6 CBA and CGE in transport: a practitioner point of view

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6.1 Introduction

In almost all European countries and international organisations such as EIB, transport infrastructure investments are assessed through procedures based on Cost-Benefit Analysis (CBA). Precise instructions define how to conduct CBA. The current practice has been recorded in the European research program "Harmonised European Approaches for Transport Costing and Project Assessment" (HEATCO) (Bickel *et al.* 2006).

The most commonly estimated effects are:

- Monetary cost savings.
- Travel time savings, transformed into money through the value of time (VoT).
- Possibly also comfort, reliability.
- Safety: number of avoided casualties, transformed in money through the value of a statistical life (VSL)
- Environmental externalities (air pollution, noise, climate change effects).

They are compared to the investment's cost of implementation through the well-known Net Present Value (NPV) concept and related indicators (Internal Rate of Return, Benefit/Cost Ratio).

As this list shows, the analysis is mainly focused on the transport market and environmental effects; it implies not only marketable goods, but also non-market goods, such as physical risk or pollution. The main non-market goods are time, reliability, comfort, safety and environmental impacts. The most accounted for externalities in current practice are those internal to transport: congestion and externalities linked to the environment, and safety issues. It appears that the relative weight of environmental effects such as pollution, noise, and effect on climate change is less important than safety or congestion (Shroten *et al.*, 2019).

Externalities related to congestion imply that changes in one link in the geographical network have repercussions on prices in the other links. This means that the effect of a change in one link cannot be studied in isolation: effects on the whole network must be considered. There are as many transport markets involved as there are Origin-Destination (O–D) pairs, and those markets are dependant both on the demand side (an agent may consider that, for instance, a leisure trip to cinema X is a substitute for a trip to cinema Y), and on the supply side (if, for one reason or another, the transport cost increases on link A-B, the cost to go from A to B will increase, but also the cost to go from A to C if the route from A to C goes through B) . Thus, the whole set of markets must be considered. This is the role of traffic models, which consider these interactions and provide the traffic flows on each link of the network both before and after project implementation.

Externalities related to the environment and safety are not specific to transport; they also occur in health and environment economics and have been the subject of both theoretical and applied studies. Shroten *et al*., (2019) provides a comprehensive review of how to evaluate these non-market goods and external effects and how to monetize them.

These procedures are firmly established in most countries that use cost-benefit analysis; however, they are unsatisfactory in many respects; first, from the point of view of integration into the decision-making process, they do not answer many of the questions that decision-makers ask themselves, in particular the effect of the project studied on economic activity and/or employment. Second, from the point of view of scientific rigor, they are based on theoretical foundations that include very restrictive assumptions. This leads for ways to address these shortcomings, and in this context two categories of procedures will be analyzed: the use of corrective factors, and the implementation of general equilibrium models. These considerations dictate the rest of this paper. In the second section, the theoretical assumptions on which the cost-benefit analysis is based will be developed, and the third highlights the shortcomings that these assumptions reveal, both from the user and scientific point of view. The fourth section presents the means to overcome these drawbacks, and the fifth proposes recommendations for use of the most complete of these means: the spatialized general equilibrium model.

6.2 The theoretical basis: the surplus theory

The theoretical justification of these procedures comes from Surplus theory and dates to the work of Jules Dupuit (1844) and Alfred Marshall (1922). There are many ways to introduce this approach; some are very sophisticated, while others are very simple. For more developments, see for instance de Rus (2010) or Johansson and Kriström (2018).

Box 1 develops those well-known results through one that is intermediate,[1] based on the Social Welfare Function, justifying the basic relation : $dW = -\sum_i p_i dq_i$.

Box 1. A short presentation of CBA principles

Let's assume that society itself has a utility function (its social welfare function), which depends on the utilities of each individual within that society: $W = F(U^1,...,U^n)$.

Then, the change in the social welfare resulting from a marginal change is given by:

$$dW = \sum_j F_j^{'} dU^j$$

Normalizing individual utilities according to the classic convention that assumes the marginal utility of different individual's income is constant and equal to unity we obtain:

$$dW = \sum_j [F'_j \sum_i (p_i dq_i^j)]$$

Assuming that the initial distribution of income is optimal, society as a whole is indifferent to a marginal transfer between individuals; thus F'_j is independent of j, and:

$$dW = \sum_i p_i dq_i \quad (1)$$

dq_i being the total change in the quantity consumed of good i.

If society does not give the same weight to each individual (if for example it chooses to favour certain groups) this can be translated into a distributional weight attached to each individual's utility.

If the change in price is non-marginal, change in quantity cannot be ignored. Intuitive reasoning [2] shows how the area under the demand curve measures the surplus (figure 1). In the case of a nonmarginal change in price, going from P_0 to P_1, the surplus equals the grey area which covers two parts: a rectangle, which reflects the surplus from

[1] Drawn from Quinet and Vickerman (2004) and Quinet (2009)

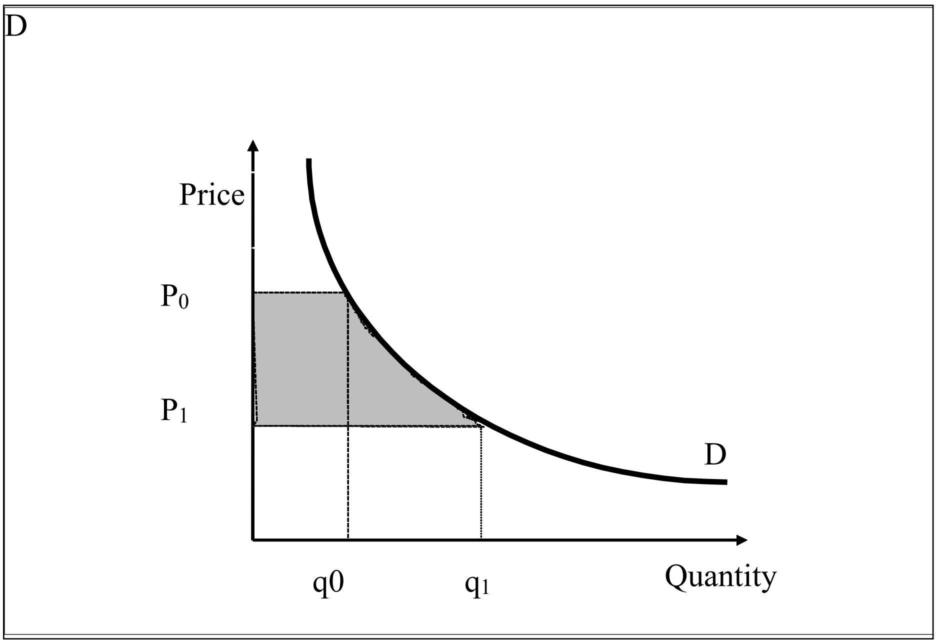
[2] Which is rigorous under some currently-made simplifying assumptions (for example, assuming a quasi-linear utility function) and if only the price of one good changes.

the change in price without accounting for change in quantity, and a curvilinear triangle, which reflects the surplus from the change in quantity.

$$\Delta U_i = -\int_{p_j^o}^{p_j^1} q_{ij} dp_j$$

The formula for the surplus is approximately $(P_0 - P_1)*(Q_0 + Q_1)/2$. This formula is known under the expression of "rule of a half".

Figure 1. Surplus from a non-marginal change in price



This formula can be extended to the presence of non-market goods, such as time or safety and external effects. Box 2 shows a simple way to introduce them and to show how, theoretically, they can be given a monetary value, in the case of time and environmental effects.

Box 2. Introduction of time and external effects

Let's assume that the utility function of an agent depends not only on the goods they can buy, but also on the available time for consumption *T* and on an external effect *e,* which they cannot control:

$$U = U(q_i, e, T)$$

Let's assume that each quantity of good *i* needs t_i time to be spent. Then the agent must maximize their utility *U* subject to a budget constraint and time constraint:

$$\sum p_i q_i < R$$

$$\sum t_i q_i < T$$

Introducing the two dual variables λ and μ, it is easy to derive the conditions of optimization:

$$U_i' = \lambda p_i + \mu t_i$$

Normalizing λ (the marginal utility of income) to 1 leads to the interpretation of μ: this is the value of a unit of time. Similarly, it appears that the unit of externality e can be valued at $\lambda U_e'$.

In order to assess the welfare effects of an investment, it is necessary to consider, not only the benefits delivered in its lifetime (and which can be assessed through the calculation of yearly surpluses), but also the costs, and to take into account the fact that yearly benefits and costs are spread throughout the project's life. This point is addressed through the discount rate. Summing up, we get the general formula of the Net Present Value (NPV):

$$NPV = -\frac{I}{(1+i)^{t_0}} + \sum_{t=t_0+1}^{t=T} \frac{A(t) - r(t)}{(1+i)^t} + VR/(1+i)^{T+1}$$

where:

i: is the discount rate

I: is the investment cost, possibly discounted over the construction years, if the building phase lasts several years, as generally happens.

T: project life

A(t): the benefits (the surpluses) of year t

r(t): the maintenance and operation expenses of year t

VR: the residual value of the investment after the final year of operation

The advantage of CBA is that it requires very little information: it is based on a partial equilibrium analysis, which is limited to the market where the change happens. Of course, the benefits do not stay inside this market, but propagate through the whole economy. For instance, when you improve a commuting mass transit link, the benefits initially provided to the commuters will more or less be transferred to the landowners through rent increases.

The crucial point (Lesourne 1972) is that this partial result, limited to the market where the change appears, represents social welfare as long as certain assumptions are fulfilled: marginal changes, no externalities and no increasing return to scale (or, more precisely, in presence of increasing returns to scale, marginal cost pricing).

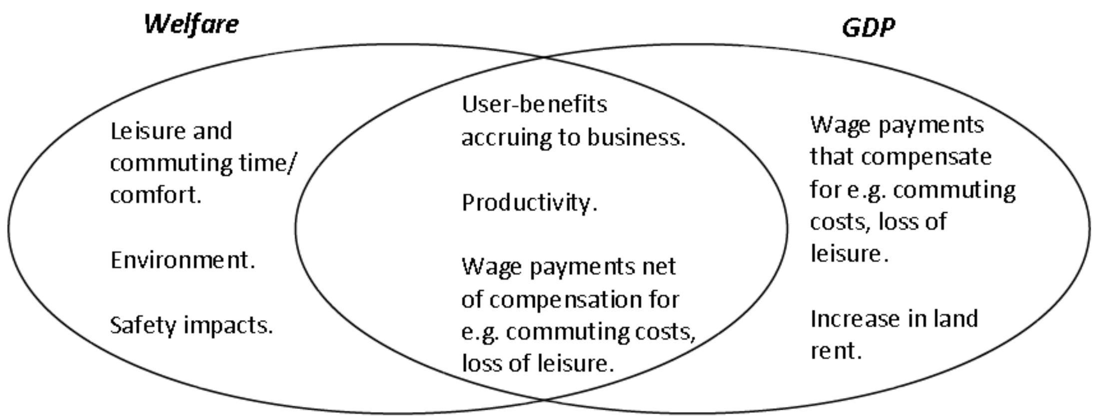
6.3 The shortcomings of current practice of CBA

This body of concepts and the derived practices are viewed somewhat differently by users (the analysts who apply CBA in projects and the decision-makers who use the results) and economists. CBA is based on the measurement of welfare changes and this is not necessarily the same as changes in GDP and the level of employment.

6.3.1 The preoccupations of decision makers

The welfare measure through the surplus, as described above, provide a single figure, the NPV, which is not very expressive and meaningful for decision-makers. Generally speaking, in the case of a single figure, many decision-makers would prefer GDP. The problem is that the two notions do not necessarily coincide, especially when there are externalities. Figure 2, from Venables, Laird, and Overman (2014), highlights differences and common features of welfare and GDP in the case of transport.

Figure 2. How welfare and GDP overlap in the case of transport



Source: Venables, Laird, and Overman (2014).

Consider the example of job creation. From the perspective of GDP, the benefit would be wage payments, whereas from the perspective of welfare (surplus), the benefit would be the surplus above the social opportunity costs of labour, including the tax wedge associated with the job.

Furthermore, decision-makers are eager to break-down the consequences of the investment: which socio-economic category will benefit or lose from it; which geographical zone will be impacted? These concerns are especially important in the case of geographically localized investments, which is the case of transport investments. Unfortunately, CBA calculations of the economic surplus give no indication of the final distribution of the investment's effects, as the initial changes in the transport sector lead to changes in the production and consumption of all other goods. And to identify the final beneficiaries, it would be necessary to follow these transmission mechanisms. Unfortunately, surplus theory provides no answer to this question, unless existing information allows the disaggregation: it just states that final welfare is equal to the surplus calculated on the transport market. But even this result depends on whether the aforementioned theoretical assumptions are fulfilled.

6.3.2 Pitfalls for economists

Economists have two sets of concerns about the use of CBA related to concepts and mechanisms that are either not considered or are done so only imperfectly. One set is concerned with evaluation norms and the other with the assumption of first best.

Restrictive evaluation rules

The classical formula of surplus implies, among others, two assumptions relative to evaluation rules. First, the distribution of benefits and costs is assumed to be optimal, or the society has other mechanisms to deal with the redistribution of income, so there should be no equity concern. If that were not the case, and if decision-makers wanted to support one person over another, they would have to assume that a dollar going to that person has a superior value to a dollar going to the other. But in that case, the decision-maker would need to know the final beneficiaries and, as said, the basic CBA formula does not generally give this information.

The other basic hypothesis underlying the usual CBA is that changes are marginal. However, that assumption is not always valid, for instance, in the case of assessing new transport infrastructure (which leads to the price of a good going from infinity to a finite value); though sometimes even new transport infrastructure or technology can be assessed as an incremental change with respect to generalized price without the project.

In situations of non-marginal changes, the classical formulas are valid only under restrictive assumptions, such as the assumption that the marginal utility of income is constant, an assumption that is not very realistic when spending on transport takes a large share of the budget (Jara-Diaz 1986). Removing this assumption requires a dependence on on more complicated indicators than surplus, such as the compensating variation (the income variation that, with final prices, makes the individual as happy with the initial situation as with the final one); equivalent variation (the income variation that, with initial prices, makes the individual as happy with the initial situation as with the final one). But these alternatives entail other difficulties; for instance, in the case of a logit random utility model, which is widely used in transport and in urban economics, departing from constant marginal utility of income implies huge complications (Karlstrom 1998).

Assumption of the first-best

The whole construction depends on the first-best assumption, which is necessary for the classical surplus calculation, even for marginal changes. This is a necessary condition in order for the partial equilibrium analysis of a single affected market to represent the surplus that will transmit with no distortion to the rest of the economy, and benefit the entire economy (Lesourne 1972; Jara-Diaz 1986). This useful property enables us to calculate the economic surplus from the initially-affected market, without knowing how the surplus will be distributed and without having to follow the complex path of transforming that result.

Unfortunately, this assumption is not supportable, as evidenced by modern economic analysis that emphasizes imperfect taxes and subsidies and imperfect competition in the general economic picture. It is even less supportable in the case of investments implying geographical effects, such as (but not only) transport. It is well-known that economic geography is based on increasing returns to scale and externalities, especially agglomeration externalities. We now develop these various points.

General market imperfections: taxes and market powers

Taxes modify the behavior of economic agents and then distort the optimum as long as they are not lump-sum taxes; for instance, labour taxes are an incentive to reduce employment, and an extra dollar generated by the tax is not a simple transfer, but causes a loss in welfare. This mechanism leads to the marginal cost of public funds (as in Snow and Warren 1996, among many others).

Industrial economics increasingly recognizes the role of imperfect competition or market power (Tirole, 1988). Market power exists within sectors, in particular the transport sector—for example, in ports and airports or between railway lines and airline companies. Market power is also spread throughout the economy, as demonstrated in studies that calculate the Lerner index (the relative gap between prices and costs; Meunier *et al.* 2014).

Demand externalities and increasing returns in transport

As noted, transport demand analysis implies many externalities, mainly based on congestion and scarcity. Demand externalities linked to congestion have already been discussed. It is worth noting here that there are also frequently increasing return to scale in transport supply, for example due to the size of vehicles, or to network effects (hub and spoke system, logistic centres).

Positive externalities in transport

There are several research trends that demonstrate positive externalities in transport.

A first trend was initiated by Aschauer's (1989) first paper. Following his work, many studies, both theoretical and empirical, have focused on the relationships between infrastructure investments, especially in transport, and growth. A recent meta-analysis by Melo, Graham, and Braga-Ardao (2013), which considered several factors (the methodology used in the study, the region examined) that might explain differences in results, found an average elasticity of private output to road investment of 0.05. Thus a 10 percent increase in the stock of roads would increase private output by 0.5 percent.

Another trend is known by the term “agglomeration externalities”. This is mainly an intra-urban effect, while the previous one was at the level of a country or a region, and can be expressed in many ways. For example, the larger an agglomeration, the higher is the productivity of the workers. Or, the greater the density of jobs, the higher is productivity - where density can be either real density (number of jobs per square kilometers) or effective density (which considers virtual distance and includes the cost and journey time, for which accessibility indicators can be used). These are externalities, because those who enjoy the positive effect of agglomeration on productivity do not pay for it—agglomeration depends on the actions of other individuals over which the beneficiary has no control. The idea was initially presented by Marshall (1922) and is also laid out in Perroux (1952). Duranton and Puga (2004) identify three sources of agglomeration externalities:

- **Learning:** The learning of good practices and the diffusion of innovations through communication.
- **Matching:** When there are many agents, firms more easily find employees who meet their precise needs, and workers more easily find jobs that suit them.
- **Sharing:** The possibility of sharing and making refined specializations profitable.

Melo et al. (2009) have made a survey of estimates of these elasticities.

(New) Economic Geography

Space, simply by virtue of the presence of transport costs, can create conditions of imperfect competition independent of the presence of increasing returns to scale. City size is explained by the existence of increasing returns. Additionally, the tendency to polarization has been recognized for a long time, beginning with Marshall (1922 [1890]) and Perroux’s (1952) development of the idea of the cluster. Analysis of the location decisions of firms highlighted the importance of nodes of communication networks and the presence of natural resources. Hysteresis effects have also been noted: once a location is chosen, it develops even if there is no economic logic for selecting it in the first place. Many such effects have been analyzed independently without resort to a unified theory.

These kinds of observations and theories have been brought into a larger framework by the contributions of the New Economic Geography (Fujita, Krugman, and Venables 2001; Ottaviano, Tabuchi, and Thisse 2002). Its most salient features are:

- Increasing returns to scale for industrial firms and constant returns to scale for agricultural activities.
- Imperfect competition in industrial firms, following Dixit and Stiglitz's (1977) model of monopolistic competition.
- Trade costs generally assumed to follow the Assumption Iceberg.
- Various assumptions about factor mobility—often immobility for workers at international level and mobility at regional level

It is beyond the scope of this paper to survey, even partially, the findings of this rich strand of research.

6.3.3 Summary

Concerns relating to, and dissatisfaction with, these two categories of actors (decision-makers and economists) analyzed above can be summarized in a few bullet points:

- The inappropriate use of excessive simplifications in CBA, which ignore the complexities of the modern world (market power, increasing returns, externalities, position of public authorities).
- The inability of current assessment methods to highlight the final effects of policies or projects, identify the beneficiaries, and assess the effects on growth and GDP.

- The inability of current methods to assess major, non-marginal projects and programs, at least in transport.

The following section explores ways of addressing these ‘dissatisfactions.

6.4 Improving on basic cost–benefit analysis: the possible role of CGE

6.4.1 Correction factors

One way to deal with the limitation of market imperfections that diverge from the first-best case without greatly altering current CBA practice is to apply coefficients to the rough CBA results. CBA-users already employ this approach to take environmental effects into account. This practice has been formalized in many countries, where such correction factors are recommended or compulsory in CBA assessments, especially for transport investments. These correcting factors are drawn from the theoretical and statistical analyses that prove their existence and allow the corresponding mechanisms to be quantified, as shown above.

Imperfect taxation

One application of the correction factor method concerns the cost of taxation in terms of social utility. Mandatory levies tend to modify relative economic prices, distort the competitive equilibrium between supply and demand, and thus create a gap between the choice of consumers and the socioeconomic optimum—the opportunity cost of public funds. This can be seen through a partial equilibrium analysis, following the principle of Harberger’s deadweight loss. Furthermore, the gap can be evaluated using a general equilibrium model that determines the loss of social utility resulting from an increase in different types of taxes (Mayeres and Proost 1997). This loss depends on the nature of the tax, and to be rigorous, a different coefficient should be used for each tax; in practice, however, only average values are calculated.

Market power

The existence of market power also calls into question CBA formulas. Changes in costs are not transmitted to prices on a one-to-one basis. The distortion coefficient depends on market conditions. In practice, CBA does not provide these exact details, but can incorporate the price-cost margin information in the calculation of the project's net benefit. In France and the United Kingdom (UK), the proposed coefficient of 0.1 (to be applied to the classical benefits of professional trips and merchandise transport) is thus an approximation.

Agglomeration externalities

Other correction factors are added to take agglomeration externalities into account. These factors are based on assessments of the elasticity of production to density or to the accessibility of jobs in a given zone. France and the UK apply such factors in their CBA. In France, the driver is the change in employment density, with an elasticity productivity density of 2.5 percent, where the gains of productivity are calculated from the changes in density, and which also implies determining changes in location. In the UK, the driver is change in accessibility, with variable elasticities depending on the sector.

Market or factor prices in employment

Another correction factor concerns replacing market prices with factor prices when market prices are distorted by taxes or subsidies. This point is especially relevant for the price of gasoline, which is heavily taxed in some countries and subsidized in some others.

The same correction factor is relevant to employment.[3] When, for example, there are externalities in the job market corresponding to taxes applied to salaries, it is logical to consider variation in the tax wedge due to changes in jobs. The same happen with the existence of unemployment benefit. The difficulty lies in assessing labour force variations, which like other final impacts of a project, are not given in the CBA. In order to go deeper in this direction, it would be necessary to take into account mechanisms such as search barriers through a specific modelling of the labour market and its

[3] Another correction factor relates to search. But, as shown earlier, the corresponding effects are not well-known, and even less well-estimated. Therefore, they are not introduced as a correction factor.

dependence on accessibility. With this information available for the practitioner, the right measure of the opportunity cost of labour is straightforward.

Limitations of correction factors

Correction factors are used to deal with multiple deviations from first-best situations to proceed with classical CBA and maintain its validity. But these methods have limitations.

1. First, they are susceptible to double-counting. Many analysts (such as Kidokoro, 2004 and Kanemoto, 2013) question double-counting between agglomeration externalities and market power effects.
2. Second, each correction factor assumes that the only imperfection is the one it seeks to correct for. But even if all correction factors do not intersect, it is not certain that they are additive, especially in large-scale projects.
3. Third, the correction factors do not address limitations related to the description of effects and assessment of the issues of large projects or programs.
4. However, the most important limit comes probably from the fact that, to implement most of them, it is necessary to have some information on the final situation and final effect of the investment. This point is now developed through a few examples:
    - In the case of noise and air pollution, the corresponding costs' unit values should be applied to the final agents suffering from these costs; but, due to migration, those near the infrastructure at the end will not necessarily be the same as those at the start.
    - In the case of agglomeration externalities, it is necessary to know the final densities in all modelled zones and final changes in accessibility. Here too, due to changes in locations and changes in travel patterns, both parameters can change ex-ante and ex-post.
    - In order to apply the tax wedge procedure for employment, it is necessary to have an estimate of how many jobs are created by the investment.

The next step is thus to abandon partial equilibrium analysis and to implement general models that may provide such information.

6.4.2 General equilibrium models

Computable General Equilibrium (CGE) models measure the multimarket effects of the intervention, and overcome many of the major flaws of traditional CBA that arise from the partial equilibrium focus on a given sector, with results that yield a single overall number, the NPV or internal return rate, rather than identifying the multiple impacts of an investment. In any case, it is worth stressing that CBA is concerned with net welfare changes instead of the project's impact. We will concentrate on spatial models.

A classification of spatial models

Wegener (2011) and Bröcker and Mercenier (2011) describe many classifications of spatial models, while Vickerman (2007) develops the use of models. In these models, there is interaction between the transport and economic activities of each zone. Changes in transport supply induce first changes in the level and distribution of spatial activities. Conversely, this change in the spatial distribution of activities generates new displacement flows on transport networks that connect the different places. Successive feed-back between transport and economic activities lead to a fixed point equilibrium where transport conditions and economic activities are in accordance.

Depending on the model, the impact of transport on the location of activities relies on an explicit economic mechanism corresponding to land rents or, more heuristically, on an accessibility index leading to estimate the effect of the investment on migration, without ambition to deduce land rents.

A classical distinction is made between dynamic models and static models. Dynamic models allow for discrepancies in the adjustment speeds of different markets, while static models define the equilibrium state with no indication of the channel or speed at which it is reached. Dynamic models are more realistic, but static models are more adapted to calculating welfare differences of the “with and without” conditions.

Even within these restrictions, there are multiple models that differ by size, complexity, and basic assumptions.

In terms of complexity, spatialization of CGE models induces at least two more dimensions of complexity than the usual non-spatial models. The first dimension is that, on top of the dimensions of socio-economic characteristics of consumers and sectors in the production sector, the spatial dimension is added and implies multiplying the number of required data and of forecasted variables by the number of zones. The second one comes from the fact that transport economics and economic geography stress the importance of considering heterogeneity of agents; the paradigm of the representative agent does not work well as it is prone to dramatic errors; accounting for heterogeneity is achieved through the intensive use of random utility models based on Weibull, normal, GEV or Frechét distributions for consumers and users, as well as for producers. The management of such models is of course more complicated and raises the level of complexity. The counterpart of this complexity is of course the black box effect and difficulty in communicating with decision-makers.

While all spatial CGE models are complex by nature, there is a variety of degrees in this dimension. For simplicity, we distinguish two polar cases, which we name Spatial General Equilibrium Models (SGEM) and Land Use Transport Integration (LUTI) models. In what follows, SGEMs treat transport as an activity, with a unique cost that generally depends on distance,[4] and do not model land rent; while LUTI models include feed-back between a full transport model that distinguishes several modes and an economic activity model, where transport conditions affect the economic activities, and which take into account the price of land.

In all LUTI models, movements of households and labour are endogenous, and many models include land rents as endogenous variables. SGEMs are less developed in this respect: they do not include land rent, and many of them imply no migration of household and labour. SGEMs are traditionally used in trade, while LUTI models are used more frequently in transport. LUTI models are usually more complex and need very detailed data about zones to reproduce land price, location, and, for most of them,

[4] In CGEurope –Bröcker 2002- , for instance, there are several modes whose costs are constant (and independent of traffic), and the choice between them is represented by a logit model; so the outcome boils down to a unique mode whose cost is the logsum of the costs of the elementary modes.

modal and itinerary choice phenomena; while SGEM models cover a wide range of sizes and complexity.

In transport, a typical example of a LUTI spatial model, which in one of its versions, is based on first-best assumption (no externalities other than congestion in transport and no increasing returns) is the Regional Economy Land Use and Transportation (RELU-TRAN) model (Anas and Liu 2007), which is a spatial computable general equilibrium model applied in many agglomerations and with interregional versions. This model considers the location of activities and introduces the mechanism of land rent. It permits calculation of an economic surplus and specifies the beneficiaries. UrbanSim is another urban model. Unlike RELU-TRAN, it is a dynamic model, and the location of agents does not result from a land rent mechanism but is based on a hedonic function based on accessibility of locations (Waddell 2002). There are many other examples of LUTI models.

Perfect and imperfect competition models

Should there be no market imperfections, then the main advantage of CGE models would be to provide an identification of the final winners and losers of the investment at stake. Further, use of CGE would provide a rigorous treatment of non-marginal changes, allowing to calculate an exact evaluation of the surplus, beyond the approximation resulting from Dupuit's basic formula or the Rule of a Half. Then the Equivalent Variations (EV) or Compensated Variationss (CV) can be calculated – with the well-known issues of aggregation if there are more than one category of agent.

But, as we have seen, transport, and more generally all geographically-based investments, are subject to market imperfections.

So, we must consider that CGE includes market imperfections, and that a variety of models with such features exist. It is worth detailing the characteristics of some current models, without trying to be exhaustive, to give a flavour of the variety in this respect.[5]

In the SGEM category, CGEurope assumes monopolistic competition (Bröcker 2002). Prices and quantities respond to changes in transport times and costs, resulting

[5] For more information, see Wegener (2011) and Bröcker and Mercenier (2011), cited above.

in changes in income and welfare in each region. The CGEurope model predicts the spatial distribution of production factors without migration. In the Relative Acculturation Extended Model (RAEM), each sector consists of identical firms, each producing a unique specification of a particular commodity, which gives them monopolistic power (Tavasszy, Thissen, and Oosterhaven 2011). Households and domestic sectors consume transport services in their consumption and production activities. Martinez and Araya (2000) introduce agglomeration externalities in the land use MUSSA model (Martinez and Donoso 2004) through a parameter in the utility function of the economic agent that represents the location advantages, which depend on the accessibility of the place and its characteristics. Borjesson *et al.* (2014) uses this kind of model, representing the externality (density of the zone in which consumers live) in the utility function. Some transport models, such as RAEM 2, also integrate labour market imperfections, especially through the reservation wage and search procedures, which depend on transport (Koopmans and Oosterhaven, 2010). The latest RAEM version, RAEM 3.0, includes international trade and interregional migration.

Lessons

When second-best mechanisms are introduced in CGE models, these mechanisms depend on several key parameters, and the issue becomes about our knowledge of these parameters. It generally happens that the CGE models are too huge to be calibrated through rigorous econometric procedures, especially in the case of spatial models which, as we have seen, embed a lot more complexity than the other models. From this point of view, it is interesting to refer to Anas and Chang (2017) and to the procedure they used to calibrate those parameters.

Anas and Chang ran the Relu-Tran model to assess a large automated mass transit project in the Paris Region (named the G*rand Paris Express*). Relu-Tran includes a version with agglomeration externalities, and a market imperfection on which we will focus. The authors adopt the following formula for agglomeration externalities:

$$A_{rj} = C_{rj} \left(\sum_{\forall i} \left(\frac{Jobs_i}{Total\ Jobs} \right) \frac{Jobs_i}{Area_i} \cdot G_{ij}^{-\beta} \right)^{\alpha}$$

In which:

- i, j are the zones
- r is the production sector
- G_{ij} is the accessibility from i to j
- C_{rj} is a constant for each $r\ j$
- α and β are parameters

The point is that α and β are not econometrically calibrated through the data of the zone but transferred from other studies through expert guess. Depending on the study from which the estimates are transferred, the value of accessibility varies according to a wide range, from 1 to nearly 10.

Similar statements around the results' sensitivity to some of the model's parameters, and of course to the general structure of the model, can be derived from the many studies comparing the results of different models applied to the same situation (Hof et al, 2012; Koopmans and Oosterhaven, 2010; Prager, 2019 or Bröcker et al, 2004).

This situation can be compared to the modelling framework used, for instance, by Ahlfeldt, Redding, Sturm, and Wolf (2014). They build a model based on CES utility functions, and monopolistic competition with random productivity following a Frechet distribution, allowing for agglomeration effects; while location of agents is modelled through a two-level process, first choosing a residence and then where to commute to (that depends on residential amenities, which are a function of accessibility to places of interest). Several key parameters intervene in this model, some of which are calibrated through external information, such as the share of residential land in consumer expenditure and the share of land in firms' cost functions. But the most relevant parameters linked to the effects of transport are through econometric procedures, as shown by the following table, where we see several econometric estimates of three basic accessibility elasticities of productivity, residence and commuting; for each the average value and the effect of distance are shown and the significance of theses values is estimated, as shown by the following table; furthermore the econometric treatment allows us to distinguish between two periods: before and after 1986.

Table 3: Generalized Method of Moments (GMM) Results

	1936-1986		1986-2006	
	One-step Coefficient	Two-step Coefficient	One-step Coefficient	Two-step Coefficient
Productivity Elasticity (λ)	0.1261***	0.1455***	0.1314***	0.1369***
	(0.0156)	(0.0165)	(0.0062)	(0.0031)
Productivity Decay (δ)	0.5749***	0.6091***	0.5267***	0.8791***
	(0.0189)	(0.1067)	(0.0128)	(0.0025)
Commuting Decay (κ)	0.0014**	0.0010*	0.0009	0.0005
	(0.0006)	(0.0006)	(0.0024)	(0.0016)
Commuting Heterogeneity (ε)	4.8789***	5.2832***	5.6186***	6.5409***
	(0.0423)	(0.0074)	(0.0082)	(0.0031)
Residential Elasticity (η)	0.2212***	0.2400***	0.2232***	0.215***
	(0.0038)	(0.0037)	(0.0093)	(0.0041)
Residential Decay (ρ)	0.2529***	0.2583***	0.5979***	0.5647***
	(0.0087)	(0.0075)	(0.0124)	(0.0019)

Note: Generalized Method of Moments (GMM) estimates using twelve moment conditions based on the difference between the distance-weighted and unweighted mean and variance of production fundamentals and residential fundamentals. Distance weights use the distance of each West Berlin block from the pre-war CBD, inner boundary between East and West Berlin, and outer boundary between West Berlin and its East German hinterland. One-step estimates use the identity matrix as the weighting matrix. Two-step estimates use the efficient weighting matrix. Standard errors in parentheses. See the text of the paper for further discussion.

Therefore, this kind of model avoids the previous draw-back of non-estimated parameters. It is less informative on the general economic process but provides econometric estimates of the main geographic parameters.

6.5 Conclusion: how to use geographical CGE?

On top of the previous considerations, which advocate for the use of CGE, several practical points should be taken into account, which induce us to qualify and limit their use.

First, CGE are long and costly to calibrate, and should therefore only be used for very large projects or programmes. Due to the big investment, they should be used for a long period. It makes no sense to build such a model for only a one-shot use. Repeated uses should be recommended, and not only for the purpose of amortizing sunk costs: it can be said that applying a model to a variety of different situations uncovers some rules of thumb and regularities.

Second, the choice of the model and its characteristics in terms of market imperfections (labour market imperfection, land market imperfection, agglomeration externality, oligopolistic competition, etc.) should be made after a careful qualitative analysis of the situation.

Third, for the most important projects, it makes sense to run several models in parallel. A comparison of the results allows us to obtain fruitful insights into the relevant hypotheses and enables better insight into the outcomes.

Last, comparison of the ex-ante and ex-post studies would certainly provide a lot of information on the relative merits of each model and possible rules of thumb for a rough assessment of various mechanisms.

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