

A short introduction to macroeconomics model in EUCalc

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Summary

This report provides a short introduction to the methods used to assess the economic impacts of energy and environmental policies, in particular Input-Output and CGE models.

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1 Introduction

There exist three main approaches to assess the economic impacts of environmental and energy policies:

1. Input-Output (IO) analysis: linear model based on IO tables which are tables of all the monetary flows in a country. We describe the IO method, its advantages and drawbacks in section 2.
2. CGE model: non-linear model describing the behaviours of households, government, firms and markets. We present the basics of CGE models, their advantages and drawbacks in section 3.
3. Econometric analysis: Econometrics is statistics applied to economics. The idea behind this approach is to use historical data to identify long-run relations between economic growth (and employment) and energy consumption, installed capacity of renewables, investment in energy efficiency, etc. The econometric analysis is useful for studying some past or current policy questions. However, relying on econometric analysis is not adequate for the EUCalc project because:
 - a. In EUCalc, a user's scenario can be associated with large economic changes (e.g. in meat consumption and energy mix) while econometric relations can provide relevant insights only if the new policy creates a small deviation.
 - b. Econometric analysis relies on historical data. It is unlikely that similar relations remain valid in 2050. Moreover, little is known about recent (disruptive) technologies that are not yet widely adopted (e.g. electric vehicles).
 - c. Most econometric studies focus on energy efficiency or solar and wind investment. In EUCalc, many others sectors (e.g. agriculture, transport) are affected.

2 National Accounting and Input-Output model

In this section, we first introduce some notions of national accounting, then we present what are Input-Output Tables and the Input-Output method, and finally we discuss the limitation of this method.

2.1 GDP and National Accounting

The Gross Domestic Product (GDP) is a monetary measure of the production (Y) of a country. Since all the products must be bought by somebody, the GDP is also equal to the total expenditure. The total expenditure is the sum of the consumption of households (C), the investment (I), the government spending (G) and the trade balance, i.e. the export (EX) minus the import (IM). Thus, we have:

$$GDP = Y = C + I + G + (EX - IM)$$

Moreover, the GDP also measures the income of a country, i.e. the income of households, firms' owners and government. The income of households and firms' owners can be split into revenues from labour (L) (=sum of wages \times number of hours worked) and capital (K). The revenue of the government consists in the taxes minus the subsidies (T). Hence, we have:

$$Y = L + K + T$$

Another way to understand national accounting is to note that the amount saved in an economy must be equal to the amount invested, i.e. the savings equal the investment (I):

$$I = (L + K - C) + (T - G) + (IM - EX)$$

Where $S_H = (L + K - C)$ is the private savings, i.e. the disposable income minus the consumption; $S_G = (T - G)$ is the public savings and $(IM - EX)$ is the capital inflow in the country.

2.2 Input-Output tables

An Input-Output (IO) table is a table of all monetary flows in a country. It expands the national accounting presented above to detail several economic sectors. An economic sector is the aggregation of all firms working in a defined sector (e.g. Agriculture, Electricity distribution, Water supply, Industry, Services, etc.). Suppose we represent the economy with n sectors. An example of IO table is provided in Table 1 below.

The output of each sector j is called X_j . The sectoral output can be produced domestically or imported (IM_j). To produce X_j , firms need inputs. First, they need intermediate inputs, i.e. inputs from their sector and other sectors (X_{ij}). For instance, the agriculture sectors need electricity, water, fertilizers, tractors, fuel, etc. Firms also need *factors of production*, which include labour (L_j), land and capital (K_j). Finally, firms pay taxes and receive subsidies (T_j). The sum of all the inputs is equal to the output (column summation in Table 1), i.e. we have:

$$X_j = \sum_i X_{ij} + T_j + L_j + K_j + IM_j$$

Now if we look at a row in the table. The output X_i must be consumed domestically or exported (EX_i). Domestic consumption includes the intermediate consumption of firms (X_{ij}) and the domestic final demand. The domestic final demand includes household consumption (C_i), investment (I_i) and government spending (G_i). Thus, we have:

$$X_i = \sum_j X_{ij} + C_i + I_i + G_i + EX_i$$

The table is called "balanced" when the sum over a row is equal to the sum over a column.

Table 1: An Example of IO table²

	Intermediate demand			Final expenditure				Output (X)
	Sector 1	...	Sector n	Consumption C	Investment I	Government Spending G	Export EX	
Sector 1	X_{11}	...	X_{1n}	C_1	I_1	G_1	EX_1	X_1
...	...							
Sector n	X_{n1}							
Taxes T	T_1							
Labour L	L_1							
Capital K	K_1							
Import IX	IX_1							
Output	X_1							

Suppose that the j^{th} sector, in order to produce one unit, must use a_{ij} units from sector i . We have then $X_{ij} = a_{ij}X_j$. The a_{ij} are called technical coefficients. We can rewrite the summation over a row, noting D_i the final demand (sum of domestic final demand and export):

$$X_i = \sum_j a_{ij}X_j + D_i$$

In matrix form, we get:

$$X = AX + D$$

Hence, we can express the output in function of the final demand:

$$X = (I - A)^{-1}D$$

² We include in T_i the taxes paid by households. Similarly IX_i includes all imports. Alternatively, it is possible to expand the taxes and imports row to the final expenditure.

2.3 Input-Output analysis

2.3.1 Assessing economic impacts

To better understand the IO method, let's take an example. Suppose that we want to assess the impacts of consuming less meat and more vegetables. The meat production sector is called M , and the vegetables production sector V . Consuming less meat and more vegetables means that the final demand of meat (D_M) will decrease by $\Delta D_M < 0$, while the final demand of vegetables (D_V) will increase by $\Delta D_V > 0$. The other components of the final demand remain constant. We can calculate the effects on the output:

$$\Delta X = (I - A)^{-1} \Delta D$$

The change in food patterns affects directly the meat and vegetables production sectors output (X_M, X_V). Moreover, it affects indirectly all the other sectors. For instance, if more fertilizers are needed to produce vegetables than meat, then the output of the fertilizers will increase.

From the change in output, it is possible to estimate the employment impacts using employment factors. An employment factor (e_i) links the output of a sector X_i to the employment E_i such that $E_i = e_i X_i$. Thus, the change in employment is:

$$\Delta E = e \cdot (I - A)^{-1} \Delta D$$

This simple methodology can be replicated to study the impacts of monetary incentives in all the sectors. In EUCalc, this would mean to:

- (a) Translate bottom-up material inputs (food consumption, fuel consumption of households and energy efficiency, change in electricity mix, persons travelling by cars, trains, planes, etc.) into monetary flows.
- (b) Associate each bottom-up to one or several sectors of the IO tables.

2.3.2 Issues and limitations

There are several limitations associated with the IO method, which explains why economists are reluctant to use this methodology:

1. In the standard IO framework, the technical coefficient a_{ij} are assumed fixed (i.e. the proportion of input needed are constant) and only changes in final demand are considered. However, in EUCalc, the intermediate demand will also be impacted. For instance, if there is a material switch in the construction of buildings (e.g. more wood, less concrete), the inputs of wood and concrete by the construction sector will change.

Solution: it is possible to also modify the technical coefficient using inputs from the calculator. This "modified IO method" was applied in the Swiss calculator, Energyscope (Füllemann et al. 2018).

2. In the standard and even in the modified IO framework, prices, substitutions and income effects are not taken into account. However, these effects are key in economics. Going back to our material switch example, if the demand of wood increases, its prices will also increase. Due to this price increase, the construction might want to substitute this input with a cheaper one such as metal or concrete.

3. In the standard and in the modified IO framework, constraints on income and resources are overlooked. Going back to our example, suppose that the material switch implies that the total demand of workers by the firms increases. In the IO model, this means that the employment increases. However, the population is limited, i.e. there is a maximum amount of workers. Thus, equilibrium must be found between the demand of workers by firms, and the “supply” of workers by households. In other words, the wages will adjust (increase) so that the demand of labour equals the supply. Since the wages increase, firms will substitute labour with cheaper inputs (see point 2). Consequently, the IO method overestimates the impacts.

Due to these limitations, the IO method is better suited for small deviations in the economy than for large economic transition that could happen in EUCalc scenarios.

3 Computable General Equilibrium

A Computable General Equilibrium (CGE) is a model describing the whole economy (General³) when no agent has an incentive to deviate (Equilibrium). Due to its complexity, the solution is obtained from numerical simulations (Computable). We present below the ingredients of a CGE model, then we explain how they can be used to assess the economic impacts of energy and environmental policies, finally we discuss the limitations of CGE in the context of EUCalc.

3.1 The ingredients of a CGE

A CGE represents the behaviour patterns of all the economic agents (households, firms, government). We present below the main ingredients of a CGE model, which are: household, firms, and markets. These are the same as in others macroeconomic models.

In the following, we will note p_i the price of product or factor (e.g. capital, land) i and w the wage. Note also that a CGE is used to perform long-run analysis and typically includes several regions, but we will omit time and regional indices for simplicity.

We will also abstract from discussing the government behaviour so that taxes and subsidies are not included (if you want to include them, simply replace the prices p_i by $p_i(1 + \tau_i)$ with τ_i the tax/subsidy).

3.1.1 Households

Households receive income from labour (wL) and capital (p_kK) (what is called factor incomes in Figure 1). They spend their revenue consuming different goods (C_i) and saving (which is the sum of the sectoral investment I_i).

To allocate between the different goods, households are assumed to maximize a function of preferences called utility $U(C_1, \dots, C_n, L)$ subject to their budget constraint, i.e. their spending should be equal to their income (or lower):

$$\max U(C_1, \dots, C_n, L) \text{ s.t. } \sum_i p_i C_i + \sum_i p_{Ii} I_i \leq wL + p_k K.$$

Deriving the first-order conditions of the households' problem yields the goods demand functions, i.e. how much the households are willing to purchase of each good depending on their relative prices (i.e. the price of one good with respect to another).

Moreover, note that labour enters the utility function such that working more decreases the utility (less time for leisure).⁴ Thus, there is a trade-off: by working more, the households sacrifice some utility, but they get a better income and can purchase more goods which increase their utility. The first-order condition on labour gives the supply of labour, i.e. how much households are willing to work depending on the wage.

Note that most CGE models assume a representative agent, i.e. all households are aggregated into one agent. This is not a required feature, but including

³ vs Partial: only one sector included

⁴ Not all CGE models include labor in the utility function.

households' heterogeneity increases the complexity of the model. This becomes necessary if one wants to look at distributional effects.

3.1.2 Firms

Each good i is produced by a representative firm. As in the IO model, firms need intermediate inputs (X_{ij}) and factors of production (e.g. labour L_j and capital K_j). However, in a CGE model, the production function (how the inputs are used to produce, called X_j) is non-linear and accounts for prices and substitution effects $X_j(X_{1j}, \dots, X_{nj}, L_j, K_j)$. In each sector, the representative firm aims to maximize their profit π_j which is their revenue minus their cost:

$$\pi_j = p_j X_j - \sum_i p_i X_{ij} - w L_j - p_K K_j.$$

Deriving the first order conditions yields the intermediate demand, the demand of labour and capital.

3.1.3 Market clearing

A market is an actual or nominal place where goods and factors of production (labour and capital) are exchanged. At the equilibrium, the demand should equal the supply for each good and factor of production. This is called "market clearing". In other words, we have:

$$X_i = \sum_j X_{ij} + C_i + I_i + G_i + EX_i - IM_i$$

$$L = \sum_j L_j$$

$$K = \sum_j K_j$$

Note that the first equation is the same as in the IO framework.

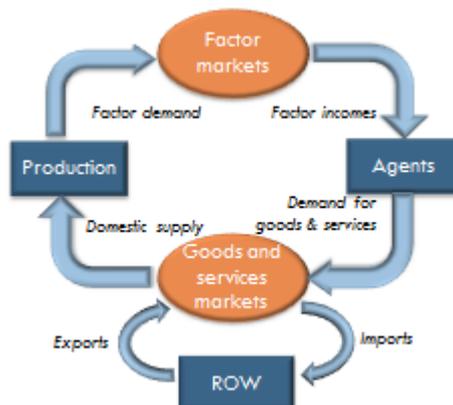


Figure 1: Representation of a macroeconomic model (ROW stands for Rest of the World)

The non-linear systems of equilibrium equations given by the households' problem, the firm problem and market clearing can be solved with a few closing equations (e.g. capital accumulation, savings pattern and trade balance).

Moreover, the simple framework presented here can be adapted to better represent empirical observations depending on the research question. For instance, the labour market clearing above implies that there is no involuntary unemployment (i.e. unemployment arises because workers are not willing to work more) but it is possible to model involuntary unemployment by adding some complexity to the model.

3.2 Assessing economic impacts

CGE models are often used to analyse the long-run effect on the economy of energy and environmental policies.

Since the economic growth depends on many determinants such as population growth or technological change, the first step is to define and simulate a baseline, i.e. a business-as-usual scenario (without the new policy). This includes assumptions for instance on the demography, on economic growth and on international energy prices. A description of the baseline and its assumption in EUCalc is available in Deliverable 7.1 (Yu W. and Clora F. 2018).

Then, the objective is to compare what happens in the baseline and in the scenarios with the new policy.

For instance, suppose we would like to assess the impacts of different levels of carbon taxes. In this case, the parameter shocked (i.e. modified) is simply the carbon tax, and depending on the scenario, different levels can be assumed for different sectors.

Now suppose that we would like to analyse the impacts of the government investing more in energy efficiency and renewable energy. Then, it is possible to: (a) modify the government spending pattern or (b) modify subsidies to energy efficiency and renewable. This requires designing an industrial disaggregation (choice of economic sectors) with sufficient details to represent well energy efficiency and renewable.

3.3 Issues and limitations in the context of EUCalc

In EUCalc, users can design their own alternative future scenarios. They make decisions for instance on energy consumption in buildings, electricity mix, transportation mode, food habits, etc. To assess the socio-economic impacts of this alternative future in a CGE model, we need to translate these inputs into the language of the CGE model. However, conciliating the bottom-up inputs with the top-down framework in a CGE model is a quite challenging task:

1. The CGE top-down approach is not as detailed as the bottom-up approach of the calculator, so that some sectoral details are suppressed (e.g. not as many electricity production sources).
2. In the calculator, each user of the calculator can decide on the allocation of consumption between the different products (e.g. the consumption of meat, vegetables, or energy) without taking into consideration the prices. On the other hand, in a CGE, the consumption of different products is determined endogenously as a function of the prices. Hence, the food and energy demand cannot be directly shocked to reproduce the users' scenario. It is therefore necessary to assume exogenous changes such as a shift in households' preferences (utility function) or a change in taxes.

The questions are then: (a) what parameters should we shock? and (b) what shock level enables to reproduce the users' scenario?

3. In a CGE, the behaviours of households and government are constrained by their income. In turn, the income is constrained by the production factors (i.e. labour, capital, and land) which cannot exceed the available economic resources. Similarly, firms' production is also constrained by the labour, capital and land availability. On the other hand, constraints on labour and capital do not exist in the calculator. This means that some pathways can be feasible technically but not economically.
4. The production and utility functions used in a CGE model (as in most other economic models) rely on parameters called elasticities.⁵ These elasticities are estimated to represent the responsiveness of a variable to exogenous local shocks. Hence, the drastic changes in ambition levels 3 and 4 may not be reconcilable with the CGE framework. In particular, it is quite challenging to model the rapid adoption of disruptive technologies.
5. Finally, important features of EUCalc are the simplicity, tractability and transparency of the model. In particular, the model should allow fast calculation (a few seconds) to be more attractive for the users. But CGE models are computationally and time-expensive. Simulations require several minutes⁶ to compute one solution. Hence, it is impossible to directly link a CGE model with the online calculator. The alternative would be to simulate all possible scenario combinations in advance, and compile the results in a library. However, the number of possible scenario is too high. Indeed, considering 20 levers and 4 levels, this gives 4^{20} scenarios for each country, i.e. more than 3×10^{13} scenarios for EU28 countries and Switzerland.

Consequently, not all users' pathways are compatible or can be simulated using a CGE model. The best option is thus to simulate a set of predefined scenario, which are representative of the different sustainable pathways.

The linkages between EUCalc and GTAP (the CGE model used to obtain the trade flows due to different pathways), the advantages and limitations of this coupling exercise and the "representative" scenario selection are further explored in D7.2 (Baudry et al. 2018).

⁵ In economics, the elasticity measures how a variable responds to a change in another variable. For instance, the price elasticity of demand is the percentage change of the quantity demanded of a good with respect to a 1% change in its price.

⁶ Representing the user's scenario implies to have a large number of economic sectors and at least 30 regions (EU28, Switzerland, Rest of the World). Since the complexity increases with the disaggregation, such a model could take more than one hour to compute a solution.

4 The method to assess employment impacts in WP6

Given the advantages and drawbacks of IO analysis and CGE model presented above, WP6 designed a method “in-between” the two approaches. We quickly present here its main features:

1. Households’ behaviour is similar to a CGE model, i.e. households maximize their utility subject to their budget constraint. However, households only decide on their aggregate consumption and labour level (contrary to a CGE where households decide on the consumption of each product). The allocation of aggregate consumption between the different products is derived using inputs from the calculator, as in an IO method. This allows considering the resource constraints on labour, capital and land.
2. Firms’ production function is a simplified version of the one used in a CGE model. Moreover, the production functions are exogenously shocked using inputs from the calculator, in a similar way of the modified IO method used in the Swiss calculator.
3. We look at each country independently, i.e. imports and exports are either derived from inputs of the calculators or from a simple assumption, as in the modified IO method.
4. We distinguish workers between two levels of education (skilled and unskilled) to better evaluate the differentiated impacts.

Thanks to this design, the system of non-linear equations can be reduced to only three equations. We tested this methodology in a scale model for Germany using the MATLAB software, and we obtained (coherent) results in a few seconds. However, this remains to be seen if the methodology can efficiently be implemented in the calculator (in KNIME) taking into account all the interactions.

If not, WP6 will use a simpler method which combines CGE simulation and modified IO analysis. This method and the (preliminary) interactions between the core and employment modules are described in Deliverable 6.1 (Thurm et al. 2018).

5 Summary of economics vocabulary

Baseline	Reference scenario used in a CGE analysis
Budget constraint	Constraint specifying that the spending of individuals should be lower than their income
CGE (Computable General Equilibrium)	Non-linear model representing the behaviour of households, firms, government markets and prices at the equilibrium
Demand (factor)	Function linking the quantity of a factor that firms need with its price
Demand (goods)	Function linking the quantity of a good that households are willing to purchase with its price
Econometrics	Statistics applied to economics
Factor of production	Resource needed by firms to produce a good. It generally includes Labour, Capital, Land
Final demand	Sum of household consumption, investment and government spending (+ export – import)
General Equilibrium	Production, demand and prices of goods such that no economic agent (households, firms, government) are willing to deviate
GDP (Gross Domestic Product)	Measure of the production/income/expenditure of a country
IO (Input-Output) method	Linear model linking the sectoral output to the sectoral final demand thanks to the matrix of technical coefficient
Macroeconomics	Branch of economics dealing with the performance, structure and decision making in an economy as a whole, with the objective to better understand for instance economic growth, unemployment, or international trade.
Microeconomics	Branch of economics that studies the decision making of individuals and firms and the interactions between them.
Market clearing	Supply equals demand
Production function	Function linking the inputs needed by a firm to the quantity of output it produces
Supply (factor)	Function linking the quantity of a factor supplied by households with its price
Supply (goods)	Function linking the quantity produced by firms with the prices of a good
Technical coefficient	In an IO framework, coefficient linking the quantity needed of an input to produce one unit of output.
Trade Balance	Export minus Import
Utility function	Function representing the preferences of individuals, mapping for instance the allocation between different goods and leisure

6 References and further reading

6.1 Further reading

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