Integrated Economic-Environmental Modeling for Evidence-Based Public Policy and Investment Design

IEEM (Integrated Economic-Environmental Modelling) and CGE Modeling: A Primer

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Introduction

- In this session, we make a discursive (or verbal) presentation of IEEM -- only selected equations are shown.
- The detailed mathematical statement of IEEM can be found in the workshop material and at https://openieem.iadb.org/.
- IEEM is a recursive dynamic Computable General Equilibrium (CGE) model initially developed at the Inter-American Development Bank to analyze medium- and long-term policies.
  - dynamics = endogenous adjustment of factor endowments and stocks of natural resources and productivity
  - follows Dervis et al. (1982) tradition; neoclassical-structuralist; also, relationship with literature incorporating environmental issues in CGE models

What is a CGE Model?

What is a CGE Model?

- In a nutshell, A CGE model is the computer representation of a real economy.
- Mathematically, a CGE model is a system of simultaneous non-linear equations. Types of equations:
  - behavioral (e.g., profit maximizing producers)
  - balance/equilibrium (e.g., savings = investment)
  - definitions (e.g., household income)
- IEEM contains extensions to capture the interaction of the economy with the environment.

What is a CGE Model? – cont.

- Computable → solvable numerically
- General → economy-wide (all production, consumption, investment, and trade that is covered by the national accounts)
- Equilibrium →
  - optimizing agents have found their best solutions subject to their budget constraints
  - quantities demanded = quantities supplied in factor and commodity markets
  - macroeconomic balance: receipts = spending for government, balance of payments, and savings-investment balance

What is a CGE Model? – cont.

- CGE models capture all interactions between the components of an economy
  - direct and indirect effects
  - **ensure consistency**
  - quantitative results (i.e., not just sign)
  - particularly useful when policy and/or external shocks are large.
- Typically, defined as open-economy, economy-wide model with
  - (a) flexible prices clearing most markets
  - (b) one or more production sectors and household groups
  - (c) a government with policy tools (taxes, spending)
- In practice, almost all models are “real” – only relative prices matter, not the general price level.

Application Examples

- **Example 1**: increase in worker migration and remittances
  - Direct effect: increased incomes for recipient households
  - Key indirect effects
    - increased demand from recipient households
    - exchange rate appreciation
    - wage pressures in labor market
- **Example 2**: tariff cuts
  - Direct effect: decline in domestic prices for imported commodities with tariff cut
  - Key indirect effects
    - production and consumption responses to price decline
    - government responses (decreases in spending?; tax increases?; increased borrowing?)
    - responses related to the balance of payments (real exchange rate depreciation?; loss in foreign reserves?; higher foreign borrowing? changes in exports and imports?)

The Production Function: A Digression

Production Function

- The production function is used to model the economy-environment relationship and to introduce shocks – e.g., productivity changes. Mathematically,

$$QA_a = f_a(L_a, K_a)$$

- where
  - QA_a = output activity a
  - L_a = labor use activity a
  - K_a = capital use activity a
- This production function violates the law of conservation of matter (material balance) -- matter is neither created nor destroyed, it is only transformed.

Production Function – cont.

- $QA_a = f_a(L_a, K_a, R_a)$
- where
  - R_a = natural resource use activity a; extracted from the environment
- This production function is widely used in economics of natural resources.

Production Function – cont.

- $QA_a = f_a(L_a, K_a, M_a)$
- where
  - M_a = waste flow activity a; M is input because <M → <QA
- This production function is widely used in environmental economics.

Production Function – cont.

- The most general version of the above production function is

$$QA_a = f_a\left(L_a, K_a, M_a, A\left[\sum_{a'} M_{a'}\right]\right)$$

- where
  - A = environmental concentration of any pollutant; depends on total waste emission; then, >A → <QA
- Note: it violates the law of conservation of matter (material balance) - matter is created in the form of waste.

Production Function – cont.

- The synthesis "Natural Resource Economics" and "Environmental Economics" generates the production function

$$QA_a = f_a\left(L_a, K_a, R_a, M_a[R_a], A\left[\sum_{a'} M_{a'}\right]\right)$$

- where we see material inputs R_a and material outputs M_a y QA_a

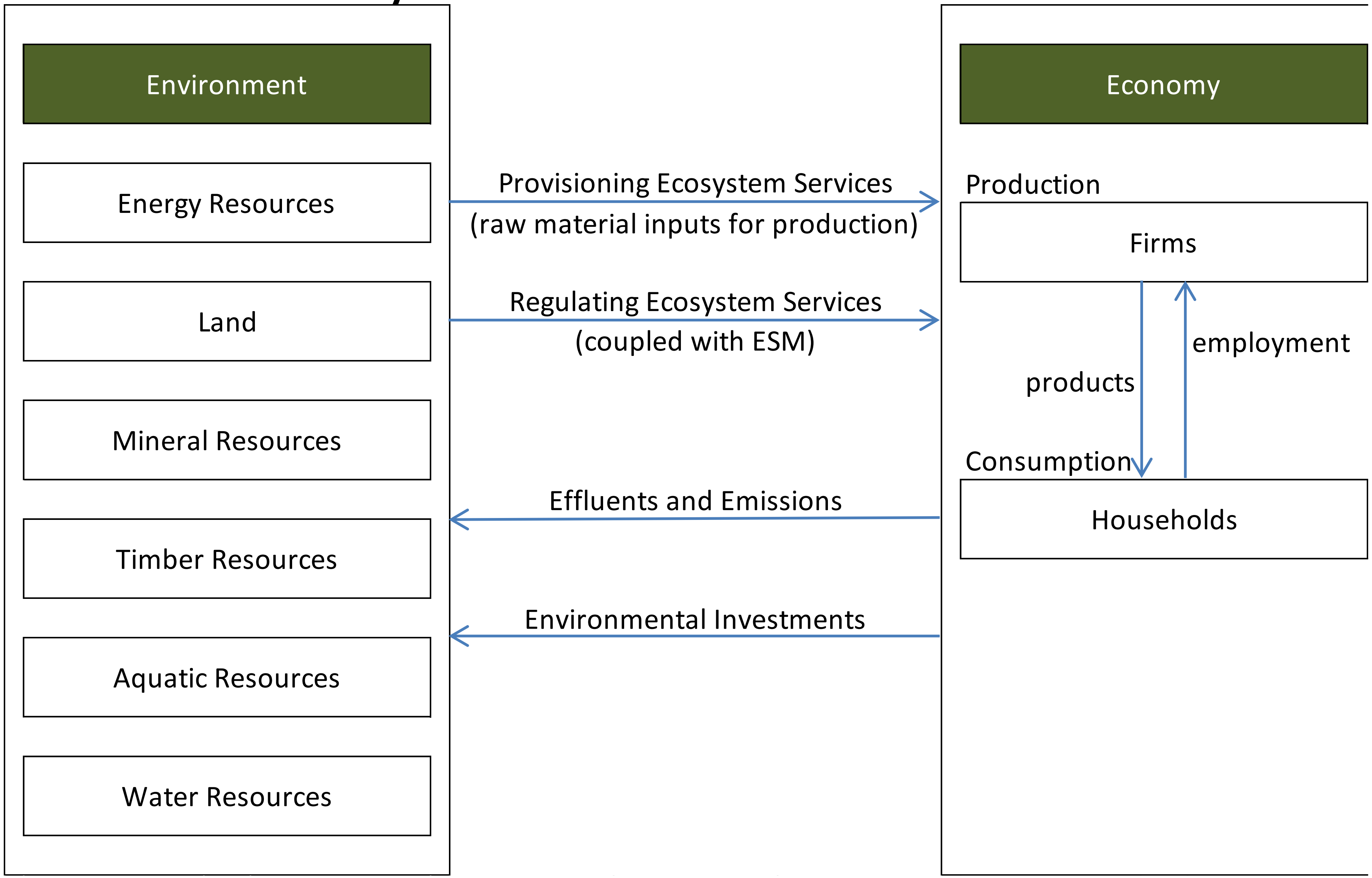
Production Function – cont.

$$QA_a = f_a\left(L_a, K_a, R_a, M_a[R_a], A\left[\sum_{a'} M_{a'}\right]\right)$$

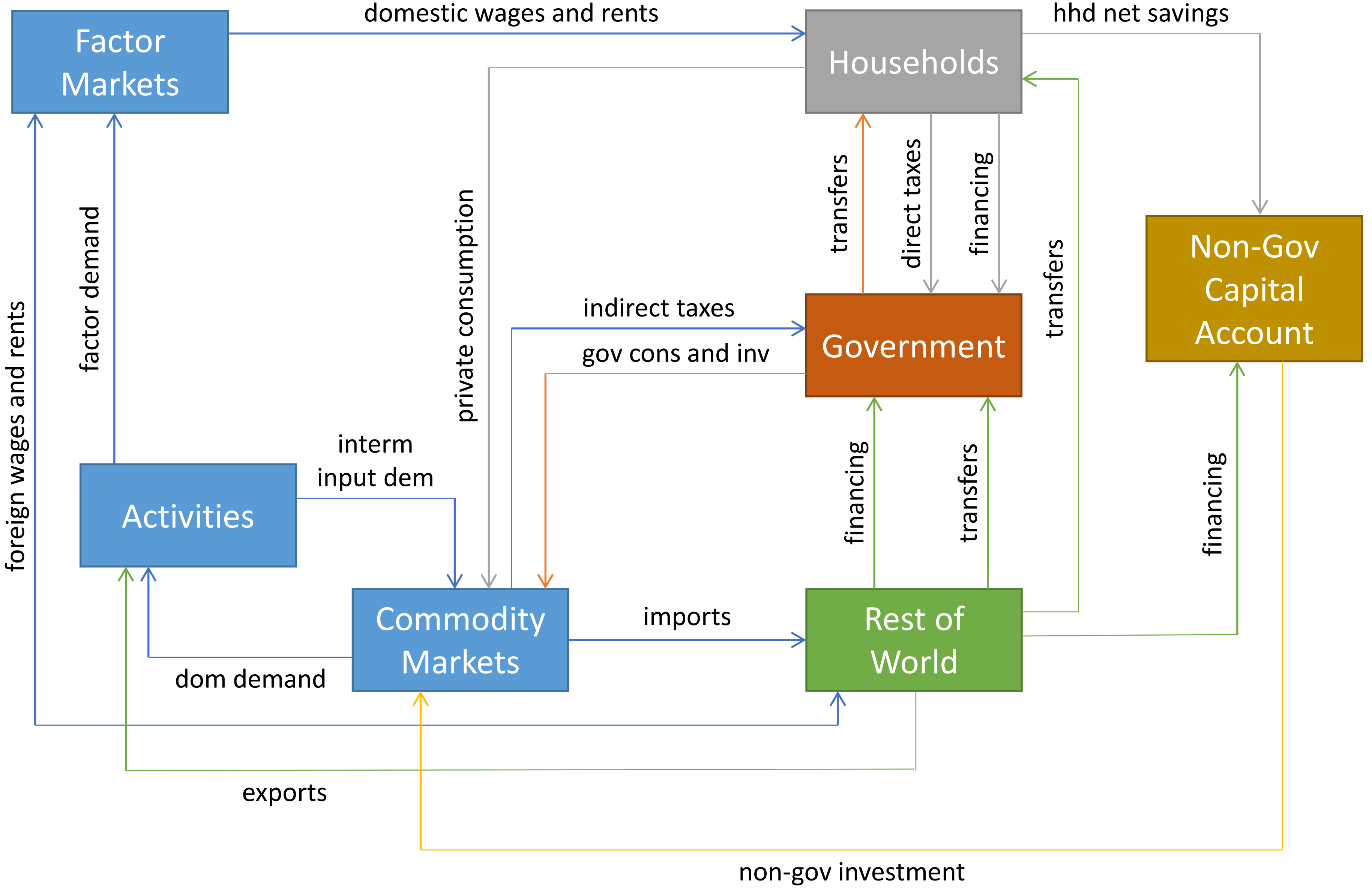
- In this production function,
  - production has a material base
  - the emission of waste results from that material basis
  - consistent with one of the fundamental laws of nature
  - incorporates possible feedback effects of wastes on production; through environmental concentration of pollutants

IEEM – Short Presentation

Economy and Environment Interactions



The Circular Flow of Income - Intra Period



Macro SAM Chile 2016 (GDP%)

	act	com	marg	f-lab	f-cap	hhd	ent	gov	row	tax	cap-ngov	cap-gov	cap-row	inv-prv	inv-gov	dstk	total
act		171.9															171.9
com	81.7		14.7			63.4		13.8	26.8					20.4	2.4	-0.4	222.8
marg		14.7															14.7
f-lab	38.8								0.0								38.9
f-cap	50.3																50.3
hhd				38.7	13.2		23.6	5.1	0.6								81.2
ent					35.9	6.6											42.5
gov					1.2	1.9				17.1							20.1
row		26.4		0.1			2.6	0.0									29.1
tax	1.1	9.8				1.7	4.5										17.1
cap-ngov						7.6	11.9						1.4				20.9
cap-gov								1.2			0.9		0.3				2.3
cap-row									1.7								1.7
inv-prv											20.4						20.4
inv-gov												2.4					2.4
dstk											-0.4	0.0					-0.4
total	171.9	222.8	14.7	38.9	50.3	81.2	42.5	20.1	29.1	17.1	20.9	2.3	1.7	20.4	2.4	-0.4	

In a SAM for IEEM, we have capital accounts for the institutional sectors.

In IEEM application, several activities (act), commodities (com) and factors (f-lab and f-cap) are usually singled out.

Account in Macro SAM Chile 2016

- act = activities
- com = commodities
- marg = trade and transport margins
- f-lab = labor
- f-cap = capital
- hhd = households
- ent = enterprises
- gov = government
- row = rest of the world
- tax = taxes (indirect and direct)
- cap-ngov = capital account domestic non-government institutions
- cap-gov = capital account government
- cap-row = capital account RoW
- inv-prv = private fixed capital formation
- inv-gov = government fixed capital formation
- dstk = changes in inventories

IEEM as a Standard Model

- IEEM is written as a “standard” (flexible structural) model; i.e., as a model that can be applied to different databases without changes in its GAMS (General Algebraic Modeling System) code.
- The term “database” is defined broadly, among other things covering or identifying:
  - typical model data (SAM, elasticities, labor employment, population, etc.) with application-specific disaggregations;
  - time period for simulations;
  - base scenario GDP growth; and
  - a wide range of assumptions for the base scenario:
    - rules for government and non-government payments; and
    - rules for macro balances (government, rest of the world, savings-investment) and factor markets

IEEM as a Standard Model – cont.

- To make this possible, the file system has a rigorous separation between model code and database:
  - a generic set of model files in GAMS
  - application-specific files in Excel for the database and simulations
  - anything that is not specific to a database appears in the model code
    - if you want to correct an error, you only need to do it once
  - model code is written to capture what is found in each database.

Steps for Conducting Analysis with IEEM

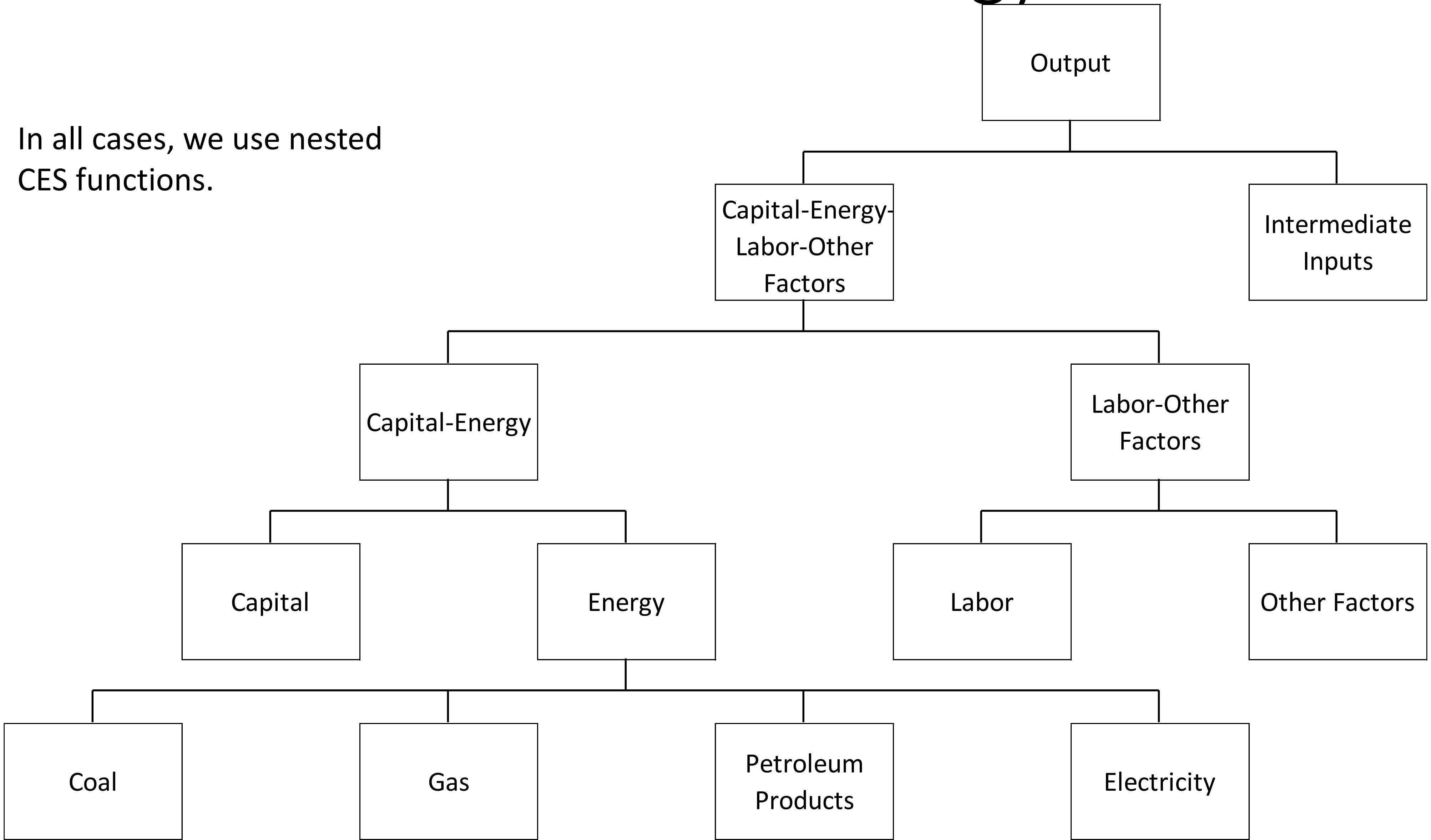
1. Base Scenario
   - projection; BaU - allows imposing GDP growth; domestic and international exogenous variable trends
2. Non-Base (Shocks) Scenarios
   - change policy instrument
   - change parameters such as world prices, water availability, productivity, etc.
3. Analyze and Validate
   - explain differences between base and non-base scenarios
   - adjust data and/or simulations
   - write report

Production Function

- In general, the production functions of the different productive sectors are a key element for the analysis of shocks related to natural capital.
- Thus, consider which elements of the production functions could be used for the introduction of shocks.

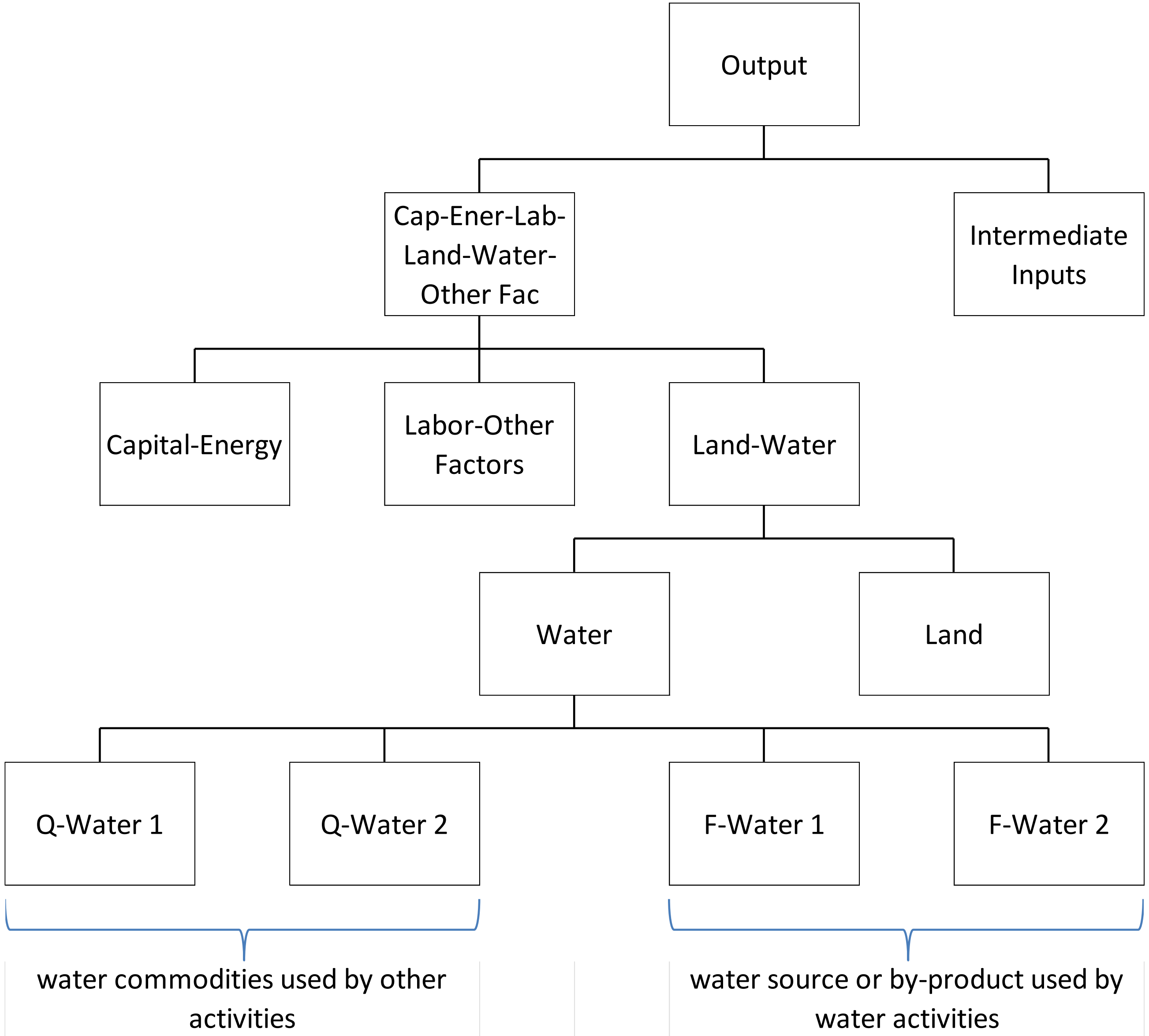
Production Function: Energy Treatment

In all cases, we use nested CES functions.



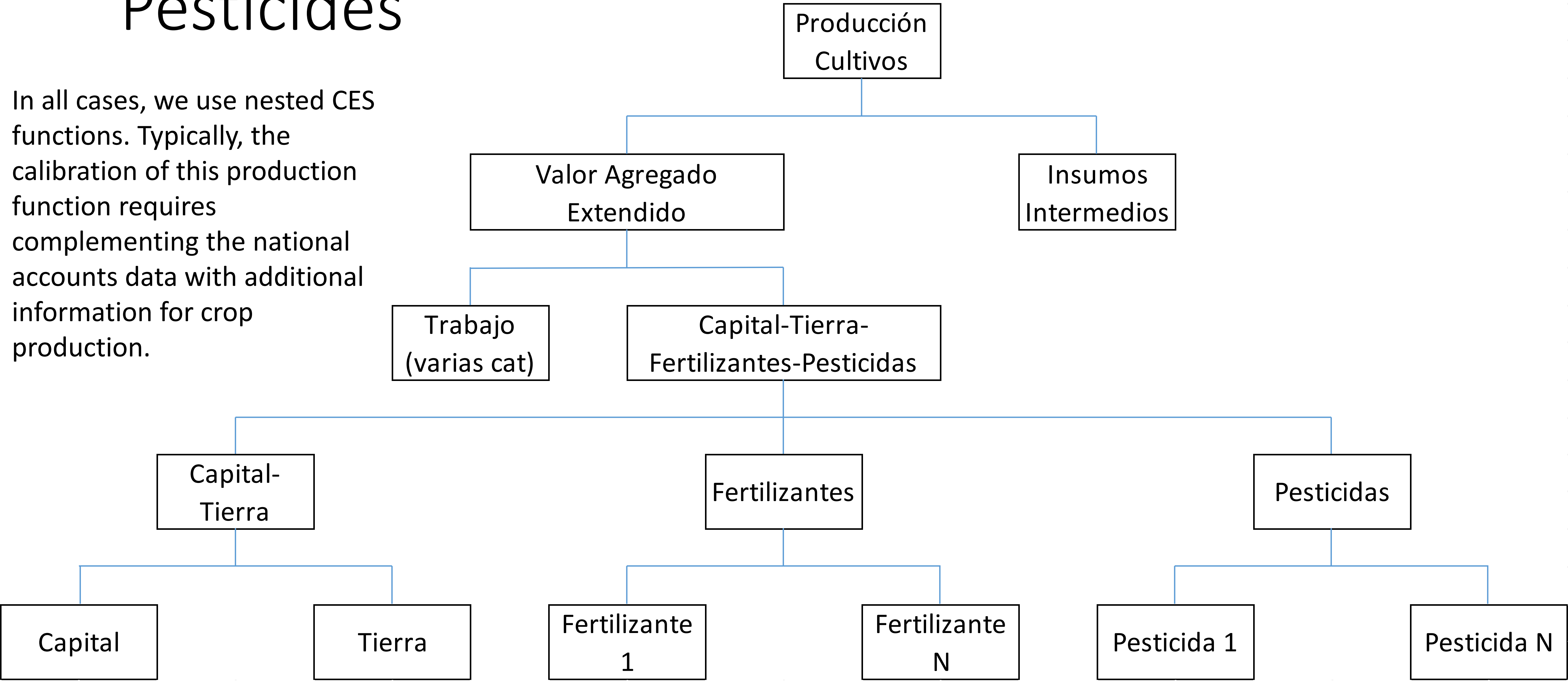
Production Function: Water Treatment

In all cases, we use nested CES functions. It is necessary to single out the rent of the natural resource "water".

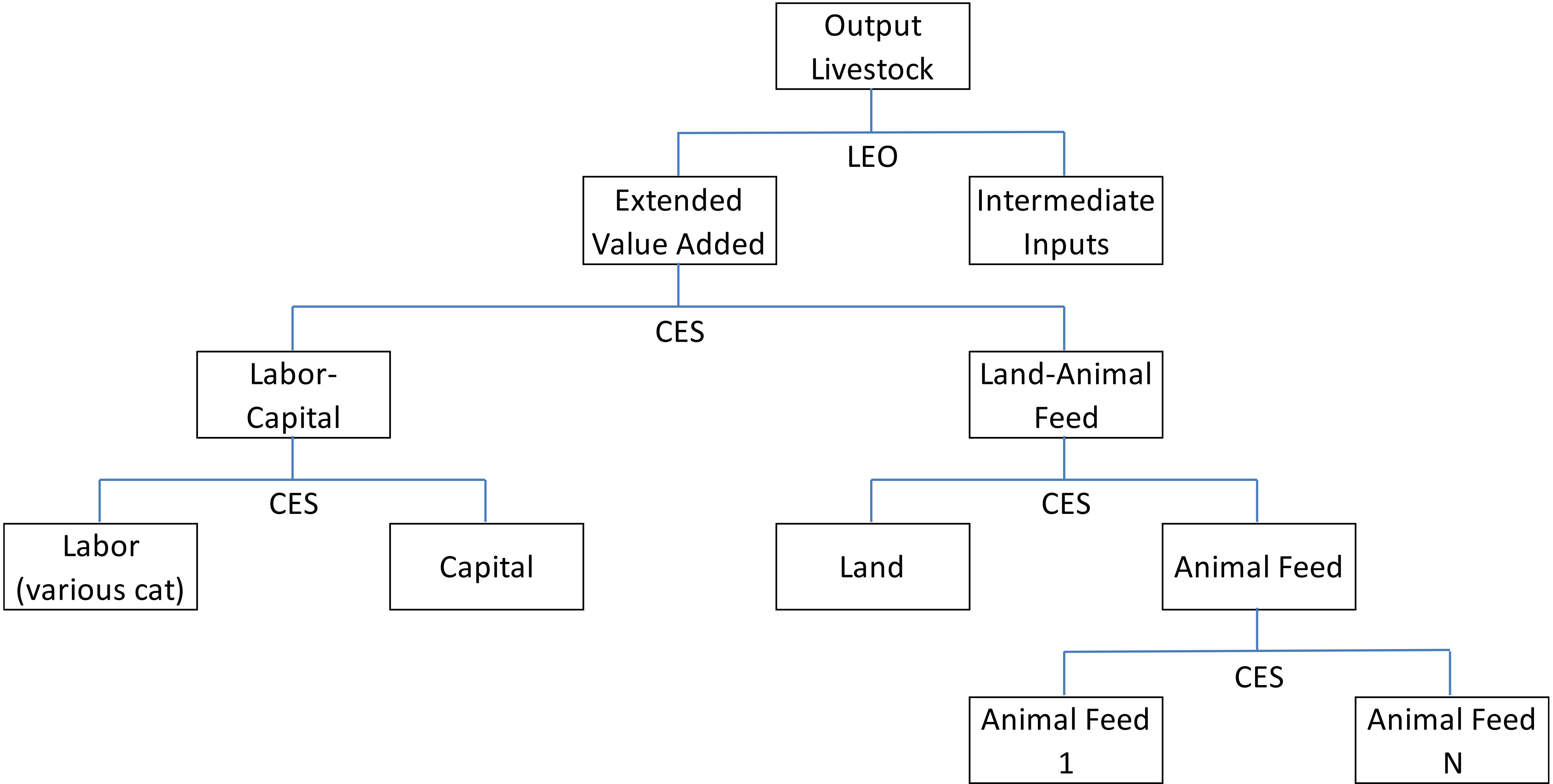


Production Function: Crops - Fertilizers and Pesticides

In all cases, we use nested CES functions. Typically, the calibration of this production function requires complementing the national accounts data with additional information for crop production.



Production Function: Livestock



Production Function: Mining

$$QA_{a,t} = A_{a,t}\left(\delta_a^K \cdot QF_{K,a,t}^{-\rho} + \delta_a^L \cdot QF_{L,a,t}^{-\rho}\right)^{\frac{-1}{\rho}}$$

$$A_{a,t} = QS_{a,t}^{\eta_a} \cdot \varphi_a$$

$$QS_{a,t} = QS_{a,t-1} - QA_{a,t-1}$$

where the usual notation is used and

QA = extraction volume

A = scale parameter

QS = underground resource stock

ϕ = technology parameter

η = elasticity of production (extraction) with respect to stock

Production Function: Fishing

$$QA_{a,t} = q_a \cdot QB_{a,t} \cdot E_{a,t}$$

$$E_{a,t} = \left(\delta_a^K \cdot QF_{K,a,t}^{-\rho} + \delta_a^L \cdot QF_{L,a,t}^{-\rho}\right)^{\frac{-1}{\rho}}$$

$$QB_{a,t} = QB_{a,t-1} + \left[grwfsh_a \cdot QB_{a,t-1}\left(1 - \frac{QB_{a,t-1}}{kfsh_a}\right)\right] - QA_{a,t-1}$$

where the usual notation is used and

QB	= resource stock (biomass)
QA	= fishing volume
grwfsh	= intrinsic growth rate resource stock
kfsh	= environmental carrying capacity
E	= fishing effort as a function of labor and capital
q	= catchability coefficient coefficient
A	= q.B

Production Function: Fishing – cont.

$$QA_{a,t} = A_{a,t}\left(\delta_a^K \cdot QF_{K,a,t}^{-\rho} + \delta_a^L \cdot QF_{L,a,t}^{-\rho}\right)^{\frac{-1}{\rho}}$$

$$A_{a,t} = q_a \cdot QB_{a,t}$$

Factor Demands – Simplest Case

$$WFA_{f,a,t} = WF_{f,t} \cdot WFDIST_{f,a,t} \cdot \left(1 + TFA_{f,a,t}\right)$$

$f \in FVA$
$a \in A$
$t \in T$

$$WFDIST_{f,a,t} = wfdistb_{f,a}$$

$f \in FVA$
$f \in FMOB$
$t \in T$

$$WF_{f,t} = wfb_f$$

$f \in FVA$
$f \in FNMOB$
$t \in T$

$$QF_{f,a,t} = \left(\frac{PVA_{a,t}}{WFA_{f,a,t}}\right)^{\sigma_a^{va}} \left(\delta_{f,a}^{va}\right)^{\sigma_a^{va}} \left(TFP_{a,t} \cdot \varphi_a^{va}\right)^{\sigma_a^{va}-1} \cdot QA_{a,t}$$

$f \in FVA$
$a \in A$
$t \in T$

Imperfect Factor Mobility

$$WFRAT_{f,f',t} = \frac{WF_{f',t} \cdot \left(1 - UERAT_{f',t}\right)}{WF_{f,t} \cdot \left(1 - UERAT_{f,t}\right)} \qquad f \in F,\; f' \in F,\; t \in T$$

$$QFMIGR_{h,f,f',t} = QFINS^0_{h,f,t} \left(\frac{WFRAT_{f,f',t}}{WFRAT^0_{f,f',t}}\right)^{\psi} - QFINS^0_{h,f,t} \qquad h \in H,\; f \in F,\; f' \in F,\; t \in T$$

$$QFMIGR_{h,f,f,t} = QFINS^0_{h,f,t} - \sum_{f' \in MFFP(f,f')} QFMIGR_{h,f,f',t} \qquad h \in H,\; f \in F,\; f' \in F,\; t \in T$$

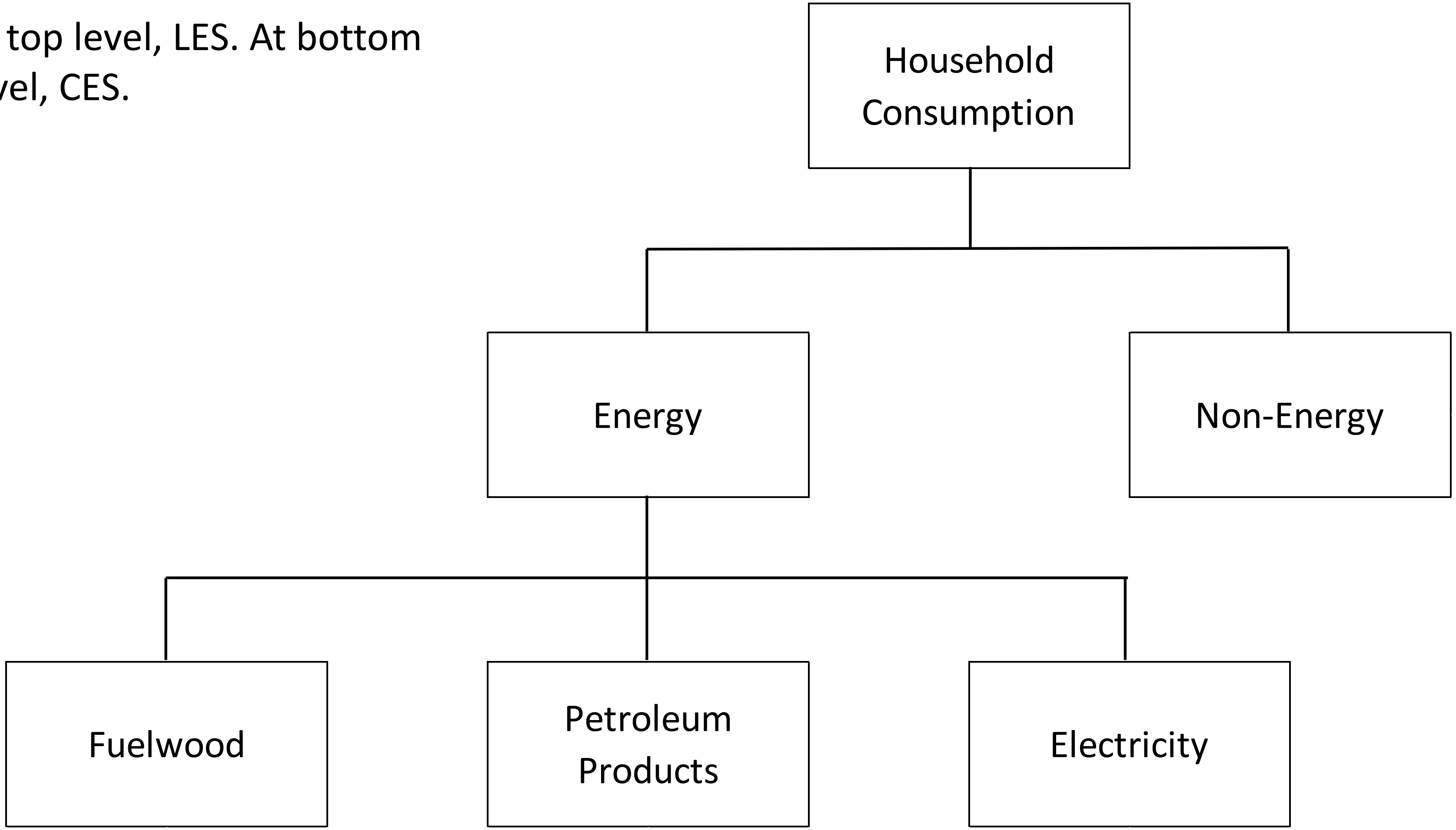
Imperfect Factor Mobility – cont.

$$QFINS_{h,f,t} = \sum_{f' \in F} QFMIGR_{h,f',f,t} \qquad h \in H, \; f \in F, \; t \in T$$

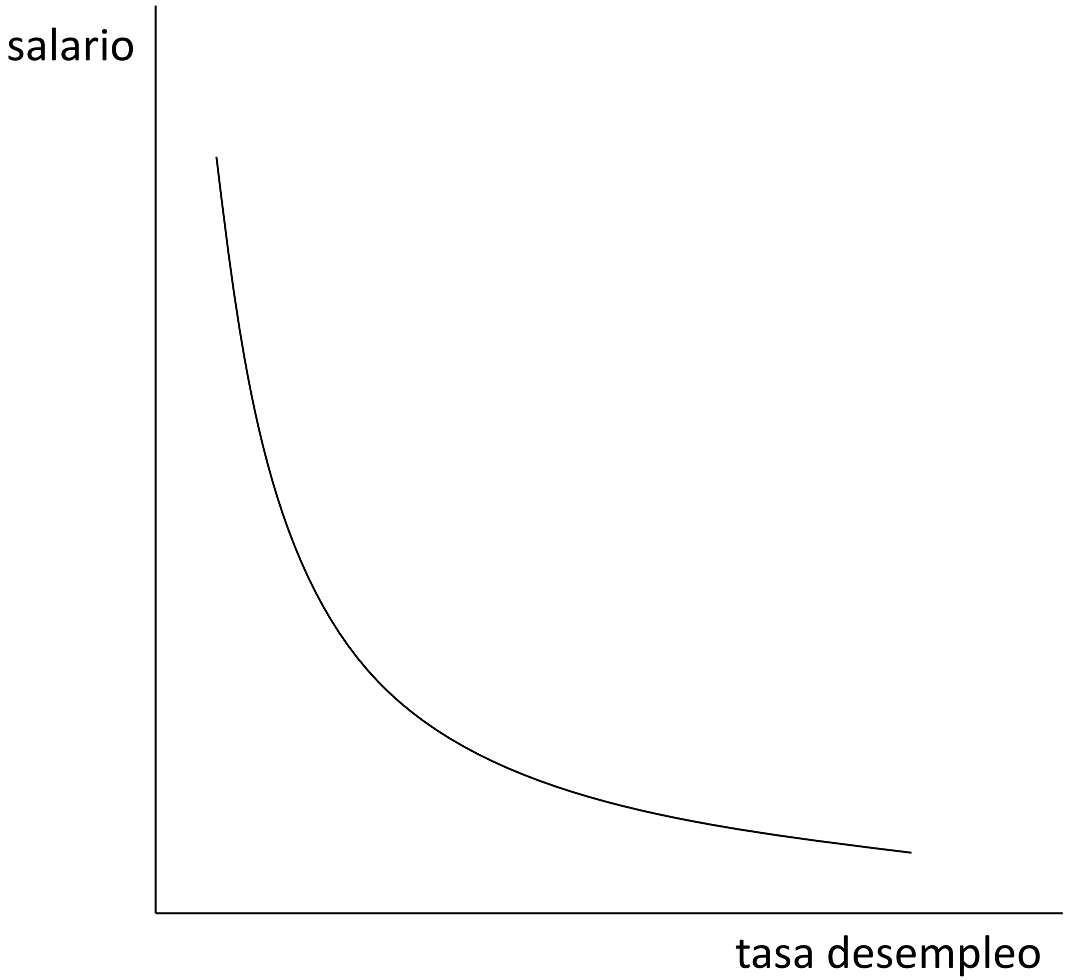
$$QFS_{f,t} = \sum_{h \in H} QFINS_{h,f,t} \qquad f \in F, \; t \in T$$

Household Consumption: Utility Function

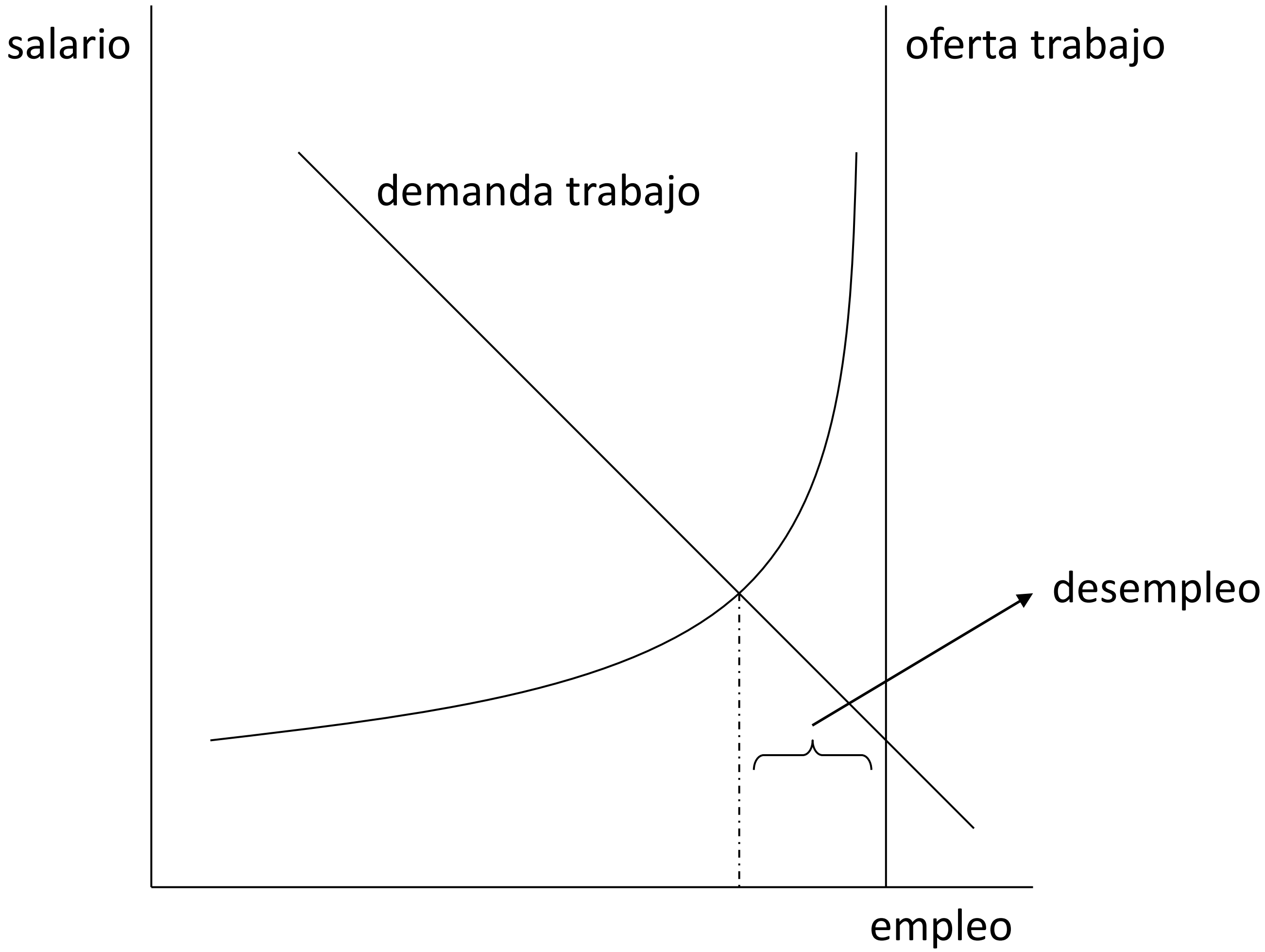
At top level, LES. At bottom level, CES.



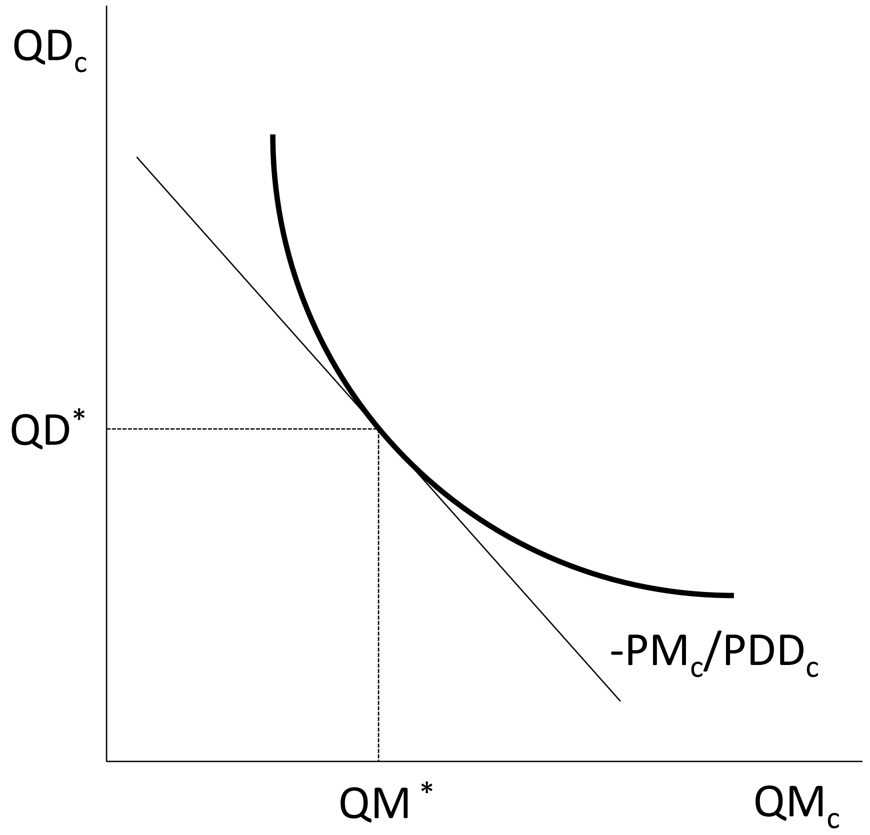
Wage Curve



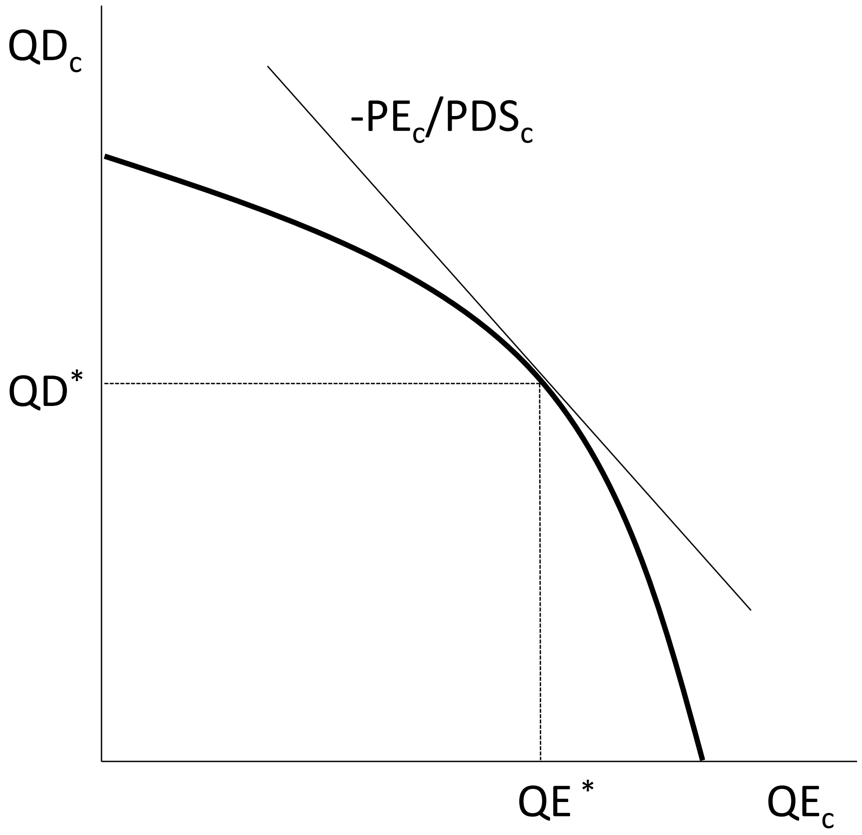
Labor Market



International Trade: Domestic Purchases and Imports



International Trade: Domestic Sales and Exports



Government Budget and Balance of Payments

$$INVG_t = (YG_t - EG_t) + ndfg_t \cdot \overline{CPI}_t + nffg_t \cdot EXR_t$$

$$\sum_{c \in C} pwe_{c,t} \cdot QE_{c,t} + \sum_{i \in INSD} trnsfr_{i,row,t} + \sum_{i \in F} trnsfr_{f,row,t} + SAVF_t$$
$$= \sum_{c \in C} pwm_{c,t} \cdot QM_{c,t} + trnsfr_{row,gov,t} + \frac{\sum_{i \in INSDNG} TRII_{row,i,t}}{EXR_t}$$
$$+ \sum_{f \in F} trnsfr_{row,f,t}$$

$$SAVF_t = nff_t + nffg_t + \sum_{f \in FCAPNG} invf_{row,f,t} - drf_t + WALRAS_t$$

Investment by Activity

$$WFAVG_{f,t} = \frac{\sum_{a \in A} WF_{f,t} \cdot WFDIST_{f,a,t} \cdot QF_{f,a,t}}{\sum_{a \in A} QF_{f,a,t}} \qquad f \in FCAPNG, \quad t \in T$$

$$DKA_{f,a,t} = \left(\sum_{i \in INSNG} DKINS_{f,i,t} \right) \left(\frac{QF_{f,a,t}}{\sum_{a' \in A} QF_{f,a',t}} \right) \left(1 + \kappa_f \left(\frac{WF_{f,t} \cdot WFDIST_{f,a,t}}{WFAVG_{f,a,t}} - 1 \right) \right) \qquad f \in FCAPNG, \quad a \in A, \quad t \in T$$

$$QF_{f,a,t} = QF_{f,a,t-1}\left(1 - depr_f\right) + DKA_{f,a,t-1} \qquad f \in FCAPNG, \quad a \in A, \quad t \in T, \quad t \notin TMIN$$

Greenhouse Gas Emissions - Products and Factors

$$EMI_{ghg,c,a,t} = iemi_{ghg,c,a,t} \cdot QINT_{c,a,t}$$

$ghg \in GHG$
$c \in C$
$a \in A$
$t \in T$

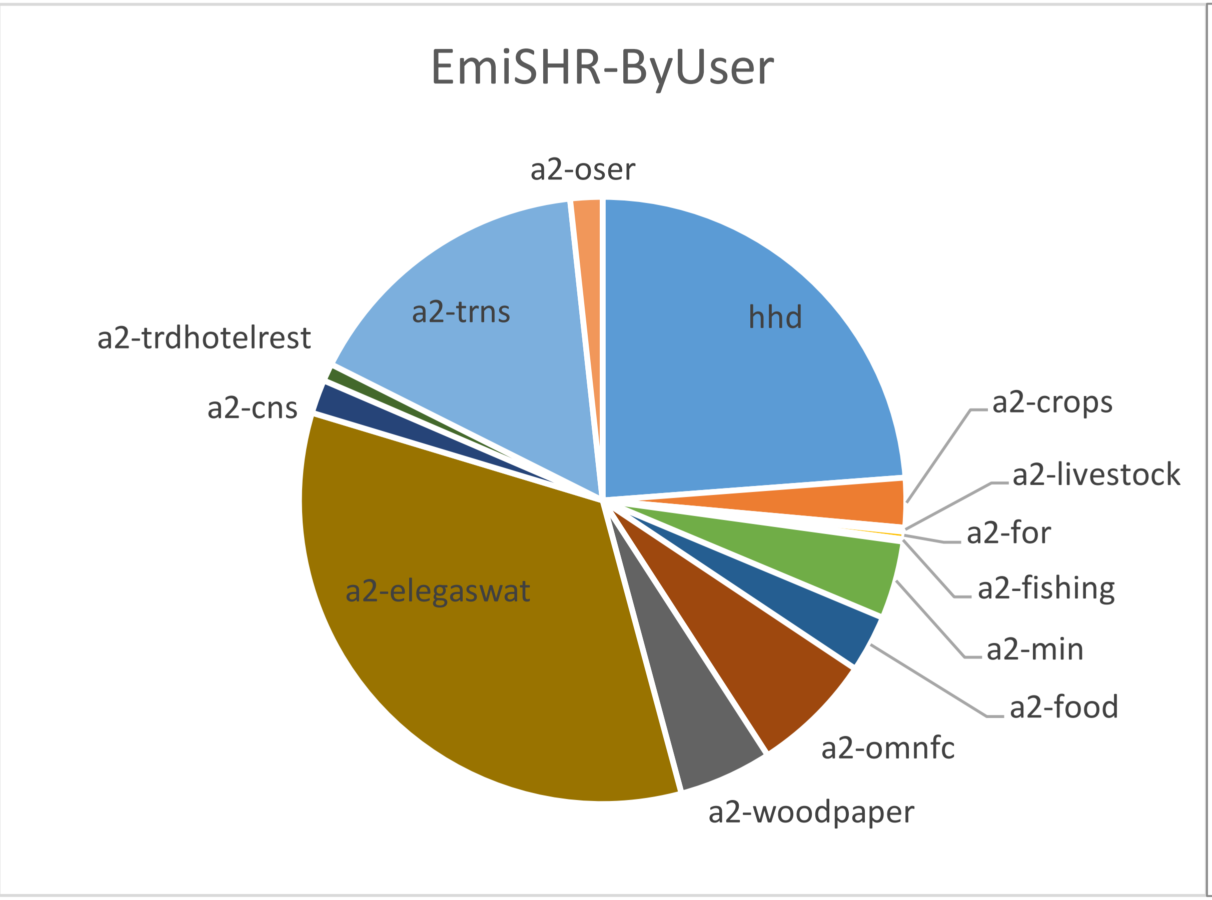
$$EMI_{ghg,f,a,t} = iemi_{ghg,f,a,t} \cdot QF_{f,a,t}$$

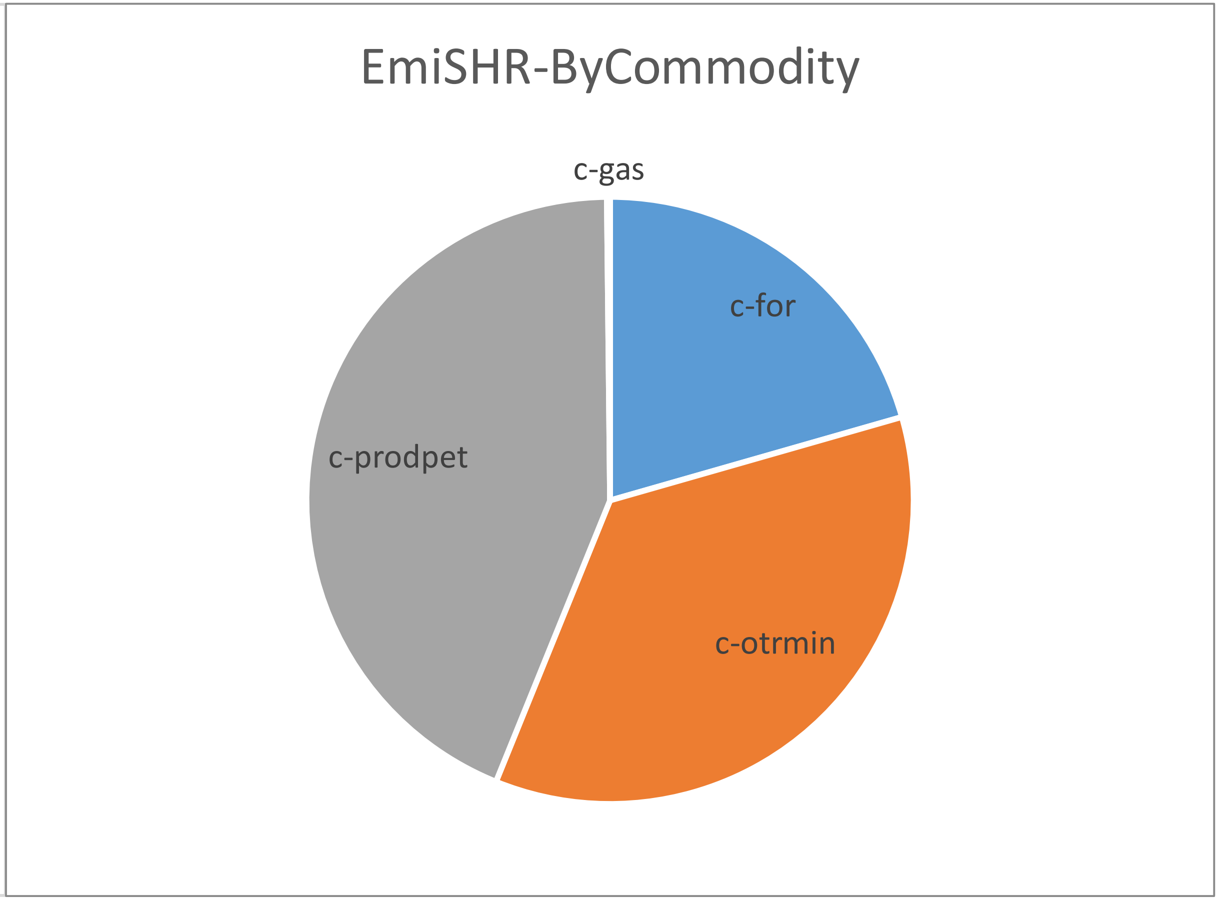
$ghg \in GHG$
$f \in F$
$a \in A$
$t \in T$

$$EMI_{ghg,c,h,t} = iemi_{ghg,c,h,t} \cdot QH_{c,h,t}$$

$ghg \in GHG$
$c \in C$
$h \in H$
$t \in T$

CO2 Emissions Chile (%) – Energy Balance





Greenhouse Gas Emissions – cont.

- In IEEM, emissions from changes in LULC are calculated as follows (IPCC, 2006)

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$
$$\Delta C_{LU} = \Delta A_{LU} \times (F_{AB} + F_{BB} + F_{DW} + F_{SO})$$
$$Emissions = \Delta C_{AFOLU} \times (-{}^{44}/_{12})$$

- where
  - AFOLU = Agriculture, Forestry and Other Land Use, FL = Forest Land, CL = Cropland, GL = Grassland, WL = Wetlands, SL = Settlements, and OL = Other Land
  - AB = above-ground biomass, BB = below-ground biomass, DW = deadwood (DW), and SO = soils.
  - ΔC = carbon stock change
  - ΔA = change in area in hectares
  - F = carbon storage factor
  - $Emissions$ = Net CO_2 emissions from land use changes.

Carbon Storage Factors -- Chile

lucode	LULC_name	C_above	C_below	C_soil	C_dead
0	Forest	102	0	0	0
1	Crops	5	0	0	0
2	Shrubs and herbs	2.5	0	0	0
3	Sparse vegetation and bare area	1	0	0	0
4	Snow and ice	0	0	0	0
5	Wetland, water and tidal	0	0	0	0
6	Urban	0	0	0	0

Other Extensions, Distributional Analysis and Interaction with Ecosystem Services Model

- For the forestry sector, some alternatives:
  - exogenous/endogenous deforestation
  - transition from forest land to agricultural/livestock land
  - disaggregation legal/illegal logging; resource rent
- IEEM implements a module to capture waste generation.
- For distributive analysis, relatively simple top-down approach – microsimulation model.
- In addition, top-down and TD-BU approach for interaction with ecosystem service models.

Policy Instruments Government

- IEEM provides several instruments to implement public policies.
  - Expenditures:
    - current
    - capital (investment); infrastructure and other
  - Revenues (financing):
    - taxes; "green taxes“
    - transfers from the rest of the world
    - borrowing (domestic and/or external)
- In addition, flexibility to design scenarios; macro closure rule.

Main Results

- IEEM reports the evolution over time of
  - private and public consumption, private and public investment, exports, imports, value added, and taxes
    - all indicators at the national level or disaggregated (by activity, product, and/or type of household)
    - various environmental indicators (e.g., per capita water consumption)
    - genuine savings proxy = savings accounting for natural resource depletion, pollution, and investment in human capital
    - domestic and external debt stocks
    - distributional indicators (poverty and inequality)

Questions that Can Be Answered

- What would happen if...
  - changes in water availability?
  - changes in energy consumption efficiency?
  - changes in deforestation?
  - changes in tax policy?
  - changes in world export/import prices?
  - external debt relief?
  - changes in population growth rate with/without changes in population age structure?
  - alternative patterns of productivity growth in private sectors?

Questions that Can Be Answered – cont.

- What would happen if the government...
  - expands the provision of one or more services with financing from
    - foreign aid
    - taxes
    - domestic/foreign borrowing?
  - shrinks in one area and expands in another with no change in "fiscal space"?
  - becomes more/less productive, adjusting one or more types of spending and/or financing in response?