Research Programme on Improving the measurement of the indirect effects of investment projects: Specifying and calibrating EIA methods to maximize compatibility with CBA

DELIVERABLE 1

OVERVIEW OF THE METHODS: CBA, IOA, SAM and CGE

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1. Cost-Benefit Analysis: Basic principles for project appraisal

1.1 Introduction

The Cost-Benefit Analysis (CBA) of projects aims to determine what is their contribution to "Social Welfare", establishing whether the reference society, this is usually the society that funds the project, gains or loses with them, what implies to quantify their impact in monetary terms.

This objective requires the definition of, at least, three main components:

The concept of Social Welfare. The definition of this concept emanates from Welfare Economics principles, with two equivalent approaches for its measurement that are commonly applied in CBA: (a) the approach based on the sum of surpluses of the economic agents affected by the project; (b) the approach based on the sum of willingness to pay (WTP) and resources ignoring transfers (De Rus, 2010). Therefore, the CBA of projects puts their impact on the welfare of society (economic efficiency) in the centre of the analysis. Such analysis from a social perspective, is usually complemented with another one from the financial perspective that sticks to the study of a project viability from the point of view of accounting profits as obtained by the main producers (firms) involved in the project. This, in turn, can be crucial in a context of public budget deficits constraints. Therefore, the social profitability of projects is the main element to be considered, though their financial profitability complements the former in case of budget restrictions (see De Rus et al., 2010).

The Counter-Factual Scenario. A base scenario for comparison purposes must be defined too. This is the reference that allows estimating the impact of a project in incremental terms by comparing it to what would have happened if the project were not implemented. The counterfactual scenario is also known as the "base case" or the "without project situation". Hence, the impact of a project, both, in social welfare and in financial terms, is incremental and estimated with respect to this counterfactual.

Definition of the Project Life or horizon. The projects and their social benefits and costs (and accounting revenues and costs for the financial analysis) spread over time along the project life. This implies that we need, not only to monetize impacts in incremental terms with respect to the base case scenario, but to add them conveniently over time. Actually, this aggregation happens at two dimensions (De Rus, 2008): (a) the inter-temporal one, as impacts in different moments of time are added, making us to apply a social (and financial) discount rate (i.e. changes in social welfare in year zero of the project are added with the rest of changes in social welfare in other years once discounted); and (b) the inter-personal dimension, as we also add variations of welfare affecting different economic agents whose total impact is added at the group level too (e.g. different consumers whose impact on welfare as a group is given by the change in consumer surplus).

Currently the CBA methodology is widely applied for the analysis of public and private projects. The modern history of CBA starts in the US in 1936 when such analysis was requested for waterways projects carried out by the US Corps of Engineers (Brent, 2017; Nas, 2016). In other countries like the UK, the experience of project appraisal goes back as much as 60 years (Mackie, 2011). Nowadays, many countries and public bodies, and the majority of multilateral development banks have available different manuals and guidelines that orientate the appraisal. In the European context there are two main references:

European Commission (2014): Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020.[1] This guideline was prepared by the Directorate General for Regional and Urban Policy to evaluate projects susceptible of getting funding from the European Regional Development Fund (ERDF) and the Cohesion Fund. This is a wide manual, referred to a diverse set of projects (transport, energy, telecommunications, environment, etc.), and with a high degree of detail with respect to both, the social and the financial analysis.

European Investment Bank (2013): Economic Appraisal of Investment Projects at the EIB.[2] The methodology presented in this document refers to CBA as well as to Cost-effectiveness and Multi-Criteria analysis. It also covers several sectors ranging from transport, to energy, health, education and many others.

[1] Available at: http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

[2] See: www.eib.org/infocentre/publications/all/economic-appraisal-of-investment-projects.htm

1.2 Type of effects and markets: the risk of double counting

When measuring the impact of a project (or policy) in social terms, the CBA commonly distinguishes among three types of effects:

Direct effects, or those that appear in the market where the intervention takes place (e.g. the transport market in a transport project). This market is also known as the "primary" market.

Indirect effects, or the impacts that arise in other markets (secondary markets) that are related to the primary one (e.g. the final markets of goods that need to be transported to reach such final market).

Wider economic impacts (WEIs), that can be identified in the rest of the economy. These refer to impacts given by effects like agglomeration economies, changes in the labour market, changes in the level of competition, and so forth. In any case, note that we are interested in such changes as far as they imply changes in welfare of the relevant society.[3] For the sake of simplicity we will refer to these markets as secondary too.

Once the different effects are identified, it is very important to ensure that the evaluator does not incur in double counting when including them all. In other words, the effects may exist, and may be reflecting actual benefits/costs of the project, but this does not necessarily mean that they should be included within the assessment. There are two main concerns regarding their inclusion within the CBA assessment (Jorge-Calderón, 2014): firstly, many of these effects are just a reflection of other savings already accounted for within the direct effects heading; secondly, in many cases these effects (especially the WEIs) do not incorporate a counterfactual comparison, and hence would not be measuring the incremental relevant benefits. Therefore, the inclusion of indirect and WEIs impacts within a CBA framework needs a well economically founded justification.

Indeed, the analysis of indirect effects and particularly the WEIs, is currently subject to an important debate. The methodologies that analyse them can be very different, using

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[3] In some assessments it is possible to find a reference to impacts on employment, GDP or the value of land. This should be translated in welfare terms to make the CBA homogeneous, otherwise is just another insight to consider in addition to the CBA result as far as it does not represent a double counting of effects.

several micro and macro models for their estimation, all with advantages and disadvantages. Actually, neither the evaluation objectives nor the methodologies are consistent among the set of evaluation models and procedures. In some cases, the objective seems to be maximize social welfare, and in other occasions, this objective blurs and the focus moves to macroeconomic variables such employment or GDP, which implicitly are assumed to be closely linked to social welfare. Of special interest is the impact of a project on employment, and moreover with a CBA view, on its impact on the employees' welfare.

Following De Rus (2010), let us consider a simplified economy in which we can identify six groups of economic agents: consumers (C), owners of capital (O), owners of land (R), owners of labour (L), taxpayers (G) and the rest of the society (E), with all groups being equally weighed. Therefore, social welfare is given by the addition of all agents' surpluses, as shown in the following expression, where the symbol Δ denotes changes with respect to the base case scenario:

$$\Delta SW = \Delta CS + \Delta OS + \Delta RS + \Delta LS + \Delta GS + \Delta ES, \qquad (1)$$

where,

SW=social welfare, with a benevolent government that aims to maximize it.

CS= consumers' surplus, or the difference between willingness to pay and what is actually paid.

OS= owners' of capital surplus, or the difference between firm revenues and variable costs.

RS= owners' of land surplus, or the difference between revenues from land minus the opportunity cost of land.

LS= owners' of labour surplus, or the difference between revenues from labour minus the opportunity cost of labour.

GS= taxpayers' surplus or tax revenues minus public expenditure in relation to the project.

ES= other agents' surplus, or the value of external effects.

In a project assessment, the evaluator measures welfare changes as given by variations in these six components over the project life. To proceed so we assume the following:

1. All values are discounted over the project life.

2. Alternatively, we can also use as an approximation of the change in SW the following expression, where PS is the producer surplus (or difference between revenues and variable opportunity costs):

$$\Delta SW = \Delta CS + \Delta PS + \Delta GS + \Delta ES, \qquad (2)$$

3. For ex-ante analysis, in case of a public project investment costs are included in GS, whilst in a private project, investment would be in the PS heading, or alternatively, within OS in equation (1).

Assuming we are not double counting, equation (1) can be further developed by separating effects in primary (P) and secondary (S) markets:

$$\Delta SW = \Delta SW^P + \Delta SW^S =$$

$$= [\Delta CS^P + \Delta OS^P + \Delta RS^P + \Delta LS^P + \Delta GS^P + \Delta ES^P] +$$

$$+ [\Delta CS^S + \Delta OS^S + \Delta RS^S + \Delta LS^S + \Delta GS^S + \Delta ES^S] \qquad (3)$$

Finally, let us also consider that there are two types of individuals affected by the intervention: nationals (N) and foreigners (F). Then, expression (3) becomes:

$$\Delta SW = \Delta SW_N + \Delta SW_F = [\Delta SW_N^P + \Delta SW_N^S] + [\Delta SW_F^P + \Delta SW_F^S] \qquad (4)$$

In a global world, a benevolent planner would be interested in increasing the welfare of both types of agents. In the real case of different countries that promote their own projects, the current practice is just to account for changes in the nationals' welfare.

Let us consider the different components in expression (4):

$$\Delta SW_N^P = [\Delta CS_N^P + \Delta OS_N^P + \Delta RS_N^P + \Delta LS_N^P + \Delta GS_N^P + \Delta ES_N^P]$$

$$\Delta SW_N^S = [\Delta CS_N^S + \Delta OS_N^S + \Delta RS_N^S + \Delta LS_N^S + \Delta GS_N^S + \Delta ES_N^S]$$

$$\Delta SW_F^P = [\Delta CS_F^P + \Delta OS_F^P + \Delta RS_F^P + \Delta LS_F^P + \Delta GS_F^P + \Delta ES_F^P]$$

$$\Delta SW_F^S = [\Delta CS_F^S + \Delta OS_F^S + \Delta RS_F^S + \Delta LS_F^S + \Delta GS_F^S + \Delta ES_F^S].$$

The traditional CBA approach has usually concentrated on the estimation of component ΔSW_N^P, this is the estimation of welfare changes in the primary market for nationals. To proceed so several assumptions need to be fulfilled. These are as follows:

The planner aims to maximize nationals' social welfare, hence components ΔSW_F^P and ΔSW_F^S are neglected.[4]

Secondary markets are assumed to be perfectly competitive with neither distortions nor market failures. Further, no changes in welfare appear in these markets that are only marginally affected by the project, with $\Delta SW_N^S = 0$.

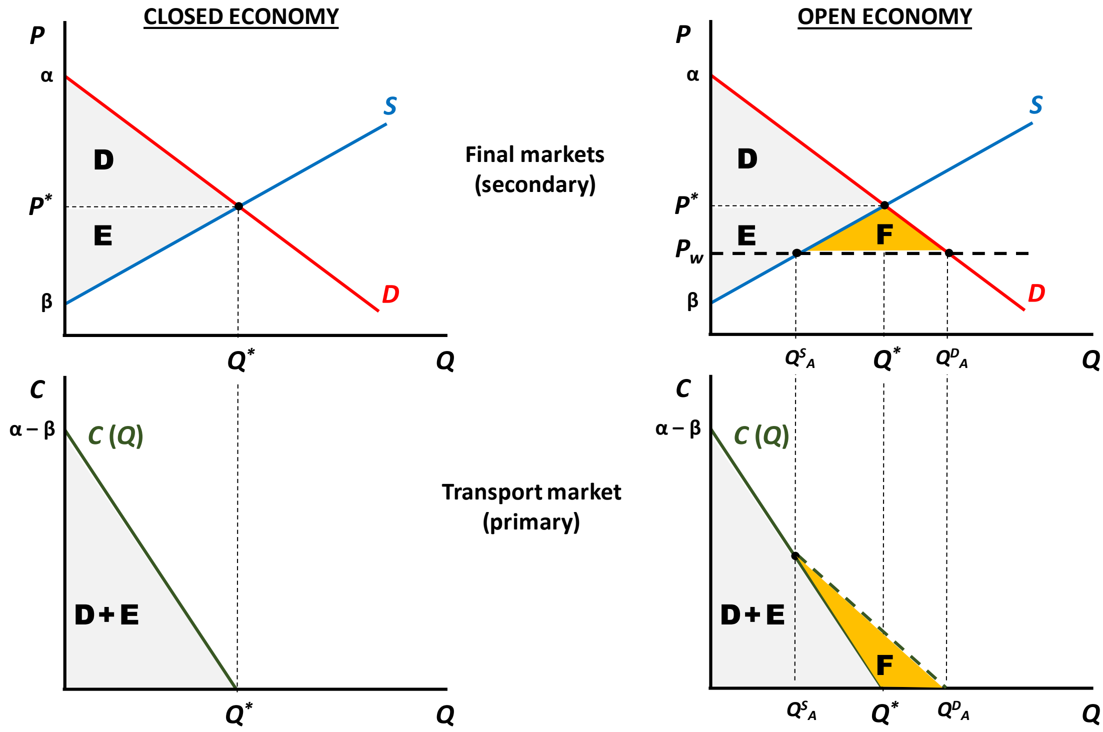
So far we have assumed that we are not double counting effects. However, when incorporating within the appraisal effects in secondary markets, the risk of double counting is quite high. For example, an increase in the price of land around a new railway station will be just a reflection of travel time savings experienced by those using the railway services. According to the formulas above, this should appear in component ΔCS_N^P or in component ΔRS_N^S, but for the evaluation purpose only one of them (usually the former rather than the later) is included to avoid double counting.

Another example coming from transport projects appraisal, which illustrates very well the double counting risk is given by the relationship between transport markets and final markets. In general, the demand for transport is a derived demand that obeys to the existence of another need in a final market. Passengers and freight need to be transported because they need to concur at other final markets.

Figure 1 shows how transport markets (specifically, the demand for transport) and final markets are linked. The case of a closed economy is represented on the left hand side of the figure, with the upper part of it showing the final market of a good that requires to be transported, and the lower part representing the transport market where only the derived demand for transport services is depicted. Both markets are assumed to be perfectly competitive and free of distortions and market failures (Jara-Díaz, 1986 and De Rus, 2010). The notation is standard: *C* denotes the cost of transport or the generalized price of it (price and value of travel time).

[4] Johansson and De Rus, (2019) show that the net benefits for foreigners should not be excluded without further consideration of the type of assets, the type of preferences and the existence of fixed factors when the resource approach is followed.

Figure 1. Transport markets and final markets: a closed and open economy



Sources: Jara-Díaz (1986), De Rus (2010) and Campos and Betancor (2017).

In a closed economy, when the cost of transport is zero transport services are demanded for Q*, or the equilibrium quantity in the final market. When the cost of transport is positive, the quantity of transport services demanded reduces (in fact this also implies a shift to the left of the supply curve at the final market once transport costs are included, and hence there is a new equilibrium). It is important to note that the area below the transport demand curve shows the maximum WTP for transport services, being equal to the sum of areas D and E, which in the final market correspond to the consumer surplus and the producer surplus, respectively. Therefore, when a transport project is implemented, this will imply changes in the consumer surplus at the transport market that, in turn, will be reflecting changes in the consumer surplus and the producer surplus in the final market. Under the assumptions considered, the correct CBA approach must account for the impacts in one of the two markets, but not in both. Commonly evaluators choose to include the change in consumer surplus at the transport market.[5]

[5] There are also other impacts that must be included in the evaluation as direct effects too: the changes in other surpluses different from the consumer one in the transport market.

However, it is possible to identify two cases in which it may relevant to take into account changes in final markets:

When the final market is not perfectly competitive or is affected by distortions. In that case the transport project will have an impact upon the market inefficiency or upon the tax collection that should be considered. (Jara-Díaz, 1986, Just *et al*. 2004 and De Rus, 2010).

When consumers' welfare in the transport market is not relevant for the funding body (i.e. consumers are not nationals, as it happens with infrastructures heavily used by tourists).

Let us consider now the case of an open economy represented on the right hand side of Figure 1 for an importer country (country A). This country is a price-taker in the international market, with a world price (P_w) below the equilibrium price for a close economy (P*), with Q_A^D being the total quantity demanded that is composed of national production Q_A^S and imports $\left(Q_A^D - Q_A^S\right)$.

Now area *F* represents the gains from trade. When the economy participates in the international market, consumers gain as much as to compensate the losers (national producers), and even so are better off. In this case it is also possible to derived the demand of corresponding transport services, that now bends at the national production level Q_A^S. The underlying assumption is that it is possible to aggregate the demand for transport of national production as well as imports, as both face the same transport costs. Further, transport costs are also paid by national and foreign producers.

As in the case of a closed economy and under the same assumptions, the transport market through changes in the consumer surplus, would be already capturing any welfare changes affecting final markets. Again, the recommendation is to concentrate on the transport market knowing that the consideration of welfare impacts in the final market requires a justification according to economic grounds. The gains from trade would be also captured in the transport market.

Similar cases can be found in the energy sector when energy acts as an input to produce other final goods and services: again whatever happens with the consumer surplus in the energy market would be capturing changes in welfare in the final market. A variant of the example is the situation in which energy is bought by consumers in the final markets that require it for the functioning of electronic devices, where the utility derived from buying energy already incorporates the utility derived from using electronic devices (De Rus, 2008).

1.3 Social benefits and costs

When valuing social benefits and costs (or changes in welfare) in CBA we will encounter goods, services and production factors that are traded on markets and therefore have a price of reference. There also other cases in which the evaluator faces the fact that some goods (or even “bads” in the case of negative externalities) have no markets and therefore have no price. Furthermore, when dealing with costs, there may be a reference price that can be considered inappropriate as it does not represent the relevant social opportunity costs.

Recall that CBA aims to establish whether a society is better or worse off with a project, and to do so the objective is to monetize its impact on welfare. The literature provides enough methodological approaches that allow giving a price to many elements like the value of travel time savings, the value of statistical life and many environmental impacts. Many of the approaches that allow reaching such a price are based on the study of preferences that can be either “revealed” or “stated”. There are also other non-preference methods like those that estimate prices according to prevention or abatement costs.

The WTP is behind many estimates of benefits in CBA. Actually WTP and consumer sovereignty (individuals are the best judges of their own satisfaction) can be considered as foundation stones of CBA (Brent, 2017). WTP is used for example to obtain the value per statistical life that will reflect individuals’ WTP for small reductions in their own mortality risks within a defined period (Robinson, 2018).

The accident and environmental impacts of projects have been widely studied in the case of transport projects, with reference values for marginal and average costs available at the European level for most important impacts (European Commission, 2019).

On the other hand, within CBA the relevant costs are the social opportunity costs. Consequently, when the price of a resource applied in the project does not reflect such opportunity cost, this requires a correction. In general, if production factors markets are perfectly competitive without distortions and only marginally affected by the project, then their market prices are a good estimate of opportunity costs (De Rus, 2010). In the opposite case, a correction to incorporate the proper opportunity cost needs to be made, what is known as the "shadow price" correction. Hence shadow prices are the social opportunity costs of the resources used (Drèze and Stern, 1994). Finally, and additional consideration can be made regarding the correction with respect to the shadow price of public funds, what aims to incorporate within the assessment the distortions created when collecting taxes to fund the project.

1.4 Issues on discounting, decision criteria and uncertainty

As already mentioned, the impacts of projects and policies occur over time along the project life of T years. In order to make a decision, the flow of changes in welfare (or social costs and benefits) needs to be conveniently aggregated and discounted. The Net Present Value (NPV) of such flow is one of the most common measures used in CBA that allow doing so. The formulas applicable for the social and financial analysis are the following:

$$NPV_{social} = \sum_{t=0}^{T} \frac{\Delta SW_t}{(1+i_s)^t} \qquad NPV_{financial} = \sum_{t=0}^{T} \frac{\Delta \mathrm{PS}_t}{(1+i_f)^t}$$

Where i_s and i_f stand for the social and financial discount rates. The social discount rate i_s, reflects the social view on how future benefits and costs should be valued against present ones (for example taking into account a preference for current consumptions against future consumption). On the other hand, the financial discount rate i_f reflects the opportunity cost of capital (European Commission, 2014). For the period 2014-2020 the European Commission recommends a social discount rate of 5 % in Cohesion countries and 3 % for other Member States, whilst the recommended financial discount rate is 4%.

Note also that in both formulas above, it is assumed that the flow appears at the end of each year and that the discounting conducted is exponential, what implies that future flows are less important than current ones and more so the farther away in time they are.[6]

[6] This way of discounting has been criticized as it gives more importance to current generations against future ones.

Other decision criteria commonly used in CBA are the Economic Rate of Return (ERR) and the Benefit/Cost ratio (B/C), however their results are not always consistent with those arisen from the calculation of the NPV (De Rus, 2010).

CBA examines projects along their project lives, figuring out how the future will be, for many important and key variables like infrastructures future demand or investment costs. Indeed, as pointed out by Flyvbjerg et al., (2003, 2006 and 2018), costs overruns and overestimation of demand are the most common errors found in transport projects where CBA has been widely applied.

Actually there are three main approaches that allow dealing with the problem of uncertainty in CBA: (i) sensibility analysis, which re-estimate the NPV after varying some parameter or variable; (ii) scenario analysis, or a variant of the previous in which several parameters or variables change at the same time; (iii) risk or Montecarlo analysis where sensitive variables are modeled according to some probability distribution given rise to a probability distribution of the NPV too.

1.5 CBA: A partial equilibrium approach and open questions

Let us recall equation 2 above that allows measuring the change in welfare associated with a project:

$$\Delta SW = \Delta CS + \Delta PS + \Delta GS + \Delta ES$$

Johansson and Kriström (2018), note that this is the correct procedure only when the project is small (the rest of markets are only marginally affected). Also the following assumptions are supporting such conclusion:

a. There is a representative household that consumes and owns the firms.

b. Markets are perfectly competitive and free from distortions (this implies that $\Delta GS = 0$ and ΔES=0), what allows to concentrate on the impact of the project on the CS and PS.

Therefore, for small projects, we can consider two cases: (i) the impact of the project is infinitesimal; (ii) the impact of the project is discrete.

For case (i), we may have in turn two possible situations:

1. The project produces an infinitesimal change in price (quantity remains constant). In this case, if the market clears, the change in social welfare is zero, since changes in the CS and the PS are equal, but of a different sign and therefore cancel out.
2. The project produces an infinitesimal change in quantity (price remains constant). In this case the change in SW is given by the following Cost-Benefit rule:

$$\Delta SW = p^{*}\Delta x - \Delta C,$$

where p^{*} is the initial equilibrium price, Δx is the change in production by the small project under consideration, and ΔC is the change in the project cost. Notice that this Cost-Benefit rule coincides with a general equilibrium rule (ignoring here any distortions).

For small projects with a discrete change in prices and quantities (case ii), the change in SW can be computed according to the following expression:

$$\Delta SW = \mathrm{CV} = CV^{p} + \Delta\pi$$

Where CV represents the compensating variation of this representative consumer which is also the owner of the firms. This CV can also be decomposed as the sum of CV^{p} plus the change in profits ($\Delta\pi$). CV^{p} represents the compensating variation associated with the actual change in the equilibrium price caused by the project.

$\Delta\pi$ captures the change in profits of the representative firm producing the commodity and defined as:

$$\Delta\pi = \Delta p\Delta x - \Delta C$$

The term CV^{p} can be also approximated as the change in CS if the income effects are small. Therefore, assuming that $\Delta\pi = \Delta PS$, then the ΔSW can be re-written as:

$$\Delta SW \cong \Delta \mathrm{CS} + \Delta PS = \Delta \mathrm{CS} + \Delta p\Delta x - \Delta C$$

Finally, when the project is large, the consideration of secondary markets when impacts on those are not marginal requires an economically founded justification and to check for double counting.

2. Input-Output Tables, Social Accounting Matrices and Satellite Accounts

2.1 Input-Output Analysis

Input-Output (IO) analysis (IOA) was first developed by Leontief (1936, 1941) and it has been widely applied in different fields such as tourism (Archer & Fletcher, 1996), wind-energy projects (Varela-Vázquez & Sánchez-Carreira, 2017) or natural disasters (Okuyama, 2004). The methodology is capable of quantifying the economic impact of economic policies, events or projects in the whole economy; by assuming exogenous changes in the final demand, taxes or subsidies (Miller & Blair, 2009). The IO methodology rests on the rationale of the interdependences of the economic sectors of an economy (*economic linkages*) where the production of any sector is demanded as inputs by other sectors to produce their own goods and so on. Hence, these sectoral linkages allow capturing the successive economic impacts (round effects) triggered by the policy under analysis yielding a final change in production and/or prices.

Because changes in prices and quantity cannot be tackled simultaneously in IO analysis, the methodology distinguishes between the demand and the price model. Traditional IOA can be characterized by the following main assumptions:

- Leontief production technology (fixed proportions)
- Constant return to scale
- No secondary production
- Non-capacity constraint
- One single household

Nonetheless, some of them can be relaxed to encompass more realistic economic behavior. For instance, Miyazawa (2012) provides a comprehensive explanation for including more than one representative consumer in an IO framework. On the other hand, Raa (2006) theoretically analyses the inclusion of secondary production and Cobb-Douglas production technology, while explaining the conceptual boundaries for the inclusion of increasing economies to scale in IOA. According to this author, IO models can be translated into linear programming, allowing, for instance, for a straightforward method to address capacity constraint in the production system. Most of the current development in IOA has been focused on dealing with environmental aspects (Miller & Blair, 2009; Wiedmann, Minx, Barrett, & Wackernagel, 2006; Wiedmann, 2006; Raa, 2006; or Lenzen, 1998)

Mathematically, an IO model consists of a set of n linear equations with n unknowns variables, where n denotes the number of goods and services. Each of these goods (x_i) can be demanded as an intermediate demand by other sectors to produce (id_{ij}) or as final demand to be consumed (fd_i).

$$\begin{aligned} x_i &= id_{11} + ... + id_{1j} + fd_i \\ &...................................... \\ x_n &= id_{n1} + ... + id_{nj} + fd_n \end{aligned} \qquad (1)$$

Where x_i denotes good i, id_{ij} represents the intermediate demand for good i from sector j (inter-industrial relationships) and fd_i is the final demand for good i. Dividing the intermediate sectoral demand by the sectoral production yields the technical coefficients ($a_{ij} = \frac{id_{ij}}{x_i}$). The technical coefficients represent the technology of production (Leontief production function). Besides, they are measured in relative terms and they capture the intersectoral linkages adduced in the previous paragraph. Thus, equations within (1) can be rewritten as:

$$\begin{aligned} x_1 &= a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n + fd_1 \\ &.. \\ x_n &= a_{n1}x_1 + a_{n2}x_2 + ... + a_{nn}x_n + fd_n \end{aligned} \qquad (2)$$

In matrix notation, equations within (2) can be written more compactly as:

$$X = AX + D \qquad (3)$$

such that $X = \begin{bmatrix} x_1 \\ ... \\ x_n \end{bmatrix}$, $A = \begin{bmatrix} a_{11}.......a_{1n} \\ .... \\ a_n.........a_{nn} \end{bmatrix}$, $D = \begin{bmatrix} fd_1 \\ ..... \\ fd_n \end{bmatrix}$

An IO model assumes the production as endogenous (X) and the final demand (D) as exogenous. Thus, it calculates the necessary production to satisfy the final demand assumed (demand model). This system of equations has been traditionally solved according to the Leontief algorithm:

$$X = (I - A)^{-1} D \qquad (4)$$

where I denotes an identity matrix (i.e. 1s in the diagonal elements and 0s in the off-diagonal elements). The demand model can be accommodated to deal with changes in prices by simply inverting the coefficient matrix (A). In matrix notation, the price model is as follows: $P = (I - A^{'})^{-1} VA$; where VA denotes the value added sector by sector. It should be noted that initially all prices are equal to one.

The induced effect

So far, the aforementioned explanation only assumes the existence of the intermediate demand to be produced. Such assumption allows for capturing the direct and indirect effect (multiplier type I), but it omits the role of income (salaries) in determining the economic impact (induced effect, multiplier type II[7]). The induced effect can be easily included in an IO model by adding a new row and column representing the incomes (row) and expenditures (column) of the economy. As a result, the X and D vectors include a new row $(n+1)$, while the technical coefficients matrix (A) becomes a $(n+1)(n+1)$ matrix. Moreover, by endogenizing the final consumption, the model captures the traditional Keynesian multiplier (Miyazawa, 2012; Sandoval, 1967; and; Raa & Chakraborty, 1983).

Value-added and employment

The system of equations (4) estimates the necessary output to meet the demand. Nonetheless, such rise in output is not exactly equivalent to the value added generated in the economy. The value added (VA) is the difference between the total production ($output$) minus the intermediate costs (intermediate demand, id). When taxes on products

[7] see Katz (1980) or Miller and Blair (2009)

are included it yields the Gross Domestic Product (GDP). $VA = output - id$. In the IO model, in matrix notation, the value added is calculated as follows:

$VA = va'(I-A)^{-1}D$, where va' are the value-added coefficients transposed and $(I-A)^{-1}D$ is the total output effect. The value-added coefficients are obtained dividing the sectoral value added (VA_j) by the sectoral production (X_j) ($va_j = \frac{VA_j}{X_j}$). The employment effect can be obtained in a similar manner. $L = l'(I-A)^{-1}D$ where l' is the employment coefficients transposed. The employment coefficients (l_j) are given by the number of workers in each sector (L_j) divided by the total sectoral production (X_j).

IOA also provides the framework to carry out sectoral analysis instead of traditional demand and price models (Khanal, 2014). Additionally, IOA can also be complemented with other methodologies such as microsimulation to conduct welfare evaluation (Labandeira & Labeaga, 1999) or Data Envelopment Analysis to rank different environmental policies (Munksgaard, Wier, Lenzen & Dey, 2005).

2.2 Input-Output Tables

The input-output tables (IOTs) form the main dataset to develop any IO analysis. These tables are usually elaborated by the National Statistics office perspective and they are publicly available. These tables are a natural extension of the national accounts (the production and consumption accounts) emphasizing the intersectoral relationships. The national accounts follow international standard procedures for its development and international comparison (SNA, 1993). Three main blocks can be distinguished in IO tables:

1. **Intermediate demand block (**intersectoral demand**).**
2. **Final demand block** (household consumption, government consumption, investment and exports).
3. **Primary inputs block** (remuneration of labour and capital which form the value added).

Table 1: A simplified input-output table

	Sector_1	**……….**	***Sector_n***	***Final demand***	***Total demand***
Sector_1	$id_{1,1}$	………..	$id_{1,n}$	fd_1	$\sum_{j=1}^{n} id_{1,j} + fd_1$
……….	………..	………..	………..	………..	………..
Sector_n	$id_{n,1}$	………..	$id_{n,n}$	fd_n	$\sum_{j=1}^{n} id_{n,j} + fd_n$
salaries	$salaries_1$	………..	$salaries_n$		
Remuneration of capital	$r\_capital_1$	………..	$r\_capital_n$		
Total production	x_1	………..	x_n		
employment	L_1	………..	L_n		

Table 1 shows the general structure of an IO table, the sectoral rows represent the destination of the sectoral production: as intermediate demand and as final demand. On the other hand, the columns by sectors represent the productive-mix of each sector (the origin of the production), i.e. the intermediate demand, the salaries and the remuneration of capital required to obtain the production: ($\sum_{i=1}^{n} id_{i,j} + salaries_j + r\_capital_j = x_j$). Finally, the total demand by good (intermediate and final demand) has to be equal to the total production by sector (circular income flow): $\sum_{j=1}^{n} id_{i,j} + fd_i = x_j$, as already highlighted in (1). Dividing the intermediate demand block and the value added (salaries and remuneration of capital) by the production yield the technical and value-added coefficients (a_{ij} and va_j), respectively. While dividing the number of workers by sectors (L_j) by the sectoral production yields the employment coefficients (l_j). The IO analysis reproduces the structure and identities depicted in the IOTs, but in mathematical notation (system of equations).

2.3 Social Accounting Matrix (SAM)

The IOTs provide detailed information about the intersectoral relationships of an economy, the source of the production (supply: domestic and imported) and its respective destination (intermediate demand or final demand). Nevertheless, they lack a more comprehensive characterization of households and/or the government (Miller & Blair, 2009). However, the SAMs bridges this gap by including transfers between institutions, social transfers and direct taxation to households and firms; or the relationship of all of them with the rest of the world (household account, value-added account, capital accumulation account, the balance of payments account and the government account). Hence, the SAMs enrich or complement the IOTs characterizing the successive income distributions that take place in the economic system (Breisinger, Thomas, & Thurlow, 2009). Table 2 shows the structure of a standard SAM. The IOTs is highlighted in blue, while the rest of accounts that form the SAM are in red. The IOA can be easily extended to take into account this new information and develop their respective multipliers (Miller & Blair, 2009; Breisinger et al, 2009).

SAM focuses firstly on the primary factor incomes generated in the economic process (compensation of employees, gross operating surplus or indirect taxes) that has to be assigned to different economic agents (households, enterprises or government). But such agents can be resident or non-resident agents. At the same time, the resident agents can also receive factor incomes from abroad.

The secondary income process comprises mainly the government. It collects through direct and indirect taxation the money required for government spending but also for paying subsidies or any other social provision. The role of the government generates a second income distribution that allows for calculating the gross national disposable income. At the same time, the gross national disposable income can be disentangled into final consumption and savings.

Finally, and briefly, the domestic economy exchanges not only goods and services (imports and exports) or rents, but assets with and from abroad. These economic movements are registered in the accumulation account (capital and financial accounts).

The inclusions of these aforementioned aspects together with the IOTs provides shape to the SAM. Obviously, the SAM provides a richer set of information of the economic relations than the IOTs do.

Table 2: Standard Social Accounting Matrix

	Activities	Commodities	Factors	Households	Government	Savings and investment	Rest of the world	Total
Activities		Domestic supply						Activity income
Commodities	Intermediate demand			Consumption spending	Recurrent spending	Investment demand	exports	Total demand
Factors	Value-added							Total factor income
Households			Factor payment to households		Social transfers		Foreign remittances	Total household income
Government		Sales taxes and import tariffs		Direct taxes			Foreign grants and loans	Government income
Savings and investment				Private savings	Fiscal surplus		Current account balance	Total savings
Rest of the world		Imports						Foreign exchange outflow
Total	Gross output	Total supply	Total factor spending	Total household spending	Government expenditure	Total investment spending	Foreign exchange inflow	

Source: Adapted from Breisinger, et al, (2009)

2.4 Satellite Accounts

These accounts focus on activities that are not specifically covered in the National accounts such as tourism (TSA, 2008; Frechtling, 1999 and 2010), culture (FCS, 2009; Throsby, 2008) or the environment (SEAA, 2012; Muller, Mendelsohn & Nordhaus, 2011; Bartelmus, Stahmer and Tongeren, 1991), among others. They quantify the direct contribution of the corresponding activities into the economy in terms of employment and sectoral production, demand or GDP. The information is usually deployed in a set of tables organized by topics. International organizations such as the United Nations (UN) or the Organization for Economic Co-operation and Development (OECD) in cooperation with other institutions develop and release methodological frameworks for constructing comparable and harmonized Satellite accounts which will be implemented by the respective National Statistical Office. Among all possible satellite accounts, the tourism one has received a widespread development in applied studies. For instance, it has been used as a complement to the IOTs to disentangle the production by goods into tourism and non-tourism side or to distribute the total non-resident consumption into the different good categories of the IOTs (Inchausti-Sintes, 2015). On the one hand, the account can be directly employed to quantify the economic contribution of tourism into the economy (Bryan, Jones and Munday, 2006) or to approach the contribution of tourism subsector such as the maritime tourism (Diakomihalis, 2007). Both tourism and environmental accounts can also be combined to shed light on the consequences of tourism activities in the environment (Jones, 2003; Jones & Munday, 2007; or Collins, Jones & Munday, 2009). On the other hand, the environmental account has been mostly developed to extend the IOTs (Liang, Feng, Qu, Chiu, Jia, & Xu, 2017) generating the so-called energy-environmental IOTs (Burniaux, Jean-Marc & Truong, 2002).

3. Computable General Equilibrium Models

3.1 Computable General Equilibrium

The theoretical foundation of CGE models was established by Arrow and Debreu (1954). Paraphrasing Böhringer, Rutherford and Wiegard (2003), CGE models combine microeconomic theory (general equilibrium theory) with data sets (SAMs) in order to derive policy insights. Nonetheless, it has been traditionally regarded as a *black-box* because of its complexity. CGE models are able to model the whole economy following the circular flow of income and expenditure. Thus, it does not only account for *direct effects*, but also *indirect and induced economic effects*. Briefly, the main assumptions of a standard CGE model can be summarized as follows:

Four different kinds of functions: Leontief (elasticity of substitution equals zero), Cobb-Douglas (elasticity of substitution equals 1), Constant elasticity of substitution (CES) (any elasticity of substitution), Stone-Geary (elasticity of substitution equals 1). The later also allows for an income elasticity different from 1.

- Circular flow of income and expenditure.
- Secondary production allowed.
- One representative household.
- Non-capacity constraints.
- Constant return to scale.
- Market perfect competition.

The last four assumptions can be relaxed to tackle more than one representative household, include capacity constraints, increasing or decreasing returns to scale, or imperfect market competition (unemployment, monopoly or oligopoly market behaviour) (Roson, 2006; Boeters & Van Leeuwen, 2010; or Boeters & Savard, 2011). The circular flow of income and expenditure can be summarized in the following three conditions: zero benefit, market clearance conditions and income balance (Böhringer, Rutherford & Wiegard, 2003; Hosoe, Gasawa & Hashimoto, 2010).

The three of them form the so-called Walrasian equilibrium, i.e. prices and quantities vary simultaneously so as to fulfill the following three economic conditions or equations:

Zero benefit condition:

Firms supply goods and services to the market. In order to do so, it has to combine capital, labour and intermediate goods to produce. In this process, the firms pay wages to workers, rents of capital to capital owners and the intermediate demand to other firms.

Market clearance condition:

The production generated in the zero benefit condition is supplied to the market to be purchased as final demand (household consumption, government consumption, investment and exports); or as intermediate demand to produce other goods and services by the firms.

Income balance:

Households are endowed with income obtained from firms as workers and capital owners. With such income, households demand goods and services as well as investment.

Mathematically, the aforementioned conditions are as follows (Böhringer, Rutherford and Wiegard, 2003):

Zero benefits:

The value of inputs per activity must be equal or greater than the value of outputs.

$$\prod_j (p) = R_j(p) - C_j(p) \geq 0 \quad \forall j$$

Where $\prod_j (p)$ represent the benefit by activity j and $R_j(p)$ and $C_j(p)$ are the unit cost function and unit revenues function by activity j respectively.

$$C_j(p) \equiv min\left\{ \sum_i p_i x_i \mid f_j(x) = 1 \right\}$$

$$R_j(p) \equiv max\left\{\sum_i p_i y_i \mid g_j(x) = 1\right\}$$

Market clearance conditions:

The supply of any commodity must equal or excess demand by consumer.

$$\sum_j y_j \frac{\partial \Pi_j(p)}{\partial p_i} + \sum_h \omega_{i,h} \geq \sum_h d_{i,h}(p, M_h)$$

$\sum_j y_j \frac{\partial \Pi_j(p)}{\partial p_i}$ represents the supply of good i by activity j. $\sum_h \omega_{i,h}$ represents the initial endowment of good i by institution h. $\sum_h d_{i,h}(p, M_h)$ represents the final demand for good i by institutions h given prices p and income M. $d_{i,h}(p, M_h)$ is the final demand obtained from the maximization problem of the representative household:

$$d_{i,h}(p, M_h) \equiv argmax\left\{U_h(x) \mid \sum_i p_i x_i = M_h\right\}$$

$U_h(x)$ is the utility function of household h.

Income balance conditions:

The income (value of the endowment) of each institution (households, mainly) h must be equal or exceed to the final demand.

$$\sum_i p_i \omega_{i,h} = M_h \geq \sum_i p_i d_{i,h}$$

$\sum_i p_i \omega_{i,h}$ represents the value of the endowment for the institutions h and $\sum_i p_i d_{i,h}$ represents the value of the final demand of institutions h. Figure 1 summarizes the economic structure of a CGE model.

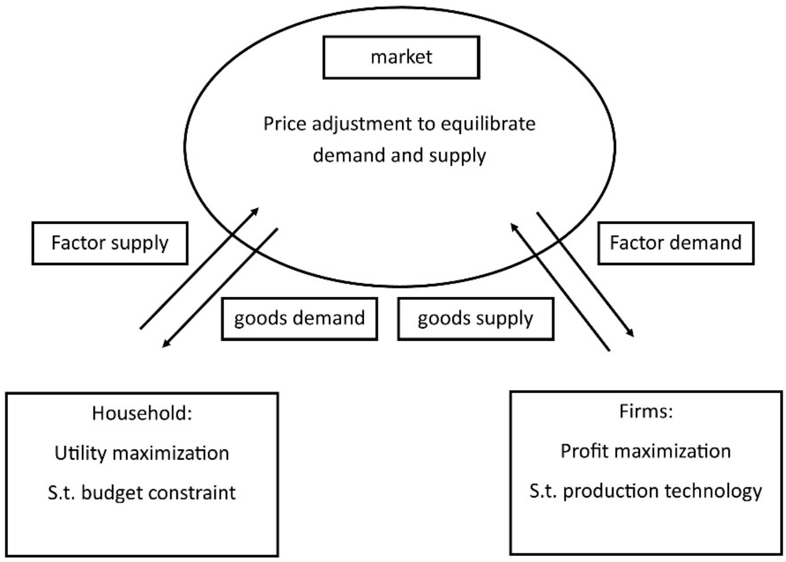
The aforementioned conditions provide a consistent framework for the economic analysis of policies with linkages effects and welfare evaluation. These equations need to be calibrated according to a SAM to replicate an initial equilibrium (application A). Finally, these conditions have to be complemented with the *model/ macro closure.* Basically, from a modelling perspective, the macro closure ends up assuming which variables are endogenous or exogenous (Hosoe, Gasawa & Hashimoto, 2010). In this regards, there are three key variables or decisions when closing the model: investment, government and the current account (open economy). Such assumptions have economic consequences and yield different results. For instance, for a closed economy without government, the following identity holds, $S = I$. In these circumstances, savings *(S)* or investment *(I)* has to be fixed or a new equation has to be included to determine their respective values. If the investment is fixed, savings will adjust freely (investment-driven or Johansen closure). On the other hand, if savings remain fixed, this model follows a **savings-driven closure**.

The same reasoning can be highlighted when addressing the government and current account closure. For instance, some governments may face a binding budget restriction *(D)*. In such case, it is reasonable to assume a fixed budget where expenditures and incomes vary in consequence. Finally, the current account closure implies determining savings, investment or the current account. In general, most of CGE models assume a fixed current account while they opt for a savings-driven or an investment-driven closure. This closure is common for developing countries where foreign credit may be limited (Gilbert & Tower, 2013). Anyhow, there is not an ideal macro closure, but it will rely on the kind of policy simulation carried out.

The structure of a CGE model can be relaxed or the SAM enriched in order to address different issues such as externalities or non-market goods. In this sense, the inclusion of natural resources in traditional IOTs has allowed a widespread development of environmental analysis using CGE models (Bergman, 2005; or Britz & Hertel, 2011). For instance, CGE models have been especially fruitful when modeling CO2 emissions trading scheme (Böhringer, 2002). SAM can also be expanded to deal with several economies, coined as multiregional models (Aguiar *et al*., 2016) and spatial markets interactions (Mercenier *et al*., 2016).

On the other hand, there are two main approaches when programming a CGE model: maximizing a representative household utility where the rest of conditions operate as constraints (Hosoe, Gasawa & Hashimoto, 2010; or Gilbert & Tower, 2013) (application C), or solving the problem as a system of equation where variables and equations form a mixed complementarity problem (MCP) avoiding any maximizing behaviour (Böhringer, Rutherford & Wiegard, 2003) (application C). Besides, Rutherford (1999) developed a straightforward subsystem (MPSGE) to program CGE models in MCP syntax[8] (application B).

Figure 2. Economic structure of a CGE model



Source: Hosoe, Gasawa and Hashimoto (2010)

3.2 Dynamic Computable General Equilibrium

A SAM provides a snapshot of an economy in one period. Nevertheless, manyeconomic policies take place during several periods/years. CGE models can be adapted to evolve over time. Such adaptation implies the following variables and parameters and their

[8] See Markusen (1995) for self-study examples in MPSGE.

respective assumptions: economic growth (g), capital depreciation (δ), interest rate (r) and the initial stock of capital ($K0$). These parameters and variables have to be set according to certain equations in order to assure a steady state economic growth, i.e. the circular flow of income and expenditure holds over time. Following Palstev (2008), a dynamic CGE model can be introduced as follows

The initial stock of capital has to equal the capital earnings (gross operating surplus, *VK*) divided by the initial return to capital ($\delta + r$).

$$K0 = \frac{VK}{\delta + r}$$

At the same time, the stock of capital multiplied by $(\delta + g)$ have to equal the initial investment level ($I0$). In general, the initial investment level is obtained from the IOTs.

$$I0 = (\delta + g)K0$$

The stock of capital will evolve according to the following equation:

$K_{t+1} = K_t(1-\delta) + I_t$, where I_t represents the investment level in period t. The rest of conditions of a standard CGE model holds in each period. Finally, the general structure of a dynamic model is as follows:

$$max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t U\left(C_t\right)$$
$$s.t:$$
$$C_t = F(K_t, L_t) - I_t$$
$$K_{t+1} = K_t(1-\delta) + I_t$$

Where the objective function denotes the present value of the utility ($U\left(C_t\right)$) of the representative household, ρ represents the individual time-preference, C_t refers to total consumption and $F(K_t, L_t)$ represents the total production.

A last key assumption is the behaviour of the representative households. Depending on the kind of assumption, **dynamic CGE models** can be divided into forward-looking models (Ramsey, 1928) and backward-looking models or recursive-dynamic models. The main difference between them is the representation of the expectation about the future. In the former, forward-looking models, the agents/households have perfect expectations, while the latter form their expectation in the period of the decision. Forward-looking models imply deeper changes in the economic structure represented than the backward-looking model (Babiker, Gurgel, Paltsev & Reilly, 2009). See Dixon and Rimmer (2010) or Fougére, Mercenier and Mérette (2007) for applications of dynamic CGE models.

3.3 Dynamic Stochastic Computable General Equilibrium

Dynamic CGE models can also encompass stochastic analysis. Although it can be regarded as an extension to traditional CGE models, they have followed a different theoretical and applied approach rooted in the macroeconomic tradition (Wickens, 2011; or Junior, 2016). Briefly, the advent of DSGE can be traced back to the Real business cycle model (RBC) developed by Kydland and Prescott (1982). This model formalized the macroeconomic process according to maximizing and minimizing behaviours, first order conditions and rational expectations, instead of ad hoc aggregated macroeconomic models. Nevertheless, the widespread development and application of DSGE emerged when including frictions in the model which allowed for more realistic economic situations, the so-called New Keynesian models. In this sense, DSGE models are capable of encompassing complex economic behaviour such as sticky prices and salaries (Smets & Wouters, 2003), risk premium (Adolfson, Laséen, Lindé, & Villani, 2007), habits formation (Fuhrer, 2000) or dollarization (Castillo, Montoro & Tuesta, 2013) among others. On the one hand, DSGE models rise the mathematical complexity limiting its applicability in project evaluations. For instance, while static or dynamic models can easily deal with around 12-20 sectors and commodities, stochastic CGE models usually assume two sectors (tradable and non-tradable) reducing the economic representation of the model. Moreover, traditional static and dynamic models are calibrated using SAMs which, at the same time, ensure finding an initial solution (Böhringer, Rutherford & Wiegard, 2003). However, the calibration procedure in stochastic models follows a more complex approach where the rank conditions and thus, the initial solution, are not always achieved (Junior, 2016). Most of the authors in applied studies opt for working in logarithms (*log-linearization*) to avoid initial values problem[9] and achieve an initial solution more easily (Junior, 2016; and Torres, 2013). These mathematical difficulties are also explained by the inclusion of rational expectations (forward or backward-looking) affecting the eigenvalues of the model.

On the other hand, while traditional static and dynamic models assume the parameters of the model as given, a stochastic approach is capable of estimating these parameters econometrically by including time series data (vector autoregressive models, VARs). The parameters can be estimated following two main approaches: Kalman filter and Bayesian estimation (Fernández-Villaverde, Rubio-Ramirez & Schorfheide, 2016). The former implies working in a state-space framework while the latter requires assuming distribution functions for the parameters. In both cases, once the initial conditions are fulfilled, the algorithm allows for a quick and reliable convergence. This is especially useful when dealing with short aggregated macroeconomic series.

While the aforementioned limitations of stochastic CGE models affect their applicability in project evaluation as previously mentioned, they have been widely applied in macroeconomics. In this sense, they have become a key tool for Central banks to conduct macroeconomic forecasting and/or monetary policy analysis (ECB, 2010; Smets & Wouters, 2004; or Tovar, 2009). From an academic perspective, in contrast to traditional macroeconomic models, a stochastic CGE approach provides a robust theoretical microeconomic foundation and it allows for econometric testing of macroeconomic theories.

[9] When calibrating the model in logarithm, the steady state imply that the initial values are zero.

4. Limitations and scope for linkages between CGE and CBA: Literature review

As already explained in sections 1 and 3, CBA and CGE rest on the same economic theory, but they are conceptually and methodologically different. Conceptually, while CBA emphasizes the welfare impact of projects, CGE is mainly focused on quantifying its economic impact in the whole economy. Regarding the methodological approach, as emphasized by Farrow and Rose (2018), CBA follows a partial equilibrium framework (PE) focusing on the primary markets. On the contrary, CGE models the whole economy (General equilibrium, GE). Additionally, such market approaches imply several assumptions that eventually yield different results when conducting economic analysis. According to Brannlund and Kriström (1996), CBA provides a good approximation when the magnitude of the impact can be isolated in the primary markets (small projects). Nevertheless, as soon as the economic magnitude rise (large projects) and more secondary markets are affected; the divergences between both approaches rise (Whalley, 1975; Kokoski & Smith, 1987; Johansson & Kriström, 2016). As shown by the latter, the economic differences between small and large projects can be mathematically illustrated through the analysis of the social welfare. Equation (1) represents the change in social welfare (ΔV) produced by a discrete change in z (from z^0 to z^1), where V denotes a continuous and differentiable social welfare function, p and w denote prices and wages respectively, and $\Pi - T$ denotes the firm benefit and taxes collected by the public institutions, respectively.

$$\Delta V = V(p^1, w^1, \Pi^1 - T^1, z^1) - V(p^0, w^0, \Pi^0 - T^0, z^0) \qquad (1)$$

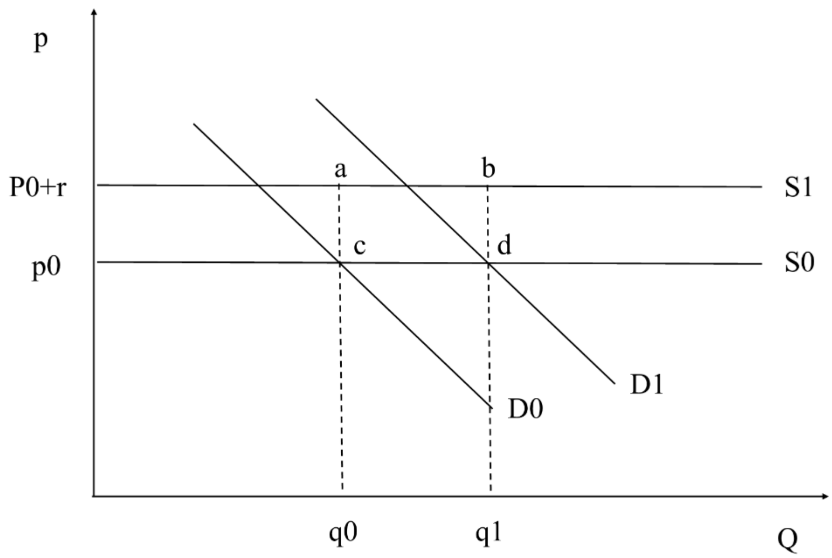
More compactly, the welfare change can be decomposed as follows:

$$\Delta V = V_p \Delta p + V_p \Delta w + V_y \Delta(\Pi - T) + V_z \Delta z + R \qquad (2)$$

Where $V_p = \frac{\partial V(.)}{\partial p}$, $V_w = \frac{\partial V(.)}{\partial w}$, $V_y = \frac{\partial V(.)}{\partial \Pi} + \frac{\partial V(.)}{\partial T}$ and R can be regarded as a remainder term which represents the impact of the project beyond the primary markets. According to these authors, in small projects where $R \approx 0$, this equation provides a good approach to real welfare changes. On the contrary, for projects with $R \neq 0$, CGE is preferable.

However, the impact on secondary markets is not a sufficient condition to adopt a CGE approach. For instance, in a CBA framework, when assuming competitive markets and fixed prices in the secondary markets, the changes experienced in these markets do not change the social surplus because the willingness to pay equals the opportunity cost. However, when assuming non-competitive markets or markets distortions, changes in these markets do affect social welfare (De Rus, 2010). In cases where market prices do not reflect the opportunity cost, CBA opts for the "shadow" prices.

Figure 3. Secondary market with externalities

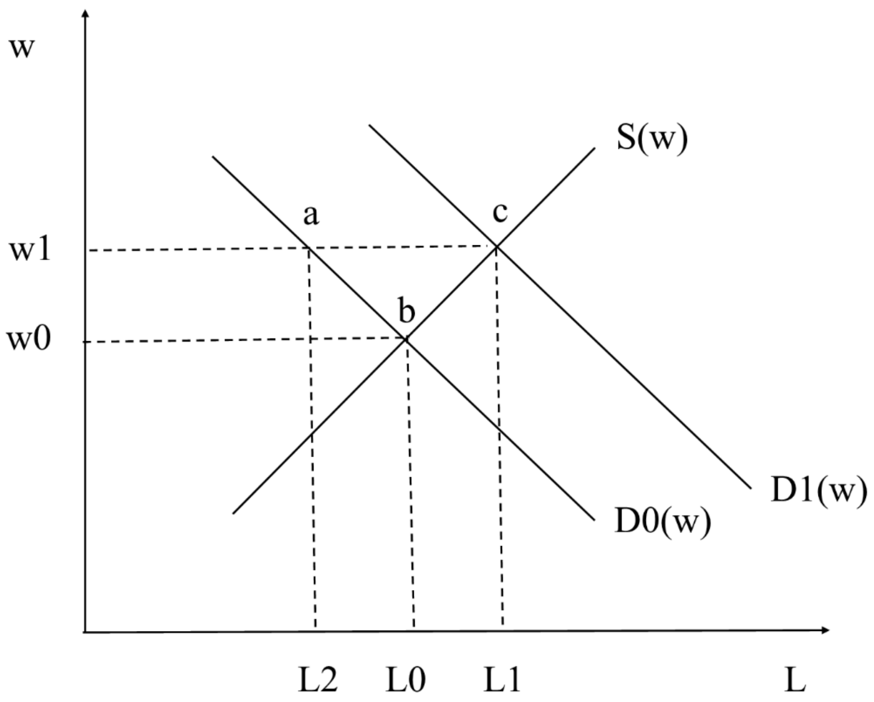


Source: De Rus (2010)

Figure 3 shows the economic impact on a secondary market with externalities. The price paid by the consumer is p_0, but the social price is $p_0 + r$. The positive demand shift of the project does not affect the price paid in this market, but it incurs in a higher social cost represented by the area (*abcd*) which detracts value from the project.

Moreover, even in competitive markets without distortions, the market price does not always reflect the opportunity cost. Figure 4 shows a competitive labor market. The project raises the demand for labor from a to c rising the demand of workers in $L_1 - L_0$ units. $L_1 - L_0$ new workers and voluntary unemployees, should be evaluated taking into account the opportunity cost of their leisure (area bcL_0L_1). On the other hand, the other $L_2 - L_0$ workers hired by the project come from other sectors and their opportunity cost should take into account the lost of such sector production area: abL_0L_2. In this sense, CGE provides a useful complement approach to the social impact when the competitive market behaviour does not hold in these secondary markets. Moreover, it should be noted that CGE can easily deal with non-competitive markets and distortions (Negishi, 1989; or Baxter & King, 1993), but also the development of environmental satellite accounts in the last decade also provides an additional necessary complement to SAM in order to address non-competitive behaviours in non-market goods and externalities in a general equilibrium setting (Börhinger & Loschell, 2006; or Wing, 2011). Finally, CGE model can also ease the analysis of projects in an open economy framework where imports and exports can play a relevant role.

Figure 4. Labour markets and shadow price



Source: De Rus (2010)

Finally, as explained in section 1, the risk of double-counting and the counterfactual scenario represent an additional source of potential conceptual discrepancies when bridging CBA and CGE. On the one hand, by definition, CGE captures the three types of effects distinguished by CBA: direct effects, indirect effects and wider economic impacts. Nonetheless, from a CBA perspective, some of these effects may not be necessary to quantify the welfare impact of a project because they are already included in other markets. On the other hand, CGE does not assume a counterfactual scenario to carry out economic impact analysis, while it is a key aspect in CBA to correctly justify the social profitability of a project. These two aspects clearly emphasize that CBA and CGE do not only differ in the methodological approach, but also in conceptual issues.

Welfare in PE and GE

The assumption of fixed prices also provides a convenience shortcut to welfare evaluation in PE, because it avoids the income effect (quasilinear preferences). In such circumstances, the consumer surplus (CS) provides an exact approach to the welfare measure provided by the equivalent variation (EV) and the compensating variation (CE)[10]. This effect can be better appreciated according to the Slutsky decomposition (equation 2):

$$\frac{\partial x_j(p,m^*)}{\partial p_i} = \frac{\partial h_j(p,u^*)}{\partial p_i} - \frac{\partial x_j(p,m^*)}{\partial m} x_j(p,m^*) \qquad (2)$$

The derivative of the Marshallian demand $x_j(p_j,m)$ with respect to price is equal to the derivative of the Hicksian demand ($h_j(p_j,u)$) with respect to price plus the derivative of the Marshallian demand with respect to the income multiplied by the Marshallian demand, where p , m and u denote price, income and utility, respectively. The former captures the change in the consumption bundle due to changes in relative prices, while

[10] EV and CV are regarded as "ideal" welfare measure see Varian (1992). The EV can be defined as the income to be given to an individual to attain the same level of utility reached with the change, but without the change. On the other hand, The CV can be defined as the income that can be taken from the individual once the change occurs, leaving him at the same level of utility as before the change (De Rús, 2010, page 223)

the latter represents the change in consumption due to changes in "purchasing power" (Varian, 1992). If the second right-hand-side term is zero (non-income effect), both the Marshallian and the Hicksian demands equal. Nevertheless, the premise of fixed prices is not always a reasonable assumption in PE. In this case, changes in price trigger the income effect and CS, EV and CV yield different results. Nonetheless, even in this context, CS can still provide a reasonable approach to social welfare (Willig, 1976).

The income effect is always latent in a GE setting because prices are allowed to vary (endogenous prices). Moreover, as demonstrated by Mishan (1976) and Blackorby and Donaldson (1990), EV and CV also provide one necessary condition to avoid welfare change induced by income redistributions: the Boadway paradox (Boadway, 1974)[11]. The other condition rests on assuming preferences with the Gorman norm -homothetic preferences-, i.e. the income propensity to consume is equal and linear for all consumers (linear Engel curve) (Varian, 1992). This assumption also allows for an exact social aggregation (Deaton & Muellebauer, 1980). If such kind of assumption cannot be held, CS, EV and CV will not yield reliable welfare results. Table 1 summarizes the effect of the aforementioned assumptions on CS, EV and CV.

Table 3. The welfare effect of income distribution.

	Homothetic preferences	**Non-homothetic preferences**
PE , fixed prices	VC =VE=EC=0	VC y VE $\neq$ 0 EC=0
PE , endogenous prices	VC =VE=EC=0	VC y VE $\neq$ 0 EC=0
GE	VC =VE=0 EC $\neq$ 0	VC, VE y EC $\neq$ 0

[11] In GE, CS report positive values by redistributing income among households.

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Appendix

Application A code

Develop a CGE model in GAMS according to the following SAM:

SAM:

	Q1	Q2	Consumption	Income	**TOTAL**
PX1	50		50		100
PX2		50	50		100
PK	30	20		50	100
PL	20	30		50	100
TOTAL	100	100	100	100	

```
variables
U       total utility
;
U.l= 100 ;

positive variables

X1     consumption of the good 1
X2     consumption of the good 2
L1     labour demand production good 1
L2     labour demand production good 2
K1     capital demand production good 1
K2     capital demand production good 2
M      income of representative household
Q1     production of good 1
Q2     production of good 2
PX1    price of good 1
PX2    price of good 2
PK     price of capital
PL     price of labour ;

*initial values
X1.l=50;
X2.l=50;
Q1.l=50;
Q2.l=50;

parameter
*briefly, the shift parameter simply scale the utility to provide the same value that the
*consumption.
*it is not relevant in partial equilibrium, but it is important in a general equilibium
approach to *ensure the circular flow of income.
sigma       shift parameter of the utility function
gamma_q1    shift parameter of production function Q1
gamma_q2    shift parameter of production function Q2;
```

```
*the shift parameters are obtained inverting the respective function.

*shift parameter for utility
sigma   = U.l / (X1.l**0.5*X2.l**0.5)     ;
*shift parameter for production;
gamma_q1 = Q1.l/(30**0.6 * 20**0.4) ;
gamma_q2 = Q2.l/(20**0.4 * 30**0.6) ;




equations
utility         utility function
demand_X1       demand good 1
demand_X2       demand good 2
demand_L1       demand labour production good 1
demand_L2       demand labour production good 2
demand_K1       demand capital production good 1
demand_K2       demand capital production good 2
market_X1       market clearance for good X1
market_X2       market clearance for good X2
production_X1   production of good 1
production_X2   production of good 2
market_K        market clearance for capital K
market_L        market clearance for labour L
income_constraint  income constraint representative household
;

*according to the SAM, the share of good X1 and X2 in total consumption is, respectively,
0.5 (50/100) and 0.5 (50/100)
utility..                 U    =e= sigma *  (X1**0.5*X2**0.5);
demand_X1..               X1   =e= 0.5 *M / PX1   ;
demand_X2..               X2   =e= 0.5 *M / PX2   ;


market_X1..               X1 =e= Q1;
market_X2..               X2 =e= Q2;

market_K..                50   =e= K1 + K2  ;
market_L..                50   =e= L1 + L2  ;

*the share of K and L in the production of good Q1 is 0.6 (30/50) and 0.4 (20/50),
respectively ;
production_X1..           Q1   =e= gamma_q1 * (K1**0.6*L1**0.4) ;
*the share of K and L in the production of good Q2 is 0.4 (20/50) and 0.6 (30/50),
respectively ;
production_X2..           Q2   =e= gamma_q2 * (K2**0.4*L2**0.6) ;

demand_L1..               L1   =e= (0.4*Q1*PX1)/PL   ;
demand_L2..               L2   =e= (0.6*Q2*PX2)/PL   ;
demand_K1..               K1   =e= (0.6*Q1*PX1)/PK   ;
demand_K2..               K2   =e= (0.4*Q2*PX2)/PK   ;


income_constraint..   M   =e=  PK*50   + PL*50  ;



model general_equilibrium  /all/;


*initial values
U.l= 100 ;
M.l= 100 ;
PX1.l= 1 ;
PX2.l= 1 ;
PK.l = 1 ;
PL.l = 1 ;
K1.l= 30 ;
L1.l= 20 ;
K2.l= 20 ;
L2.l= 30 ;
X1.l= 50 ;
X2.l= 50 ;
```

```
Q1.l= 50 ;
Q2.l= 50 ;

*replication of the initial equilibrium
option iterlim = 100 ;

solve general_equilibrium using NLP maximizing U;
```

Application B code

Develop a CGE model in MCP format, According to the previous SAM:

```
*defining variables
positive variables
X1      good X1
X2      good X2
PX1     price of good X1
PX2     price of good X2
PK      price of capital
PL      price of labour
PW      price of welfare (welfate index)
W       household
M       income household
;


equations
*zero profit
prf_X1         zero profit condition  X1
prf_X2         zero profit condition  X2
prf_W          zero profit condition  W
*market clearance
market_K       market clearance condition for capital
market_L       market clearance condition for labour
market_W       market clearance condition W
market_X1      market clearance condition X1
market_X2      market clearance condition X2
*income constraint
income_constraint   income  household;


prf_X1..         50*PX1  =E=  50 * PK**0.6*PL**0.4      ;
prf_X2..         50*PX2  =E=  50 * PK**0.4*PL**0.6      ;
prf_W..          100*PW  =E=  100* PX1**0.5*PX2**0.5    ;

market_K..            50  =E= 30*X1*PK**0.6*PL**0.4/PK  + 20*X2*PK**0.4*PL**0.6/PK   ;
market_L..            50  =E= 20*X1*PK**0.6*PL**0.4/PL  + 30*X2*PK**0.4*PL**0.6/PL   ;

market_W..           100*W  =E=  M/PW;
market_X1..          50*X1  =E=  50*W*PX1**0.5  *PX2**0.5/PX1;
market_X2..          50*X2  =E=  50*W*PX1**0.5  *PX2**0.5/PX2;


income_constraint..   M  =e=  PK*(50)   + PL*(50)  ;


model general_equilibrium /prf_X1.X1, prf_X2.X2, prf_W.W, market_X1.PX1, market_X2.PX2,
market_W.PW, market_K.PK ,market_L.PL, income_constraint.M  /;

*initial values
X1.l=1;
X2.l=1;
W.l=1;
PX1.l=1;
PX2.l=1;
PW.l=1;
PK.l=1;
PL.l=1;
M.l=100;


option iterlim = 0 ;

solve general_equilibrium using MCP;
```

Application C code

Develop a CGE model in MPSGE, According to the previous SAM:

```
$ONTEXT

$model:mpsge_intro

$sectors:

X1      !  activity level sector X1
X2      !  activity level sector X2
W       !  activity level sector W (hicksian welfare index)

$commodities:
PX1      ! price of good X1
PX2      ! price of good X2
PL       ! price of  labour
PK       ! price of capital
PW       ! price of welfare

$consumer:

M  ! income level representative household

*zero profit condition
$prod:X1 s:1

O:PX1 Q:50
I:PK Q:30
I:PL Q:20

$prod:X2 s:1

O:PX2 Q:50
I:PK Q:20
I:PL Q:30

$prod:W s:1

O:PW  Q:100
I:PX1 Q:50
I:PX2 Q:50


*The market clearance conditions are automatically generated by MPSGE when the model is
declared

*income constraint
$DEMAND:M

D:PW Q:100
E:PK Q:50
E:PL Q:50


$OFFTEXT

$SYSINCLUDE mpsgeset mpsge_intro

mpsge_intro.iterlim=0;

$INCLUDE  mpsge_intro.gen
SOLVE  mpsge_intro USING MCP;
```