Computable General Equilibrium Models:
Introduction

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Partial and General Equilibrium Modelling

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Aims for today

- Learn:
  - What is a Computable General Equilibrium (CGE) model?
  - What are its main elements (production, trade, demand)?
  - Some differences between CGE models

Approach of the CGE block

- We will look in detail at a rather simple didactic CGE model realized in GAMS, to understand methodology and code implementation

- Learn about extensions (land use, energy, new trade theory modules) especially relevant for agri-food analysis with CGEs

- Coding style, mnemonics of didactic example etc. harmonized with large-scale example CGEBox

- CGEBox later used for some example simulations

  - CGEBox (and its predecessor) was also used in APO220 "Applied Modelling" in the last years and in several master theses

  - Closely linked to globally most-known CGE model GTAP

  - Basis of CGE based work of group

Recent work with CGEs

- Escobar, N., Britz, W. (2021): Metrics on the sustainability of region-specific bioplastics production, considering global land use change effects, Resources, Conservation and Recycling 167(April 2021): 105345

- Jafari, Y., Himics, M., Britz, W., Beckman, J. (2021): It is all in the details: A bilateral approach for modelling trade agreements at the tariff line, Canadian Journal of Agricultural Economics, in: Online available 8th March 2021

- Kuhn, A., Britz, W. (2021): Long-Term Scenarios for Sub-Saharan Africa's Agro-Food Markets with varying Population, Income and Crop Productivity Trends, Journal of Agricultural and Resource Economics 46(1): 20-36

- Delzeit, R., Beach, R., Britz, W., Chateau, J., Freund, F., Lefevre, J., Schuenemann, F., Sulser, T., van Ruijven, B., Weitzel, M., Willenbockel, D., Wojtowicz, K. (2020): Linking Global CGE Models with Sectoral Models to Generate Baseline Scenarios: Approaches, Challenges, and Opportunities, Journal of Global Economic Analysis 5(1): 162-195

- Ho, M., Britz, W., Delzeit, R., Leblanc, F., Roson, R., Schuenemann, F., Weitzel, M. (2020): Modelling Consumption and Constructing Long-Term Baselines in Final Demand, Journal of Global Economic Analysis 5(1): 63-80

- Jafari, Y., Britz, W. (2020): Brexit: an economy-wide impact assessment on trade, immigration, and foreign direct investment, Empirica 47(1)

- Jafari, Y., Britz, W., Dudu, H., Roson, R., Sartori, M. (2020): Can Food Waste Reduction in Europe Help to Increase Food Availability and Reduce Pressure on Natural Resources Globally?, German Journal of Agricultural Economics 69(2): 143-168

- Britz, W., Roson, R. (2019): G-RDEM: A GTAP-Based Recursive Dynamic CGE Model for Long-Term Baseline Generation and Analysis, Journal of Global Economic Analysis 4(1): 50-96

- Nong, D., Escobar, N., Britz, W., Börner, J. (2020): Long-term impacts of bio-based innovation in the chemical sector: a dynamic global perspective, Journal of Cleaner Production 272(November 2020): 122738

- Haddad, S., Britz, W., Börner, J. (2019): Economic Impacts and Land Use Change from Increasing Demand for Forest Products in the European Bioeconomy: A General Equilibrium Based Sensitivity Analysis, Forests 10(52): 1-27

- Jafari, Y., Britz, W., Beckman, J. (2019): The impacts to food consumers of a Transatlantic Trade and Investment Partnership, Bio-based and Appplied Economics 7(2)

- Britz, W., van der Mensbrugghe, D. . (2018): CGEBox: A Flexible, Modular and Extendable Framework for CGE Analysis in GAMS, Journal of Global Economic Analysis 3(2): 106-176

- Escobar, N., Haddad, S., Börner, J., Britz, W. (2018): Land use mediated GHG emissions and spillovers from increased consumption of bioplastic, Environmental Research Letters 13(12)

- Students of „Applied Modeling of Agricultural Systems", winter term 2018/19: Impacts of US-China Trade war, presented to the OECD in Paris

- Britz, W., Roson, R. (2018): Exploring Long Run Structural Change with a Dynamic General Equilibrium Model, 21st Annual Conference on Global Economic Analysis, Cartagena de Indias (Colombia)

- Jafari, Y., Britz, W. (2018): Modelling heterogeneous firms and non-tariff measures in free trade agreements using Computable General Equilibrium, Economic Modelling

- Students of „Applied Modeling of Agricultural Systems", winter term 2017/18: Impacts of Climate Change on the Agricultural Sector and Food Security in Developing Countries, presented to the FAO in Rome

- Britz, W., van der Mensbrugghe, D. . (2016): Reducing unwanted consequences of aggregation in large-scale economic models - A systematic empirical evaluation with the GTAP model, Economic Modelling 59: 462-473

Structure of the CGE block

- Introduction, SAM as the data balance
- The production side
- Factor supply
- Final demand
- Income generation and distribution
- International trade
- Extensions and applications

What is a CGE I ?

- A Computable General Equilibrium Model:
  - Covers all sectors of an economy
  - and primary factors
  - Prices of all commodities and primary factors endogenous
  - Covers state budget, investments and savings
  - Equations guarantee closed balances in values and quantities for commodities and factors (nationally and eventually globally)
  - Explicit production technology

What is a CGE CGE II ?

- Based on behavioral assumptions of micro-theory:
  - profit maximizing producers
  - utility maximizing consumers
  - Revenue maximizing factor supply
- Competitive markets for products and factors
- Marginal returns to factors equal across sectors
  (at least in standard model where factors are fully mobile)
- Agents receive income according to their factor supply (plus/minus transfer income)
- Thus, consistent description of income generation and use

What is a CGE III ?

- Factor demand by different sectors according to first order conditions from cost minimization, at given production quantities

- Zero marginal profits, mostly zero average profits as well due to Constant-returns-to-scale

- (Zero) profits equal to
  - revenues (quantities produced times producer prices)
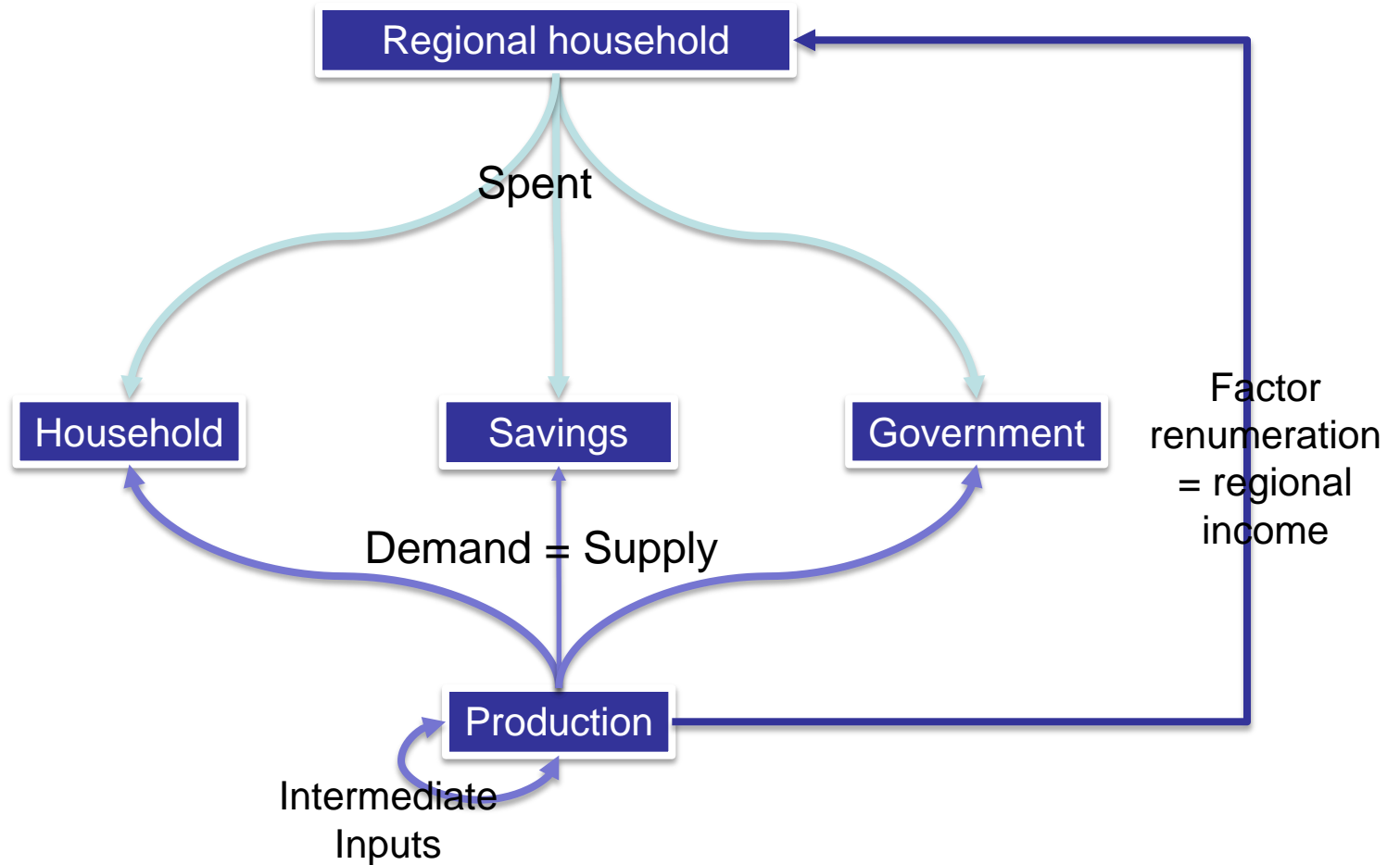 - minus costs (factor/intermediate good usage times related prices)

What are CGEs used for?

- Wide range of applications possible
  (full sectoral coverage, closed accounting):
  - Global CGEs (mostly GTAP based):
    - Trade questions
    - Global resource use
    - Global spillover effects of domestic policies
    - Long-term impacts of population growth, TFP, capital accumulation, resource exhaustion, climate change…
    - …
  - Single country CGEs
    - Domestic policies (e.g. tax reform)
    - Carbon taxes
    - Again long-term impacts
    - …

Why MCMs if there are CGEs?

- Global CGEs higher aggregated with regard to products
  (GTAP data base covers 57 sectors for the total economy,
  CAPRI has about that number for agr + food)

- Typically no sub-national regions

- Do (typically) not use physical quantities

- Policy instruments mostly as relative wedges (ad-valorem taxes and subsidies)

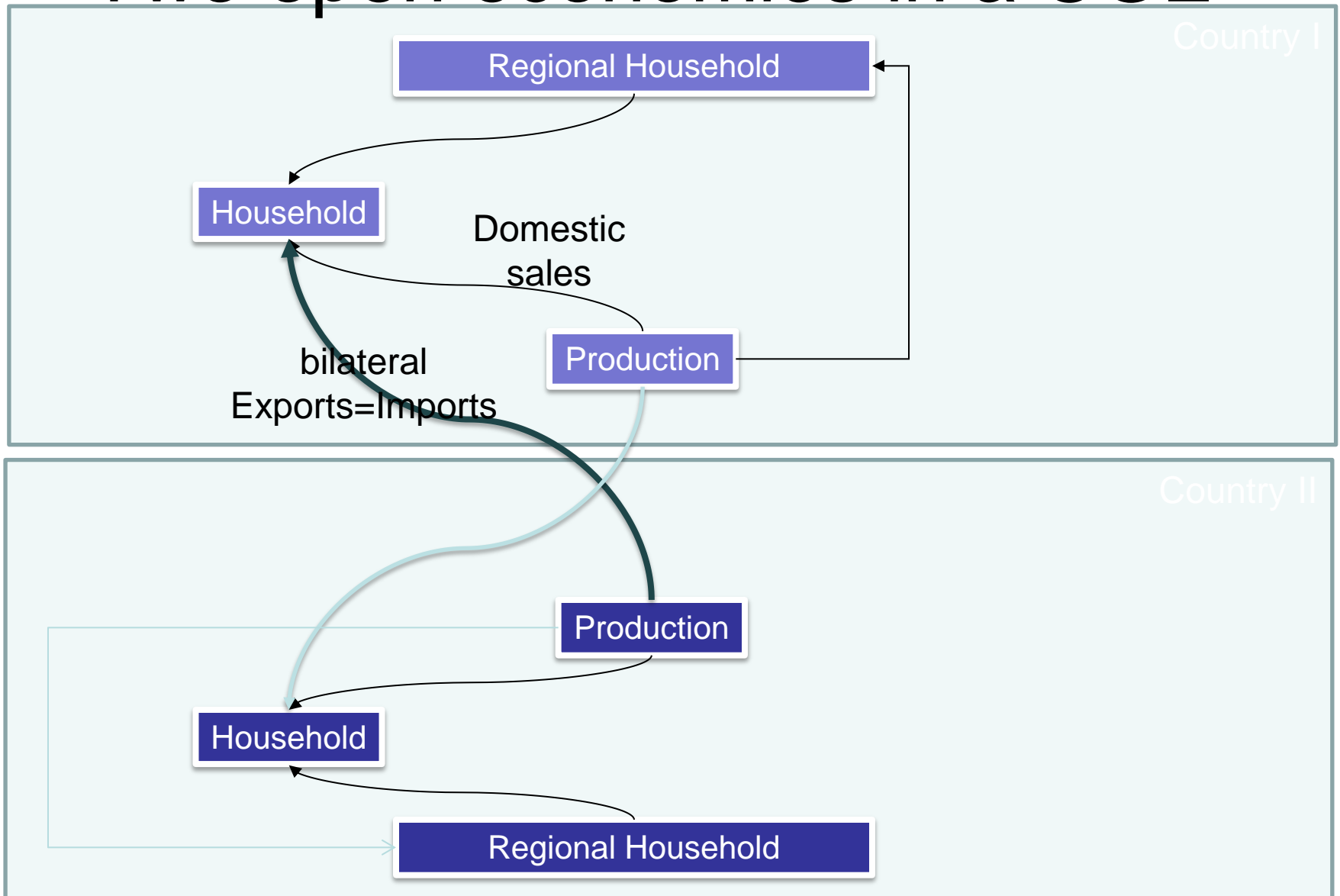- Often comparative-static in base year

CGE structure of a closed economy with only income tax

Regional household

Spent

Household

Savings

Government

Demand = Supply

Factor renumeration = regional income
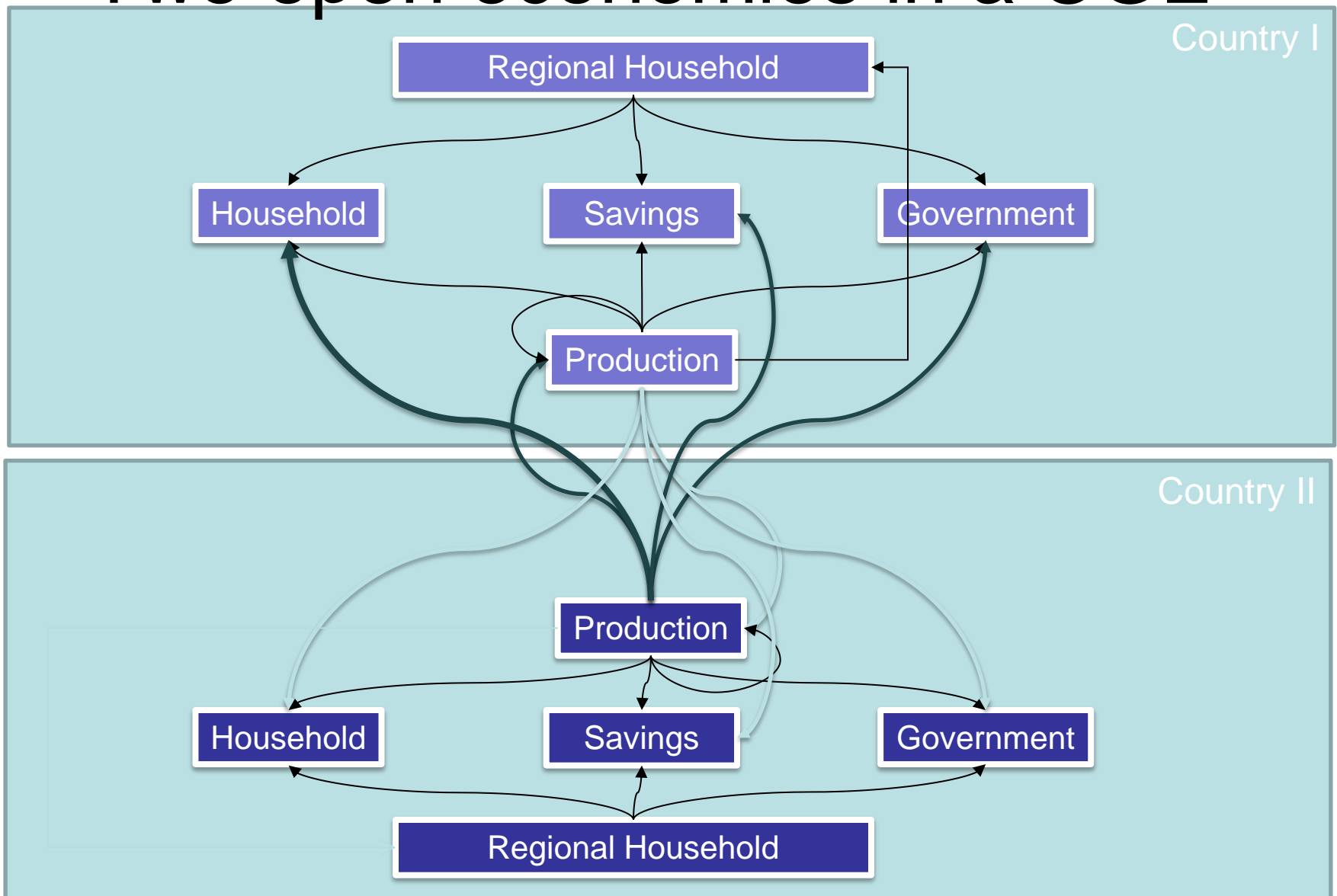
Production

Intermediate Inputs

A closed economy

- Regional household collects income (=GDP)
  - Factor income
  - Indirect tax revenues
- Distributes it to:
  - Household demand
  - Savings (= investments)
  - Government demand
- Final and intermediate demand covered by production
  - Intermediate demand are costs (for some firms) and revenues (for others) at the same time
  - Remaining costs is factor remuneration

Two open economies in a CGE

Country I

Regional Household

Household

Domestic sales

bilateral
Exports=Imports

Production

Country II

Production

Household

Regional Household

Two open economies in a CGE

Country I

Regional Household

Household   Savings   Government

Production

Country II

Production

Household   Savings   Government

Regional Household

CGE in open Economies

- Regional household collects income (= GDP)
  - Factor remuneration
  - Indirect taxes (also on export and imports)
- Distributes it to:
  - Household demand
  - Domestic savings
  - Government demand
- Final and intermediate demand covered by domestic sales and imports
- Production serves domestic sales and exports
- Revenues from (exports-imports = balance of trade), most be offset by the capital account and net foreign factor income and foreign cash transfers to close the balance of payments.

Database CGE

- Social Accounting Matrix (SAM)
  - Provides a "snapshot" of aggregated economic transactions in an economy over a certain period
  - Combination of a I/O-Table with further economy wide statistics (income generation and use)
  - eventually dis-aggregated by different household types (urban/rural, by income strata)
  - Only values, no physical quantities, not prices

=> CGE are typically based on relative prices, set to unity in the calibration point

Database CGE

Table: *Stylized macro Social Accounting Matrix*

	1 Activities	2 Commodities	3 Factors of production		5 Households	6 Government	7 Capital account	8 Rest of World	Sum	
			Labor	Capital						
	1 ... n sectors	1 ... n sectors	1 ... z types of labor							
1 Activities 1 .. n sectors		Domestic sales				Export subsidies		Exports	*Total domestic revenues*	
2 Commodities 1 ... n sectors	Intermediate demand				Household consumption	Government consumption	Investments		*Total domestic*	R
3 Factors of production Labor 1 ... z types of labor	Labor demand								*Labor income*	E
Capital	Capital demand								*Capital income*	V
5 Households			Labor enumeration	Capital costs					*Household income*	E
6 Government	Indirect taxes	Import tariffs	Labor taxes	Direct taxes	Direct taxes				*Government revenue*	N
7 Capital account					Private savings	Government savings		Remittance	*Capital account balance*	U
8 Rest of World		Imports							*Revenues*	E
Sum	*Total domestic output*	*Total domestic demand*	*Labor costs*	*Capital payments*	*Household expenditures*	*Government expenditures*	*investments expenditures*	*Exports*		S
	E X P E N D I T U R E S									

Simulation models, Computable
General Equilibrium models I

Database CGE

- How are SAMs constructed:
  - Rely on official statistics, e.g. based on tax records (typically, "black economy" is not accounted for)
  - Individual firm, customs data in a reporting period are aggregated, complemented by household surveys, data by government agencies ..
- Building global SAMs (GTAP) adds manifold challenges:
  - Availability of data for the same period and many countries must be guaranteed (think about countries during and after wars, harmonization of definitions / classifications)
  - Not all statistical offices produce I/O-tables,
  - Bi-lateral trade statistics (import and export flows between countries) must be made consistent
    => that might delete consistency in national statistics

Database CGE

- GTAP (Global Trade Analysis Project) plays crucial role:
  - Provides global data and parameters for CGE modelling since >20 years
  - Ensure completeness, consistency, quality control and comparability over countries (country blocks), sectors and now several time points
  - Data comprise bi-lateral trade flows, related policy wedges and trade margins
  - Current resolution (GTAP Version 10): 141 country (blocks) and 65 sectors
  - Comprises many interesting so-called "satellite accounts", for instance on land and water use, Green House Gas emissions, migration which fit to the SAMs
  - Access for some earlier versions free, the same holds for specific sub-data sets (e.g. on Africa)

Database CGE: flexible aggregation

- Running global CGE models at the full resolution of the GTAP data base still computational challenging (or considered impossible)
  - See cf: Britz, W., van der Mensbrugghe, D. . (2016): *Reducing unwanted consequences of aggregation in large-scale economic models - A systematic empirical evaluation with the GTAP model*, Economic Modelling 59: 462-473
  - Therefore, GTAP data base usually aggregated for model use
  - Requires "template" CGE model which can work with any structurally identical data base
  - Model code independent of the list of sector, regions, factors in current instance
  - Languages such as GAMS and GEMPack facilitate constructing template models
  - GTAP data base delivered with aggregation facility "GTAPAgg"

Walras' law, Homogeneity in prices

- Walras:
  - if n-1 markets closed in an economy, last market closed as well
  - Intuitive explanation: if available income is spent on all but one market, money spent in last market set as well
  - One equation in a GE is dependent on all others and can be dropped (linear dependency)!
- Furthermore, profit and utility maximization problem functions are homogenous in prices (and income)
      => we can fix one price (only relative prices matter), and still leave all markets the model …
- Choice in GTAP (as an example):
  - Global factor price index fixed (<= homogeniety)
  - Foreign savings in one country calculated residually (<= Walras law)

Production

- Typically based on nested CES-production function

- Equations often set-up such that a change from zero substitution elasticity (= Leontief), to Cobb-Douglas (substitution elasticity is 1) and general CES is possible

- More on that next week

External Trade

- Typically based on Armington assumption (CES-Utility function)
- No perfect substitution between imported and domestically produced goods
- Hence, no uniform prices
- Often, different Armington aggregators for household, government and intermediate demand
- Allows introduction of bi-lateral tariffs, export subsidies and transport costs
- Can be complemented by a CET-function which distributes production to domestic sales and exports
- Also new-trade policy models (Krugman, Melitz)
- More on that in later session

Final demand

- Distribution of income between savings, taxes and consumption often based on CD-utility function

- Household consumption based on demand systems (often found: LES)

- Government demand often based on fixed value shares (CD function)

- More on that in later session

„Closure"

- Defines how the system is closed, e.g. based on flexible exchange rates ..

Differences between CGEs

- Dis-aggregation regarding sectors and regions
- Assumption regarding the mobility of factors across sectors
- Different solutions to model unemployment
- Policy instruments (taxes, transfer, subsidies, tariffs ..)
- One or several household types
- Typically comparative static, but recursive-dynamic and dynamic versions exist as well
- Differences in closure

Some well-known CGEs

- GTAP Standard
  - Model matches global GTAP data base
  - Realized in GEMPACK (now also in GAMS)
  - Provides basic structure of our toy model
  - Starting point of different extensions, e.g.
    - GTAP-AGR: specific features for agriculture
    - GTAP-E: specific features for energy sectors / commodities, emissions
    - GTAP-AEZ: land use at sub-national level (Agri-Environmental Zone)
    - GTAP-HET: Implementation of Melitz trade model
    - myGTAP: multiple households
    - ….

Some well-known CGEs

- IFRI Standard model
  - http://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams-0
  - Single country CGE
  - GAMS based, open source
  - Long application history in developing countries
  - Variants with sub-regions currently used in PhD project

Some well-known CGEs

- GLOBE (http://www.cgemod.org.uk/globe.html)
  - GAMS based, Scott McDonald and Karen Thierfelder
  - Draws on GTAP data base
  - Variants for energy, migration, imperfect competition
- STAGE is "sister model" for single country analysis
- Open source, yearly courses

Some well-known CGEs

- MAGNET (http://www.magnet-model.org/About.aspx)
  - Modular extension of GTAP model
  - GEMPACK
  - Had originally a focus on EU agriculture
  - IPR protected

Some well-known CGEs

- ENVISAGE
  - http://ledsgp.org/resource/technical-reference-guide-for-envisage/?loclang=en_gb
  - Developed in the world bank for long-term analysis by Dominique van der Mensbrugghe
  - Recursive-Dynamic
  - Focus on Climate change and resource issues, versions which cover water
  - GAMS based
  - Variant now used by FAO

Some well-known CGEs

- MIRAGE
  - http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=14
  - Trade focus
  - Imperfect competition based on Krugman
  - Often used by EU-Commission for trade impact assessment
  - GAMS based, IPR protected

Not yet well known

- CGEBox
  - Developed by Dominique van der Mensbrugghe (GTAP director) and Wolfgang Britz
  - Draws on ENVISAGE structure
  - Replicates fully the GTAP Standard Model in GAMS, open source, Graphical User Interface
  - Implements various extensions (examples: GTAP-AGR, GTAP-E, GTAP-HET, GTAP-AEZ)
  - Comparative-Static or recursive-dynamic
  - Global or single country
  - Will be used by us later in class
  - Backbone of CGE work in group