly expands the number of elasticity parameters that can be used for calibration.



Example from the DART model

Steps in CGE Modeling : 3. Construct Consistent Data: the SAM

- Core of a CGE: Social Accounting Matrix (SAM)
- SAM = single-entry accounting representation of the flow of goods and services and payment between sectors, classes of economic actors and other accounts
- For every income there must be a corresponding expenditure
- Two functions of SAM: description of economy, basis for modeling
- Can be applied at different levels: village level, regional, single country, multi-country, global
- Elements of a SAM: production, factors, institutions

Construct Consistent Data: the SAM

The Institutions of a SAM

- Households supply factors of production (capital, labor, land) to firms; consume marketed goods & services and public goods; pay taxes to and receive subsidies from the government; make net current transfers to ROW; save & invest
- Government levies taxes on households, firms & commodities; undertakes current consumption; makes transfers to households, firms, and the ROW; saves & invests
- ROW supplies goods to domestic markets (imports) and consumes domestic output (exports); makes net transfers; provides saving

The Basic SAM Structure

Re-ceipts	Produc-tion P	Factors F	House-holds HH	Govern-ment G	Savings S Invest. I	ROW	Total
P	Intermed. Inputs		Private consump.	Gov. consump.	Invest-ment	Export	Demand
F	Value-added					Factor inc. from ROW	Factor income
HH		Factor inc. to HH	Inter HH Transfers	Transfers to HH		Transfer to HH	HH income
G	Prod.,sales, export, VAT	Factor inc. to G, factor taxes	Transfers to G, direct			Transfer to G	G income
S/I			HH savings	Gov. savings		Foreign savings	Savings
ROW	Imports	Factor inc. to ROW		Gov. transfers to ROW			Foreign exch. outflow
Total	Supply expend.	Factor expend.	HH expend.	Gov. expend.	Invest-ment	Foreign exch. inflow	

Construct Consistent Data: the SAM

Basic Balance Requirements:

- **Commodity Balance**: For each commodity and factor: supply = demand
- **Flow of Funds Balance:** For each institution: total income = total expenditure
- **Macroeconomic Balance:** Balance of payments; Saving = Investment

In practice it is mostly necessary to adjust data to make them fulfill these requirements!

Construct Consistent Data: the SAM

Example for a SAM for our simple CGE model

	X	Y	K	L	HH	Row Sum
X		40			80	120
Y	20				60	80
L	40	10				50
K	60	30				90
HH			90	50		140
Column Sum	120	80	90	50	140	

The General Trade Analysis Project (GTAP)

- Started in 1993
- Collects/calculates consistent set of regional I/O tables including trade data
- Also: CGE model, utilities, papers, conferences
- GTAP5: 1997 data for I/Os for 66 regions and 57 sectors
- Includes now energy data, necessary for climate policy analysis; work on non CO_2 GHG data
- http://www.gtap.agecon.purdue.edu/

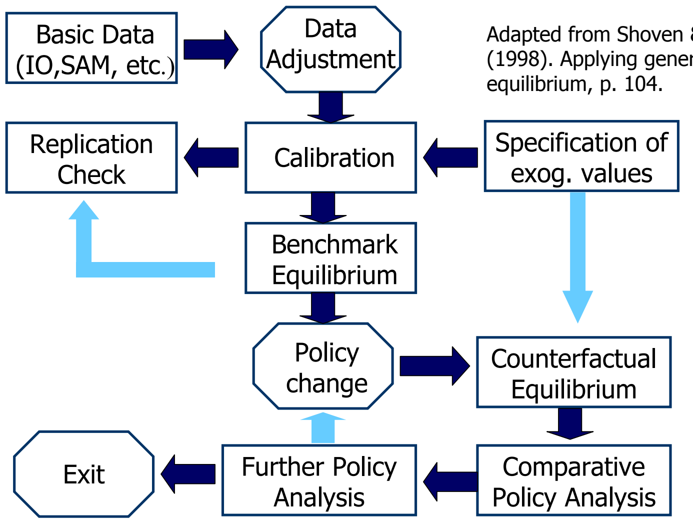
Steps in CGE Modeling:
4. Calibration & 5. Replication

- Calibration: Choose parameters of cost and expenditure functions in such a way that the benchmark data are a solution to the model.
- Choose "free" parameters e.g. according to literature estimates
- Since in the SAM there is no automatic partition of the transaction value into price and quantity we must chose one: normally all (domestic) prices are normalized to unity in the base year (= price index)
- Replication run to see if model reproduces benchmark = original SAM

Steps in CGE Modeling :
6. Counter Factual Experiments

- Define counterfactual scenarios and compare them with benchmark
- Results are not forecasts !!! Differences rel. to benchmark are important.
- Many areas of application:
  - Welfare effects of tax reforms (A. Harberger 1962: "The incidence of corporate income tax". Journal of Political Economy 70:215-240.)
  - Trade policy
  - Optimal resource management
  - Development Economics, Structural change
  - Labor markets
  - Climate policy
  - …

Steps in CGE Modeling



Adapted from Shoven & Whalley (1998). Applying general equilibrium, p. 104.

Extensions to the Simple Model

- Increased number of sectors
- Taxes and Tariffs; government
- Factor markets and intermediate inputs
- Joint production
- Saving and investment
- Open economies, trade
- Increased number of regions
- Scale economics, imperfect competition
- Public goods, externalities, "rationing constraints"

Dynamic Models

- Recursive dynamic models
  - solve a sequence of static equilibria connected through capital accumulation
  - Myopic expectations (exogenous investment) or adaptive expectations (endogenous investment that depends on expected rates of return)
- Forward looking models
  - Intertemporal optimization = fully rational expectations
  - Ramsey type growth models
- Infinite time models
  - Overlapping generations (OLG) models

Advantages of CGE Models

- Theoretical consistency
- Requires data consistency
- CGE models are explicitly structural and do not encounter the identification problem
- Thus: Force modelers to be explicit about assumptions (which can be changed)
- Can be used to address a broad range of policy issues (including environmental questions)
- Inter-industry or multi-sector interlinkages = "second round " effects of policy changes (in circumstances where basic intuition may fail)
- Considerable scope for altering aggregations

Disadvantages of CGE Models

- CGE models are complex and require skill to maintain them
- CGE models do not tolerate inconsistent data
- Difficulties of model selection, parameter specification, and functional forms
- CGE models are not "forecasting" models
- Not good for monetary of fiscal policies (only relative prices not price levels)

CGE Models in Climate Policy Analysis

Bottom-up vs. Top-Down

- Bottom-up models disaggregate the energy sector and consider specific energy technologies with both technical and economic parameters.
- Main limit: models neglect feedbacks in the economy and effects on international energy markets.
- Top-down models are very aggregated macroeconomic models
  - Input/Output models
  - Macro-econometric models
  - **CGE models**

Economic Models of Climate Policies

- Early 70s: first models mainly build by natural scientists focusing on GHG
- Late 70s: first economic models
- Toronto Climate Conference in 1988
- Late 80s/early 90s first CGE models, analysis of CO_2 taxes
- CGE modeling of climate policies really took off in the 90s
  - More powerful software to handle larger models
  - GTAP Energy
  - GAMS codes for standard models available (Rutherford)
  - The Kyoto Protocol

Jorgenson & Wilcoxen 1990

- For USA only; 35 industrial sectors, 672 household types, labor, capital, energy, materials
- Parameters estimated for 1947-1987 data
- Dynamic; until 2050
- Experiments:
  - Freeze emissions at 1990 or 2000 level
  - Cut emission in 2080 to 80% of 1990 level

Whalley & Wiggle 1990

- 6 regions: EU, North America, Japan, other OECD, Oil exporters, ROW
- 4 resources: carbon/non-carbon energy resources, sector-specific factors in energy intensive manufactures, other primary factors
- 5 products: carbon/non-carbon energy, composite energy, energy intensive goods, other goods
- Period 1990 - 2030
- Experiments: reduce carbon emissions by 50 % rel. to bench by producer, consumer or internationally levied tax

Further Models I

Model	Description	Special features	Reference
DART	Recursive dynamic GTAP5; 11- 17 regions	Capital mobility; Off-steady state growth; Climate impacts	Klepper et al. (2003)
EDGE	Intertemporal GTAP4; 8 regions	Sinks Non-carbon GHG	Jensen & Thelle (2001)
EPPA	Recursive dynamic GTAP; 12 regions Until 2100	Non-carbon GHG Derived from GREEN AEEI, backstop technology	Yang et al. (1998), MIT
G-Cubed	Intertemporal 8 regions	Financial & physical capital Econometric cost functions	McKibbin et al. (1999)*
GEM-E3	EU+ROW		http://gem-e3.zew.de/
GREEN	Recursive dynamic GTAP4; 12 regions		OECD (1994)
GTEM	Intertemporal GTAP3; 18 regions	Derived from GTAP model	Tuluple et al. (1999)*

*Description in: Weyant, J. (1999).

Further Models II

Model	Description	Special features	Reference
MERGE	Intertemporal 9 regions Until 2100	Bottom-up energy supplies Endog. technological progress, AEEI CO_2, NH_4, N_2O; Climate damages	Manne & Richels(1999)*
MS-MRT	Intertemporal GTAP4; 10 regions Until 2030	Backstop technology	Bernstein et al. (1999)*
PACE	Intertemporal GTAP4; 11 regions		Böhringer (2002)
SGM	12 regions I/Os + add. Data	Lifetime of capital	MacCracken et al. (1999)*
WIAGEM	Intertemporal GTAP4; 11 Regions	Backstop technology; Climate damages; CO_2, CH_4, N_2O	Kemfert (2001)
WorldScan	Adaptive expectat. GTAP4, 12 regions	Financial capital High & low skilled labor	Bollen et al. (1999)*

*Description in: Weyant, J. (1999).

Applications – The Kyoto Protocol

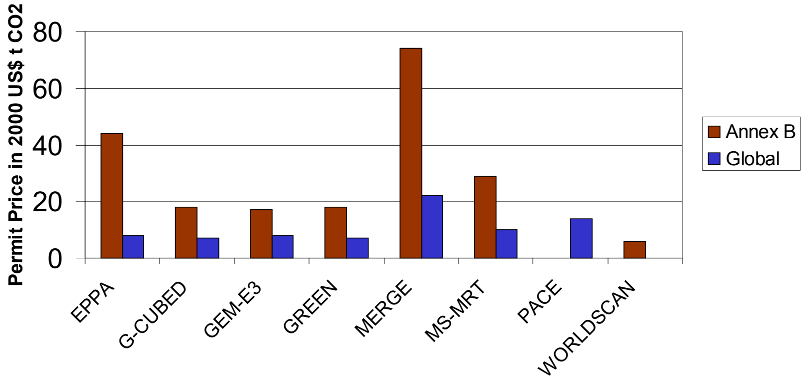
- Early 1990s: Emission reductions of up to 80% rel. to 1990 until 2080 using taxes
- After Kyoto 1997: Kyoto reductions
  - Unilateral taxes
  - Emissions trading: AXB, global
  - Hot air, market power
  - Bonn & Marrakech: sinks
  - Multi-gas abatement
  - CDM, JI

Further Applications

- Abatement cost curves
- EU emissions trading
- Double Dividend
- Capital Mobility
- Economic impacts of climate change
- Decomposition of welfare effects
- Welfare reducing emissions trading

Crucial Difference or Why the Model Results Differ?

Scenarios of emissions trading to reach Kyoto



CGE Models and their Application for Climate Policy Analysis

Crucial Difference or Why the Model Results Differ?

Major determinants of GHG mitigation cost and benefit projections for same climate policy regime (Following Weyant 2002)

1. Projections for BAU GHG emissions
2. The representation of substitution possibilities by producers and consumers
3. How the rate and process of technological change are incorporated in the model
4. The characterization of the benefits of GHG emissions reductions

CGE Models and their Application for Climate Policy Analysis

Projection of BAU Emissions

- The higher BAU emissions, the more GHG emissions must be reduced to achieve specific target
- BAU emissions rely on input assumption
  - Population and economic activity
  - Energy resource availability and prices
  - Technological availability and costs
- In EMF study (with also non-CGE models): BAU emissions in 2010: 1,576 – 1,853 MMT-C, in 2020: 1,674 – 2,244 MMT-C

CGE Models and their Application for Climate Policy Analysis

Substitution Possibilities

- Time interval over which a model solves its equations (1 year vs. 10 year time interval)
- The level of detail about capital stock and how goods are produced = degree of substitution that is possible within model structure; elasticities !!
- The specification of economic foresight (myopic expectations create higher costs than perfect foresight)
- How models capture the aging of capital
- Capital mobility
- Intensity of trade

Technological Change

- Induced technological change: costs of a product (e.g. fossil fuels) rise, in response, firms develop new processes or products that use less of the now-costlier item.
  - Learning by doing
  - Investment in R&D
- Autonomous Energy Efficiency Improvement (AEEI) = exogenous technical change. AEEI lowers overall energy use per unit of output. (AEEI normally 0.5 – 3% p.a.)
- Backstop technology and its price
- Löschel, A. (2001). Technological Change in Economic Models of environmental Policy: A Survey. ZEW Discussion Paper No. 01-62.

Characterization of Benefits

- Many models do not estimate the benefits from emission reductions
- Those models that address climate impacts vary widely in what is included
- Current range of estimates for the direct benefits of reducing GHG emission: $5 - $125 per ton (1990 US$).

Other Issues

- Discount rate in intertemporal models
- Base year
- Specification of particular climate policies:
  - Hot air in emissions trading
  - Sinks
  - Other GHG
  - Linear vs. immediate reductions
  - Revenue recycling of taxes and permit income

Importance of GE Effects: Example

- Example using the Dynamic Applied Regional Trade (DART) model.
- Recursive dynamic, 12 regions. 11 sectors, GTAP5
- Policy scenarios
  - UNI: EU reaches its Kyoto target in an efficient way (e.g. uniform tax); no reduction in other countries
  - AXB: All Annex B regions (EU, USA, JPN, ANC, FEB) reach Kyoto target by unilateral taxes
  - ET: All Annex B regions reach Kyoto target by international emissions trading
  - NOUS: All Annex B regions except the USA reach their Kyoto target by unilateral taxes
  - Targets are reached in 2010

Importance of GE Effects: Leakage

Emission reduction relative to BAU in % in 2010									
	WEU	**JPN**	**ANC**	**USA**	**FSU**	**MEA**	**CPA**	**ROW**	**Leak**
UNI	-9.9	+1.0	+0.9	+0.6	+1.2	+0.5	+0.7	+1.0	+57.5
AXB	-9.9	-20.4	-12.9	-19.8	+3.2	+2.3	+3.1	+4.6	+31.1
ET	-15.5	-12.9	-17.5	-17.5	+3.6	+2.3	+3.2	+4.7	+32.3
NOUS	-9.9	-20.4	-12.9	+1.3	+2.0	+1.2	+2.0	+2.6	+56.9

Leakage effect !

Importance of GE Effects: Energy Prices

% Change in gross oil price relative to BAU in 2010							
	WEU	**JPN**	**ANC**	**USA**	**FSU**	**MEA**	**CPA**
UNI	+11.6	-1.1	-1.3	-1.0	-1.2	-1.1	-1.1
AXB	+9.4	+26.0	+8.6	+16.5	-5.3	-6.2	-5.8
ET	+17.9	+13.7	+14.2	+13.7	-5.3	-6.0	-5.7
NOUS	+11.1	+27.1	+10.7	-2.4	-2.5	-2.9	-2.7

Importance of GE Effects: CO_2 "Price"

CO_2 tax/permit price in 2010 in US$/MtC				
	WEU	**JPN**	**ANC**	**USA**
UNI	41.1			
AXB	51.9	129.5	57.7	90.2
ET	78.6	78.6	78.6	78.6
NOUS	45.4	122.0	51.9	

Importance of GE Effects

Changes in relative energy prices effect

- Cost and production structures
- Marginal abatement costs
- Terms of Trade
- …

In a globalizing world GE effects can be expected to become even more important!

Concluding Remarks

- CGE models are a powerful tool to analyze inter-national climate policy questions
- Due to better software/data availability use of CGE models grows; many examples of existing models
- CGE models also have their limitations, and one has to know how to interpret the results.
- Future work /open questions:
  - Uncertainty
  - Integrating bottom-up elements into CGE models
  - Integrating natural resources
  - Broader treatment of "sustainability" issues

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