C-Bridge:
Reconciling CBA and CGE methods for the economic appraisal of investment projects.

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1 Introduction

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1.1 C-Bridge in short

C-Bridge is the name given to a research project aimed at reconciling methodologically Cost-Benefit Analysis (CBA) and Computable General Equilibrium (CGE) for the purposes of conducting the economic appraisal of investment projects. The objective at the outset was to formulate CGE models that resemble as much as possible the vantage point of CBA in order to explore differences in results when modelling the same project with the two methodologies in parallel.

It was managed by the universities of Las Palmas de Gran Canaria, in Spain, and of SLU-Umeå, Sweden and included participants from a number of other universities in Europe and the US. The full list of participants is included in section 1.3 of this introduction. It was funded by the European Investment Bank (EIB) Institute under its EIBURS program. C-Bridge was conducted between January 2019 and February 2023. This document compiles the full set of papers, ordered in the form of chapters, that were produced as part of the research project.

The next section in this introduction is a preamble, discussing the rationale for C-Bridge. Section 1.3 introduces the research team and discusses some peculiarities of the project and issues of interest that sprang during its production. Finally, section 1.4 introduces the structure of this document.

1.2 Preamble

CBA is the EIB's preferred method of economic appraisal for projects that are candidate for receiving EIB finance. A common question to project appraisers from stakeholders and decision makers is "how much impact are you leaving out?". This turns out to be a loaded question, in at least three ways. One is what is meant by "impact". Second — and here let's purposely change the order in which the word appears in the question—, what is meant by "out"? Thirdly, what is meant by "leaving"?

1.2.1 Impact

The meaning of the word "impact" in the context of economic appraisal is ambiguous, where the context includes both producers and consumers of the appraisal results, and where such consumers frequently include non-economists. Among non-economists, the term "economic impact" happens to be more popular than the term "welfare". Traditionally, non-economists associated "impact" to gains in incomes and jobs — perhaps tax receipts to the government also. Let us call this conception of economic impact **"traditional popular impact"**. It closely relates to the meaning that economists have usually given to the idea of economic impact. In the context of research into the economics of investment projects, economic impact studies, relying on input-output models (I/O), measure the extent to which an exogenous injection of capital expenditure in an economy leads to knock on expenditures across the economy, generating income to the various factors of production. The approach validates the connotations of exogeneity in the word "impact" —the entry into sudden, normally forceful, contact of two separate bodies. The two bodies would consist of the investment expenditure and the economy. Let's call this the **"economic impact"** vantage point.

Subsequently, CGE modelling improved upon I/O, adding flexibility to economic impact studies by allowing for price adjustments. CGE models could also turn the exogenous shock into endogenous. But the models retained the focus on income, and normally neither addressed welfare nor non-marketed goods or services, with some exceptions only more recently. Moreover, just as I/O models, CGE were originally intended to assess the effects of policies, which normally apply to markets across the economy. In the last few years CGE models have also been applied to investment projects, particularly the so-called "mega-project", or what economists would understand as "large projects" in that they can alter prices across an economy. Such large investment projects can include hosting an Olympic game, or building a major infrastructure facility, if not network.

All in all, we can make the rough generalisation that economic impact studies, whether conducted through I/O or through CGE, broadly corresponds to what the public has traditionally understood as economic impact, so that:

$$\text{Traditional popular impact} \approx \text{economic impact} \tag{1}$$

Instead, welfare economics, with its normative connotations, ultimately geared towards influencing decision makers as to what they should do, takes a broader view than incomes or jobs. Traditionally, its tool of choice is CBA, which accounts for income flows, whether explicitly or implicitly (depending on the aggregation method) as well as, explicitly, non-financial (but valued in money terms) flows arising from non-marketed goods and services, including externalities, whether environmental or otherwise. In keeping with the welfare economics framework of determining whether a change (whether a policy or an investment project) would yield a societal improvement, CBA seeks to account for differences in utility (as measured by willingness to pay, or accept), thereby always comparing the state of the world with the change against the state of the world without the change.

Initial, rudimentary CBA's, dating back to Dupuit in the 19th century, dealt with the provision of public infrastructure. Pigou's welfare economics work in the first third of the early 20th century addressed change in general, whether through investment or policies. From its inception, CBA was conceived for projects and policies, and to include flows of nonmarketed goods and services, as well as of marketed produce. We label this vantage point **"economic welfare"**. Therefore:

$$\text{Economic impact} \neq \text{economic welfare} \tag{2}$$

Recently, coinciding with the spread of what has been labelled the environmental, social and governance (ESG) movement in the operation of the private sector, the term "impact" has gained a broader meaning, to comprise benefits and costs to society, if not to the planet itself. People want to work on jobs with "impact", and ESG funds seek to buy securities in companies or sectors with impact, meaning considering effects on society and not just on financial profit. The concept of impact in the public's mind has therefore shifted to become closer to the scope of CBA. Call this **"new popular impact"**, so that:

$$\text{New popular impact} \approx \text{economic welfare} \tag{3}$$

Decision makers that may use CBA also see the need to convey to the public the rationale for the decisions taken. Since the audience expects to hear "impact", there may be a tendency to describe the output of CBA in terms of impacts, which does not match the realm of the term, at least as traditionally understood by economists, who would relate it to I/O. Recently, some CBA practitioners have arguably added to ambiguity in terminology by referring to benefits and costs in CBA studies as impacts, rather than welfare or societal gains or losses. By all means, the word impact is not unusual in the CBA literature, normally used as a synonym to “impinge”, “effect” or “affect”. By referring to benefits as impacts, CBA terminology comes closer to the new popular understanding of impact. While there is nothing fundamentally wrong with that, care has to be applied in two respects. First to acknowledge that there can be also negative impacts (i.e. costs). Second, that traditional impact studies —of the I/O or the initial CGE types—, are not mistakenly taken to stand for either a CBA, or for a CGE that takes a welfare vantage point.

Interestingly, the outset of ESG and “new popular impact”, has opened the door for CGE to strengthen its welfare credentials. CGE rests therefore somewhere between the two realms: the traditional “economic impact” and “economic welfare”, or “new popular impact”. It is important for CGE studies to make clear what their scope of analysis is.

Some governments already conduct CBA’s and CGE’s in parallel. The question arises then: is this unnecessary duplication? To answer this question, we would need to understand what CBA does that CGE does not, and vice versa.

1.2.2 Out

For “out”, in the “how much are you leaving out?” question, the inquirer means what benefits and costs are not included in the appraisal. As with “impact”, the answer to this question also has popular and professional dimensions. The popular dimension has been discussed already: the public wants to make sure that the analysis is not just about income, the “traditional popular impact”, but that it has a broader societal scope, the “new popular impact”. The public wants to see a conversation in the realm of expression (3), rather than (1).

CBA would normally address the question satisfactorily: we are not leaving anything out; or rather, in a more qualified fashion, we are not leaving anything “significant” out. We will address shortly what we mean by significant. With CGE, we could also yield the same reply: we are not leaving anything significant out, so long as the models are of the latest type, adopting a “welfare” scope.

As for the professional dimension to addressing the “out” word in the question, we face two misconceptions, one held by CBA professionals and the other held by CGE professionals. In addressing these misconceptions, we will also answer what we mean by “significant” in our answer in the preceding paragraph.

Beginning with the misconception held by CBA practitioners, they tend to be unaware of the newer, “welfare” versions of CGE, and continue to view them as belonging exclusively to the realm of impact studies in the I/O sense. CBA professionals question whether CGE models can incorporate non-marketed benefits and costs, and whether they can express values in terms of willingness to pay or accept, in the sense described by compensated demand curves in welfare economics. This leaves it to the CGE analyst to make clear when presenting appraisal results what it is that the CGE model includes. C-Bridge explores how CGE models are modified to include these newer considerations.

As for CGE practitioners, they tend to view CBA as a partial equilibrium exercise which, by focusing on the primary market (the market where the project takes place) only, leaves out all effects in secondary markets. The misconception lies in failing to see that CBA’s foundations rest is general equilibrium – as is well documented in publications like Dinwiddy and Teal (1996), Just et al (2004), and Johansson and Kriström (2016). Let’s take for granted that both CBA and CGE would both correctly model the primary market – whether distorted and undistorted. Then, as will emanate from the discussions in chapters 4, 5 and 7, in the absence of distortions beyond the primary market —or, in other words, in the absence of distortions in secondary markets—, both CBA and CGE should produce the same result. Both techniques are grounded in the Arrow-Debreu general equilibrium model of the economy. Indeed, even with distortions in secondary markets, notionally, with exhaustive modelling incorporating all such distortions, CBA and CGE must produce the same result because, in effect, the two exercises will converge into a single exercise.

That CBA can choose to focus the analysis on the primary market alone does not mean that effects on secondary markets are excluded: they are reflected in the magnitudes of the primary market, so long as the appraisal uses the right parameters (i.e. long run elasticities). The primary market would fail to register all value effects from secondary markets when these are distorted. In such circumstances, CBA practice uses two parallel strategies. First, it focuses on substantial distortions in secondary markets and explicitly models them in the CBA exercise. There is no reason why a CBA appraisal must be constrained to modelling only the primary market. Indeed, in practice, most often it does not. It includes as many (distorted) secondary markets as the CBA analyst believes are consequential to determine the societal case for the project. Second, the CBA appraisal adopts the assumption that small distortions roughly cancel out. Say, a non-consequential benefit due to a small increase in output on a taxed secondary market, broadly cancels out with a non-consequential cost caused by an increase in output on some other subsidised secondary market or, alternatively, by a reduction in output in some other taxed secondary market. Modalities of cancelling out are plentiful.

Combining this twofold strategy in the presence of distortions, CBA should catch most of the flows that are consequential to determine the case for a project and do so by focusing only on a few markets — the primary market plus, say, one, two, or three secondary markets. Bengt Kriström, one of the contributors to this project, calls this approach "partial general equilibrium". It was a central objective of C-Bridge at the outset to do exploratory work on how much partial general equilibrium leaves "out".

Clearly, appraisal design —choosing both what markets to focus on and what parameters to adopt to model market behaviour— is of primary importance for a well conducted CBA. The same applies to CGE. Which takes us to the third contentious word in our question.

1.2.3 Leave

The third and final loaded word in "how much impact are you leaving out?" is "leaving". It denotes a conscious decision on the side of the project analyst to include or exclude flows, markets, and various other elements in the appraisal. Analyst discretion is inevitable. Put two engineers to separately design a bridge in the same location over a river and they are unlikely to come up with exactly the same design, even if working under the same budget. The bridges designed by each engineer, however, should "do the job". The same applies to CBA and to CGE. Two economists doing a CBA of the same project are unlikely to take exactly the same set of decisions and therefore come up with exactly the same result. Differences may start with the primary market itself, such as in the reaction functions assumed for the various participants. The two analysts would hopefully coincide in spotting a major distortion on a secondary market, but may differ on how many other secondary markets include distortions that are consequential to the case for the project. The views as to the behaviour of each of those markets may also differ.

The same applies to CGE. The aim in CGE is to model an entire regional economy. The degree of aggregation or granularity in market modelling may vary from analyst to analyst, as would the parameters assumed for each of the markets. The assumed model closure —what set of variables are assumed exogenous—may vary as well.

Both CBA and CGE are models of the economy, and models are approximations. “Leaving” is part of analyst judgement, just as in any other profession. Differences among CBA exercises and among CGE exercises may perhaps go on to be compounded when comparing a CBA exercise with a CGE exercise. Note also that CBA and CGE modelling normally differ substantially in model size. In our bridge engineers analogy, both were working under the same budget. This element of the analogy does not apply to comparing CBA versus CGE appraisals. But C-Bridge does not go into evaluating whether the greater computational load of CGE is justified in terms of any increased accuracy and whether that eventual accuracy is consequential. The focus is rather on how the two methods can be brought to “do the same job” and then compare results.

1.3 The team and the project

C-Bridge was managed jointly by the universities of Las Palmas de Gran Canaria (ULPGC), in Spain, and SLU-Umeå, in Sweden, the former taking also the lead administrative function. ULPGC conducts CBA research, mostly in the field of transport, and CGE in the area of tourism. SLU-Umeå has research tradition in both CBA and CGE, mainly in the field of forestry, natural resources and energy. Researchers in ULPGC and Umeå counted with input and support from academics and consultants mostly in Europe but also in the US. The full list of authors and collaborators in C-Bridge is the following:

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Despite writing the introduction, I am not part of the research team. My role in C-Bridge was twofold. First, project manager on behalf of the EIB Institute. The task here was to see that the project was delivered according to the terms of reference and that any deviation from them was justified. Second, as proponent of the research topic to the EIB Institute. The idea to propose comparative research on CBA and CGE came when noticing that in Australia, and more precisely in the studies carried out to appraise the expansion of Sydney airport, the authorities commissioned both a CBA and a CGE. Some comparative literature existed already (Forsyth, 2014). The comments of Prof.

Peter Forsyth from Monash University at the early stages of gestation of what became C-Bridge are appreciated.

Economists, whether academic or practitioners, tend to specialise on either CBA or CGE. There are very few who are well versed in both techniques. As expected, during the initial phases of the research project, considerable effort was spent by each side educating the other on their respective method. This task, however, was not straightforward. Perhaps the difficulties can be explained by the differing mind frame from which professionals of each discipline approach appraisals: CGE economists focus on expenditure and income flows; while CBA economists focus on differences between marginal value (measured by willingness to pay or to accept) and opportunity cost. Four issues in particular were prone to cause confusion. I only mention them, without entering into a technical discussion:

1. The extent to which the primary market reflets welfare, or value, effects on substitute and complement markets.
2. The extent to which (i) multiplier effects and (ii) what CGE calls induced activity, account for a societal net welfare gain.
3. The assumptions that lie behind the social discount rate, particularly regarding the project counterfactual.
4. The role of leisure in the labour market as an opportunity cost.

As, quite likely, is to be expected in a project like this, there is no complete unanimity of opinions among the authors. The research team has agreed on a set of general conclusions, drawn in the concluding chapter of the document. But the reader will notice across the various chapters that some differences in opinion remain. Part of it are the relative merits of CBA and CGE, and in particularly the role that CGE — a tool aimed at modelling entire economies —may have in appraising projects which, while visibly large, may be small relative to the size of the economy.

It is not the intention of C-Bridge to judge whether one method is preferred to the other, or under what conditions. This would require judging three flows. First, the value (to the decision maker or to society) of the increased accuracy arising from the greater detail with which CBA models the project. Second, the value of the increased accuracy with which CGE models secondary markets and the economy at large. And third, the difference in the cost of performing appraisals with each of the two techniques. It is perhaps inevitable that in the papers included in this document, passing references are made to these issues, particularly given that this is a research project whose ultimate motivation gears towards practical application. But C-Bridge has not sought to address them.

Rather, C-Bridge is to be understood as an attempt to encourage research work on reconciling CBA and CGE, as well as comparing the techniques. It by no means intends to come up the last word on the topic. In particular, a number of simplifications have been used. CGE models can consist of large modelling exercises, even without entering into dynamic general equilibrium models. The CGE models included here are either relatively simple — in order to keep comparisons between CBA and CGE manageable —or consist of existing models for the relevant economy, adapted with limited tailoring to the project at hand — in order to meet the budget and time constraints of the research project.

Eventual future research should prove most interesting. Indeed, while C-Bridge authors were applied economists, at times the project had the feel of multi-disciplinary research, if only because of the time spent discussing the meaning of terms and concepts. Moreover, further research is highly desirable, even necessary. Appraising investment projects is a multi-disciplinary endeavour. Vantage points involved include engineering (with all its various sub-fields), environmental, legal, sociological, financial and economic, and that without entering into political considerations. If economists wish to retain a say, while allowing for differences in opinion among us, we should at least speak the same language.

1.4 This document

The document consists of eleven chapters or papers, each with authors identified. The document should be treated like an edited tome, where the sequence of papers follows the thrust of the project's argumentation, but where authors can diverge from each other's views. The project's argumentation proceeds in four steps. Individual chapters are assigned to each of these steps.

The first step is to define and present CBA and CGE methods. It includes chapters 2, where Ginés de Rus presents CBA, and chapter 3, where Federico Inchausti-Sintes and Eric Njoya present CGE.

The second step is to compare and reconcile the two techniques. It starts with chapter 4, by Per-Olov Johansson, setting the scene by addressing the type of project that would be most relevant for comparing CBA and CGE: a large project that affects prices in various markets of the economy. Johansson explores the applicability of CBA for such a project and extends it to CGE in the chapter's appendix. In chapter 5, Bengt Kriström makes a direct theoretical, high-level, modelling comparison between the two techniques for a single, reference application. Emile Quinet makes in chapter 6 a similar comparison, but from the vantage point of the transport sector. The reader will notice some difference in the conclusions of these authors, but no strong disagreement. Finally, in chapter 7 Federico Inchausti-Sintes, Juan L. Eugenio-Martin and José M. Cazorla-Artiles make a reconciliation of the two techniques, from the vantage point of CGE.

The third step is to apply the two techniques in parallel to the same project and compare results, for various sectors of the economy. This includes three chapters, each addressing a sector of the economy. Chapter 8 applies the techniques to a project in the transport sector. Authorship is the same as chapter 7, with the addition of Jorge Valido and Ubay Pérez-Granja. Chapter 9 by Bengt Kriström, makes the comparison for a forestry project. The third and final chapter in the group, chapter 10, does it for the tourism sector, with the same authorship as chapter 8, except for Jorge Valido.

The fourth and final step is to draw conclusions from the material and findings in the previous chapters. Chapter 11 is authored by the research team. While there emerges a well-defined line of argumentation, the reader should consider that areas for future research are plenty. This introduction has hinted at some. The reader will surely find others.

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2 CBA for the social appraisal of projects

Ginés de Rus

2.1 Introduction

Only projects with net social benefits should be approved. This simple idea is the reason why the economic appraisal of projects can contribute to social welfare and the rationale for the existence of Cost-Benefit Analysis (CBA) as a tool for guiding choice. Subjective decisions, based on goodwill and intuition, are not a sensible guide for public decision-making given the inherent difficulties of understanding the complex effects of a project on the economy.

A project is defined here as any public policy or investment that has the potential of increasing individual well-being. A public intervention with a positive impact on the economy in terms of Gross Domestic Product (GDP), and employment, does not guarantee a net positive effect on social welfare; these concepts are not synonymous. The focus of CBA is on the net welfare effect of public intervention, and its social value is to provide the government, and society, with information on the project's expected consequences on individuals' welfare. The analyst in charge of this task should be neutral (i.e., unbiased about the project) concerning technologies and alternatives to address the problem at hand. Finally, experience shows that the best methodology and good intentions are irrelevant in the absence of the right institutional design.[1]

A project consisting in investing scarce resources in the present, for a flow of consumption in the future, will affect the economy through multiple channels: directly, in primary markets and, indirectly, in upstream and downstream markets. The first round of direct effects on primary markets is followed by other effects in secondary markets, linked by relationships of complementarity and substitutability; and subsequently, induced effects (the multiplier effect) on the rest of the economy. A complex course of adjustments, in many markets, follows the initial perturbation. In this process, economic agents change their behaviour (consumption, input supply and production), which can complicate the process as these effects frequently extend

[1] This paper does not address the role of institutional design on the effectiveness of CBA on decision-making. The weakness of CBA to affect policy decisions is explained more by governance than methodology (see Mackie et al., 2014; Flyvbjerg and Bester, 2021: de Rus and Socorro, 2010).

beyond a short intervention period. They occur during the project's lifespan[2], which can be quite long in the case of infrastructure investment, and affect many heterogeneous individuals, in terms of wealth, health status, the moment in time and so on, and create winners and losers following the initial impact. Although quantifying all these effects and understanding whether the project is, ex-ante, of social value might be considered an impossible task, economists try to make an educated guess about what the net effect of the intervention is, to be able to deliver useful information to the decision-maker.

An alternative way to estimate the welfare effect of a project is through a Computable General Equilibrium model (CGE), in which the production technology, resource constraints and preferences are explicitly modelled and the equivalent variation of project effects on GDP and employment is calculated. This cannot be done with the "one model fits all", as the particularity of different public interventions requires specific modelling of some key elements not contemplated in the standard CGE model, which is more suitable for the analysis of public policies, like changes in trade policy or taxation. The difficulties and cost of this global approach are substantial and possibly unjustifiable for small or medium-sized projects, such as building a new airport or improving urban infrastructure, which would necessarily require a finer disaggregation and specific modelling.

The good news is that CBA can provide a reasonable estimation of the net welfare effect of many projects, bearing in mind the multimarket impact of such public interventions. Here, we do not seek to cover all issues involved in a standard CBA[3] but try to show the potential of this tool as a reasonable shortcut (Atkinson and Stiglitz, 2015) for the appraisal of many representative projects undertaken by governments and international agencies. CBA is incremental, meaning that the practitioner identifies effects that are like those of the counterfactual and can be safely ignored. In the case, for example, of multiplier effects, this means that if the project and the next best alternative share similar induced effects—these effects would be limited to the net value

[2] If the project affects emissions of greenhouse gases, for example, the time horizon extends beyond the life of the project. Similarly, toxic substances remain after the closure of a mine.
[3] See, for example, Boardman et al. (2018) and Campbell and Brown (2015). For a more advance treatment see Johansson (1993), Johansson and Kriström (2016). This paper draws on de Rus *et al*. (2022), de Rus (2021), Johansson and de Rus (2018) and de Rus and Johansson (2019).

of the existing distortions—, they should not be included in the net social benefit of the project.

CBA is not a partial equilibrium approach in the sense of the ceteris paribus assumption (everything remains constant in the rest of the economy). The approach has been frequently criticized as a narrow appraisal methodology, which is unjustified. There is a well-developed theoretical justification for the use of market demand functions for general equilibrium welfare effects assessment. The welfare consequences of projects can be estimated using a set of reduced-form elasticities, which incorporate general equilibrium effects in all the affected markets (Just et al, 2004; Chetty, 2009; Kleven 2018). Using the market that the project directly affects does not mean that the practitioner ignores what happens in other markets in the rest of the market related vertically or horizontally linked to the primary market. The observed general equilibrium demand is frequently sufficient to respond to the question of what the expected welfare effect of public intervention in the economy is.

Kriström (2022) argues that "a very useful aspect of CGE-modelling is that the complex market interactions are handled upfront; these are integral to the set-up of an equation system that is ultimately solved. But this does in no way mean that secondary market effects are disregarded in CBA, even though the approach is usually considered (in the textbook examples) a partial equilibrium approach. The fact of the matter is that CBA deals with the secondary market effects by definition; it is a general equilibrium approach. Indeed, depending on the project, general equilibrium welfare theory offers extremely useful simplifications. After all, the objective is to compute welfare change, the difference between utility in the status quo and the counterfactual. A correct measure is only obtained if the theory correctly represents the project".

CBA mimics the economist's way of thinking. Its philosophy is consequentialist. It identifies, predicts, and quantifies the economic effects of public action to estimate its net effect on social welfare. It seeks to measure the change in the utility (well-being) of individuals affected by public actions so that regulation and public investment are oriented to the benefit of society. In Sunstein's words: "Policies should make people's lives better. Officials should not rely on intuitions, interest groups, polls or dogmas. In a nutshell: *quantitative cost-benefit analysis is the best available method for assessing the effects of regulation on social welfare*" (Sunstein, 2018 p.22).

With CBA, the economist compares the intervention's pros and cons, relying on a set of modelling techniques and statistics that have increasingly been able to establish causal relationships and, using highly disaggregated data, obtain essential values for ex-ante evaluation. This process must be completed before the project's adoption. However, project evaluation (ex-post or in media res) is also crucial to check whether it is producing the desired results, to introduce corrections, if possible, and to create a set of statistical values and elasticities for future appraisals.

Both ex-ante and ex-post CBA are socially useful and complement each other. Project appraisal - comparing estimated costs and benefits - should be a key step in any democratic society. It provides the decision-maker, and society, with a summary of the foreseeable consequences of a policy or an investment yet to be approved.

Ex-post evaluation can be achieved by replicating the CBA model with actual data or by using statistical inference techniques to estimate the effects on certain observable variables, such as output or employment. Revealing a causal link between a policy and the employment rate, the improvement in individuals' health status, or any other outcome, is insufficient to judge a policy's impact on social welfare. The comparison of costs and benefits is unavoidable.

The following two sections highlight the use of CBA as a common evaluation method applicable to any public policy or investment project. Section 2.4 shows the equivalence of two alternative approaches to the application of CBA, as well as the use of shadow pricing. Section 2.5 discusses the treatment of indirect effects, induced effects and the wider economic impacts in CBA. The conclusions are presented in Section 2.6.

2.2 The social appraisal of projects

Although it would be uncontroversial to approve projects that only had social benefits at no cost, following a strict criterion of a social decision like this would keep us in inaction. Had we only implemented Paretian improvements (someone is better off without making anyone worse off)[4] we would still be living in the Stone Age. In practice, countries with a tradition of evaluation, follow the criterion of 'potential compensation'[5] (winners win more than losers lose). 'Imperfect compensation'

[4] This is the strong Pareto criterion. The weak version requires that everyone is better off with the project.
[5] For an intuitive discussion of the potential compensation criterion and the difficulties when relative prices change, see Johansson (1991).

however might be a better description, as the losers are somehow compensated, and equity effects and/or political acceptability are taken into account (for example, territorial imbalances).

An economic appraisal[6] specifically consists in checking if a public action, a new regulation, or an investment in educational or health infrastructures, for example, increases individuals' well-being. The social appraisal of projects lies precisely in this, and obviously, its content predates the decision to approve/reject the intervention. Although the most useful assessment is necessarily ex-ante, the ex-post evaluation aims to learn from mistakes and improve the ex-ante evaluation. Both are interconnected. Another possibility - when the decision is not irreversible - is to assess the positive and negative effects of the policy and introduce corrections.

There are other decision-support tools, such as multi-criteria analysis, which do not measure changes in social welfare. Additionally, cost-effectiveness analysis and cost-utility avoid the monetary valuation of benefits. Finally, CGE models are more appropriate for large shocks, such as the impact of trade agreements or changes in taxation. When CGE is used for the social appraisal of projects, like the construction of a new road, the use of an existing CGE model designed for large economic impacts will rarely add any value to the evaluation unless further modelling is done, which incorporates the project's specificities. However, the costs may sometimes be too high compared with the benefits. A standard CGE model built to capture the effects of changes in international trade, or similar, will barely recognize differences between the net welfare effects of an investment in urban commuting or high-speed rail. Both projects will trigger the induced effect from the transport sector on the rest of the economy, but their direct effects and wider economic benefits are substantially different (see Laird and Venables, 2017).

It is possible to use 'reduced-form strategies' instead of CGE models for the social appraisal of projects like building a dam, cleaning a natural area or opening a new railway line. The idea is to compare the intervention with the contrafactual w using sufficient statistics instead of the primitives. "The sufficient-statistic approach obviates the need to fully calibrate the structural model. This is especially beneficial in models with heterogeneity and discrete choice, in which the set of primitives is very large but

[6] The terms 'social', 'economic', and 'socio-economic' are often used as synonyms.

the set of marginal treatment effects needed for welfare evaluation remains small. By estimating the relevant marginal treatment effects as a function of the policy instrument, one can integrate the formula for the marginal welfare gain between any two observed values to evaluate policy changes" (Chetty, 2009).

CBA follows this approach. It is the most commonly used method by supranational agencies.[7] CBA is fundamentally incremental, incorporates social opportunity costs and avoids double-counting; unlike some impact studies, which include effects on output and employment, common to the counterfactual, and which often lead to the project's net benefits being overestimated.[8]

The social appraisal of projects is an economic instrument to improve public expenditure efficiency**.** CBA is available at a reasonable cost to evaluate the effects of public policies on social welfare: it requires the establishment of an analytical framework (see Section 2.3) in which the problem is identified, feasible alternatives outlined, and all those significantly affected are included. In this process, individuals' preferences are respected, evaluations include non-marketed goods, and effects are expressed in monetary terms to calculate the net social benefit. When this is not possible, we can use ranges of values and probability distributions to establish lower and upper bounds of social profitability and the probability distribution of a project's net social benefit. A summary of CBA content is:

(i) The project is a tool to achieve a defined objective.

The objective of the public action must be clearly defined, as well as identification of the set of alternatives available to achieve it. It must be justified why the course of action chosen contributes most to social welfare. It is not enough that the intervention under appraisal presents positive net social benefits; these benefits have to be greater than those corresponding to the next best alternative.

A project is usually part of a broader program. It does not make much sense to discuss a project without considering its role in the planning process. It is necessary to plan first and then evaluate the projects that respond to this broader strategy. Projects have multidisciplinary aspects, and careful discussion with experts can

[7] See, for example, EIB (2023), ADB (2017), EPA (2020), H.M. Treasury (2022), Infrastructure Australia (2021).
[8] See Crompton (2006).

prevent the economic assessment from being biased by ignoring information of interest about relevant interactions, less obvious effects, complementarities, other feasible alternatives or the inclusion of unnecessary actions.

(ii) Net benefits concerning what?

In the CBA of a project, two situations must be compared: one resulting from the approved action and the other without intervention. The latter might involve, for example, undertaking the intervention using another technology or comparing two different locations. The situation without the project is dynamic and includes minor interventions that might occur anyway without the public intervention under appraisal. The world moves on anyway in the absence of the project that is evaluated. It is essential to compare the expected effects of the proposal with the counterfactual: what would have happened had the project not been implemented? Overestimation or underestimation of the project's social benefit can be significant if the base case without intervention is not properly defined, Alternatives should include the possibility of postponing the project.

(iii) Identification and measurement of costs and benefits

The identification of costs and benefits should be straightforward if there are no significant effects on other markets if they can be ignored when secondary markets are not significantly distorted or if they are like the alternative course of action. The same applies to the income multiplier.

The benefits of projects are measured through individuals' willingness to pay, in many cases through the preferences revealed in the market. This approach applies to direct effects, indirect effects, and goods for which there is no market, but another market is found in which some useful information about willingness to pay is revealed. Where direct market data cannot be obtained, stated preferences must be used.

In general, the proposals under assessment involve the diversion (and sometimes savings) of resources from other uses. The two central concepts here are the social opportunity cost if the appraisal follows the changes in willingness to pay and in the use of resources, and the private opportunity cost if the surplus approach is chosen.

(iv) Net Present Value (NPV) as a numerical expression of the potential compensation.

The purpose of the CBA is to calculate the project's social NPV, for which it is necessary to fix the duration of its effects and the social discount rate. Where it is not possible to quantify the NPV precisely, probability distributions can be used for key variables and risk analysis can provide the NPV's probability distribution. There are cases where it may be appropriate to make a qualitative description of some effects, and then add this information to the net social benefit.

In principle, if the proposal's NPV is positive, this intervention will be among the candidates for approval, unless undesirable redistributive effects are found, or any other constraint is binding. Finally, even in the case of a positive NPV, when the intervention is irreversible and there is demand or cost uncertainty, the possibility of postponing the project should be considered.

(v) Economic profitability and financial viability

The project's CBA provides an estimate of its social profitability. Financial analysis is a part of CBA, and in competitive, undistorted markets, with optimal income distribution, the financial and economic results coincide. Although the financial analysis uses revenues instead of social benefits, and private costs instead of social costs, it is important to include the financial result alongside the social profitability. There will be many cases in which the proposal generates benefits greater than its social costs and simultaneously, presents a negative financial result.

In some proposals, it may be useful to calculate several outcomes as a function of the pricing policy. The existence of different possible combinations of social benefit and financial viability is common for revenue-generating projects. This information can be very useful, depending on the severity of the budget constraint.

Additionally, the financial analysis should provide a lot of detailed information, for example, the relevant production functions, and so on. Therefore, the CBA can be based on much more detailed production data than a typical CGE.

In short, project approval should be subject to the social benefits exceeding its social costs; and also seek that, as a whole, within the existing budget constraints, the set of proposals that maximize social welfare is selected. This requires that not only projects with net positive social benefits be approved, but that they do not block others that contribute more to social welfare.

Ignoring the appraisal of projects and leaving a politician to decide according to their intuition, or interpretation of what is good for the country, or any other motivation without technical support, is unnecessarily risky. Indeed, the monetary valuation of changes in the utility of individuals who differ in their income levels creates serious measurement problems, and this is without raising the point that an individual is always the best judge of their own interest. However, what other criterion is better than that of efficiency, which is the aim of CBA?

2.3 General equilibrium CBA rules

Supranational agencies have their own CBA guidelines for project appraisals. This is also the case for countries with an evaluation tradition. When there is no such culture in the ministries and public agencies of a particular country, there is a risk of 'copying recipes' from various sources that, when applied together, lead to inconsistencies and double-counting that bias the results. Therefore, a considered appraisal requires a rigorous analytical framework, with explicit assumptions, from which practical rules are formally derived (Johansson, 1993; Johansson and Kriström, 2016). For the results to be comprehensible and useful, it is necessary to know the original analytical framework.

Ideally, the practitioner would seek to measure the winners' increase in well-being to compare it with the reduction in that of the losers, but the problem lies in the impossibility of such measurement. Suppose that an individual whose hobby is river fishing suffers a reduction in his utility if a project is approved. Let's say the project consists of the construction of a hydroelectric complex upstream that will reduce both the price of electricity and the downstream flow of water. We know that the individual opposes the project, but we do not know how much his utility is reduced. Without a way to measure it, we cannot compare the 'harm' to that individual, nor of the many others who enjoyed the river through a variety of leisure and business activities that will be compromised by the project, with the welfare gains of those who will benefit from cheaper energy, less pollution and other leisure activities provided by the dam.

A referendum involving all those affected might solve the problem. However, one vote per person ignores the intensity of preferences. For example, suppose my net profit from the construction of the dam is marginally positive (I gain from the reduction in the price of electricity, but my environmental concerns almost offset that gain). My vote will be positive and will weigh the same as that of my neighbour whose well-being is significantly linked to maintaining the river's flow without the project (for example, in her leisure activities in the area). If my neighbour could compensate me for giving up the project, we would both be happier without the project. In sum, the referendum ignores the intensity of preferences, while the CBA incorporates them through the willingness to pay and accept.[9]

We have referred to the need for a model from which appraisal rules can be derived. Why do economists use 'willingness to pay' to measure the benefits of public policies and projects? This approach to measuring the change in individual well-being derives from the assumption that governments seek to maximize social welfare, which can take various forms but usually responds to the following four properties (Mas-Colell *et al.*, 1995, p.825): (i) Non-paternalism. In the expression of social preferences only individual utilities matter. (ii) Paretian property. Welfare increases with the utility of each individual. If one individual is made better off without making anyone else worse off, there is an increase in social welfare. (iii) Symmetry. In the evaluation of social welfare, all individuals are on the same footing. (iv) Concavity. This is based on inequality aversion. The extent of compensation is determined by the degree of inequality in society.

The function of social welfare depends on individuals' utility, and we assume that they maximize their utility, according to their preferences, and within the limits imposed by initial endowments and technology constraints. The utility of individuals is a function of the goods and services they consume, whose prices and quantities are affected by public interventions that change the economic equilibrium that affects them as consumers, owners of the factors of production, taxpayers and third parties affected by externalities. CBA seeks to assess the effects of government intervention on social welfare.[10]

The effect on firms and taxpayers has a simple metric: the monetary variation in profits and government net revenue. Measuring the change in consumers' utility, or

[9] The monetary measure of changes in utility and the aggregation of surplus across individuals is not without difficulties. See Boadway and Bruce (1984). For an intuitive explanation, see Johansson (1991), pp-40-56.
[10] For an analysis of 'who counts' in CBA, see Zerbe (2018), and Johansson and de Rus (2019).

third parties affected, for example by air pollution or noise, requires moving from what we would like to measure (utility) to what we can measure (willingness to pay).

Since utility is not observable, economists use units of income instead of welfare If my willingness to pay for a project is 300 euros per year, while my neighbour's is 1,000 to prevent it from being carried out, I would be willing to accept 500 to give up the project, as it increases the level of welfare of both with respect to the counterfactual. This is a Paretian improvement (as it would be if I were paid 300). When we jump from a few individuals to a sufficiently large and heterogeneous number, actual compensation is not feasible and economists use the principle of potential compensation, which means that in the case of the previous example, the project would be rejected as the winners could not compensate the losers and still be better off.

When calculating a project's net social benefit, and unless equity weights are used, the monetary valuations of winners and losers are added regardless of their income level. Therefore, such monetary valuations (assuming they are properly calculated) reflect both individuals' preferences and their income levels. Since the marginal utility of income is positive but decreasing, we have a problem with the comparability of those valuations.

If the distribution of income were optimal, or we were in a restricted optimum, given the disincentive effect of additional redistributive measures, transferring income from one individual to another does not increase social welfare. In other words, the marginal social utility of income is equal for all individuals; That is, a euro is a euro regardless of who wins or loses it. In these circumstances, in the previous example, if one wins 300 and the other loses 1,000, the project reduces welfare.

Does this conclusion hold when the distribution of income is not optimal? (recall that there is no compensation). We do not know because the effect on welfare depends on the marginal social utility and the marginal utility of income. Even with an identical social marginal utility for all individuals (all are equal in the eyes of the government), the marginal utility of income for the poor is greater than for the rich, and the poor's utility may increase more with the additional 300 euros than the reduction of the rich's utility by losing 1,000 euros.[11]

[11] Though one might think of a less inefficient way for income redistribution.

When the practitioner calculates the net social benefit of a project and obtains a positive result, most of the time they are applying the criterion of potential compensation, which implies that, if the redistributive consequences of the project were sufficiently undesirable, it could happen that the NPV of the project may not reflect the actual impact on welfare. What way out do we have when faced with this problem?

In practice, the potential compensation criterion is often applied under the assumption that fiscal policy has mechanisms for effective income redistribution. Its application is also justified by the argument that in the long-term everybody will be better off since the government carries out many projects, and different projects have different winners and losers. Moreover, it should not be forgotten that the potential compensation criterion is accompanied by actual (imperfect) compensations that mitigate the damage to the losers. It could also be argued that the difficulties of identifying the ultimate beneficiaries can make the task impossible; or that the costs of identifying winners and losers and establishing compensation mechanisms outweigh the benefits.

A frequent error in projects' social appraisal occurs when the practitioner mixes CBA's two main aggregation methods. A project's NPV can alternatively be calculated by adding surpluses or through changes in willingness to pay and real resources. Once one of these options has been chosen, the practitioner should follow the logic of the approach until the end. The best antidote for this common error is to employ a model with consistent rules of thumb for the practical appraisal of projects. Again, the importance of having a model from which the evaluation rules are derived is evident. If we add surpluses, we must adjust to individuals' private valuations and add them up. When information is limited, the NPV calculus follows the maximum willingness to pay for the project and the social opportunity cost of the resources. Care must be taken not to mix both procedures. In this latter approximation, income transfers do not count. In the former approximation, they are included, and they 'net out' in the sum preceding the calculation of the net social surplus.

Johansson (1993) derives general equilibrium cost-benefit rules for marginal and large projects that affect the environment. The core approach is general and can be applied to any other government intervention, such as the provision of public infrastructure. The key idea is that the economy is integrated by households and firms, ultimately owned by the former. The indirect utility function of a representative consumer is a function of prices, wages, exogenous income, firms' profits, taxes and public goods. Under the assumption of well-behaved functions and prices adjusting to equate supply and demand, the monetary valuation of the utility change produced by a large project can be approximated through the conventional rules of adding consumer, producer, and taxpayer surpluses, if the consumer´s willingness to pay does not include any change in exogenous income, profits or taxes.

CBA can be thought of as a set of shortcuts to circumvent the impossible task of precisely measuring the total effects of an infrastructure project on the economy during its lifetime. This involves the effects on many households and markets during a project's lifespan. The good news is that under some conditions, particularly the fact that prices adjust continuously to equate supply and demand, it is possible to approximate the net welfare effects by focusing on the primary market (or group of markets). "Often, we are interested not in a single market but in a group of commodities that are strongly interrelated either in consumers' tastes [...] or in firms' technologies. In this case, studying one market at a time while keeping other prices fixed is no longer a useful approach because what matters is the *simultaneous* determination of *all* prices in the group. However, if the prices of goods outside the group may be regarded as unaffected by changes within the markets for this group of commodities, and if there are no wealth effects for commodities in the group, then we can extend much of the analysis…" (Mas-Colell *et al*., 1995, p.342).

We now move to a more formal discussion of the CBA analysis framework to make explicit the assumptions behind the practical rules followed to try to answer the demanding question of whether society should invest public money in an infrastructure project. The general equilibrium cost-benefit rules derived in Johansson (1993) will be our basic framework.

Let's assume the existence of an economy with identical households, where firms are ultimately owned by households. The representative household consumes private goods and a public good, interpreted here as the level of public infrastructure, and supplies a vector of different types of labour. The indirect utility function of the economy´s representative household, $V(.)$, is written as:

$$V = V[p, w, Y + \Pi(p, w, z) - \tau, z]$$

$$= max_{x^d,L^s}\{U(x^d, L^s, z) \quad s.t. \quad Y + \Pi + wL^s - \tau - CV - px^d = 0\}, \tag{1}$$

p: price vector

w: factor prices vector

Y: exogenous income

Π: profit income

τ: lump-sum tax collected by the government

z: public good

x^d: private goods vector

L^s: labour vector

CV: compensating variation

$U(.)$: utility function of the economy's representative household.

Firms, owned by households, maximize profits (Π):

$$\Pi = pF(L, z, K) - wL - 1 \cdot K, \tag{2}$$

where $F(L, z, K)$ is the production function, and the price of capital (K) is equal to 1.

The government controls the variable z. Suppose z is the stock of public infrastructure and a project that increases z (for example, a free access new road) which requires the use of real resources as production factors and other produced goods.

Totally differentiating the indirect utility function (1) and profit function (2), the cost-benefit rule (3) is obtained. The effects of the project, time savings, accidents avoided, and so on, can be interpreted as a small change in z and evaluated according to (3).

$$dV/V_y = (x^s - x^d)dp + (L^s - L^d)dw + [(V_z/V_y)dz + pF_z dz - dC - dCV] = 0, \tag{3}$$

where V_y is the marginal utility of income; superscripts s and d denote supply and demand respectively; V_z is the marginal utility of z and F_z is the marginal productivity of z.

Even if the change in the stock of infrastructure affects other markets, if prices adjust to reach a new equilibrium, the first two terms on the right-hand side of expression (3) net out, and so we can concentrate the effort in the primary market. With a project cost, calculated at initial prices, equal to dC, the term dCV measures the representative household's willingness to pay (net of project costs).

We can then calculate the NPV of a small project from the terms within brackets in (3): the households' direct willingness to pay (V_z/V_y) plus the direct impact on profits ($pF_z dz$) minus the project costs (dC). Changes in profits or costs due to changes in prices are not accounted for in the evaluation if demand equals supply in the new equilibrium. The first three terms in brackets in (3) account for the change in resources and willingness to pay due to the infrastructure investment. In (3) access to the infrastructure is free.

The economic effects of large projects

In the case of large projects, the general equilibrium rule is a generalization of (3) if the project does not induce significant price changes. Once we abandon the assumption of perfect divisibility, we enter the world of incremental changes. Then, different sizes may be available and capacity design must be considered. There are also different technologies available to solve a common problem. The evaluation of large projects is difficult when significant price changes are expected, and the economic consequences of a particular project may have considerable long-term effects.

In the case of a large project, we can still follow the insight of expression (3) as long as the first two terms in parenthesis vanish once the project is implemented. In expression (3) the evaluation is conducted following the changes in willingness to pay and changes in resources. An alternative and equivalent approach is to add surpluses as changes in prices which do not add value (transfers) net out in the process of aggregation.

Following Johansson (1993), the social willingness to pay can be expressed as:

$$V(p^1, w^1, Y^1 + \Pi^1 - \tau^1 - CV, z^1) = V(p^1, w^1, Y^0 + \Pi^0 - \tau^0 - CV^p, z^1) = V^0. \quad (4)$$

Where V^0 refers to the level of utility attained without the project and CV^p denotes the partial willingness to pay for the project as a user of the infrastructure, excluding any effects on lump-sum income, profits, and taxes. Superscripts 1 and 0 denote with and without the project. The difference between CV and CV^p is the following:

$$CV = CV^p + \Delta Y + \Delta \Pi - \Delta \tau, \quad (5)$$

where ΔY, $\Delta \Pi$ and $\Delta \tau$ are the change in exogenous income, profits, and taxes, with the project. The change in taxes is interpreted here as the project costs.

This leads to the standard approach of defining the effect of the project as the sum of the consumer compensating variation, producer surplus and taxpayer surplus.[12]

In the actual appraisal of projects, the monetary valuations in expression (5) are commonly approximated with two alternative approaches, expressed as:

$$NPV = \sum_{t=0}^{T} \delta^t (B_t - C_t), \quad (6)$$

where B and C are the social benefits and social costs of the project in real terms, δ^t is the real discount factor, T denotes the project life, and no disaggregation by final beneficiaries is applied:

Alternatively, decomposing B and C by groups of individuals produces the aggregation of surpluses;

$$NPV = \sum_{t=0}^{T} \delta^t (\Delta CS_t + \Delta OS_t + \Delta LS_t + \Delta RS_t + \Delta GS_t + \Delta ES_t), \quad (7)$$

where ΔCS_t is the change in consumers' surplus, i.e., the difference between what consumers are willing to pay for the goods and what they pay;[13] ΔOS_t is the change in the surplus of the owners of capital, i.e., firm revenues less variable costs; ΔLS_t is the change in the surpluses of workers and ΔRS_t the change in the landowners' surplus, which is equal to the wages and land income, respectively, less the minimum payment they are willing to accept for the use of the factor; i.e., its private opportunity cost; ΔGS_t

[12] The problem with large projects with significant impacts on the prices of secondary markets is the near impossibility for individuals to give a sound answer to the questions involved in expression (5).

[13] The change of CV^p in expression (5) to CS in expression (7) is not harmless, unless certain conditions hold (see Willig, 1976).

is the change in taxpayers' surplus, which equals tax revenues less public expenditure; finally, the change in the 'rest of society' surplus (ΔES_t) includes the value for the individuals of non-marketed goods, such as the project effects on the landscape, clean air, climate, or even safety levels, that may change when a project is carried out, net of compensation payments. For example, the negative externality of a power plant that contributes to global warming, or the positive externality of an investment in alternative energy sources that reduces it, net of any compensation.

2.4 Applying the CBA rules

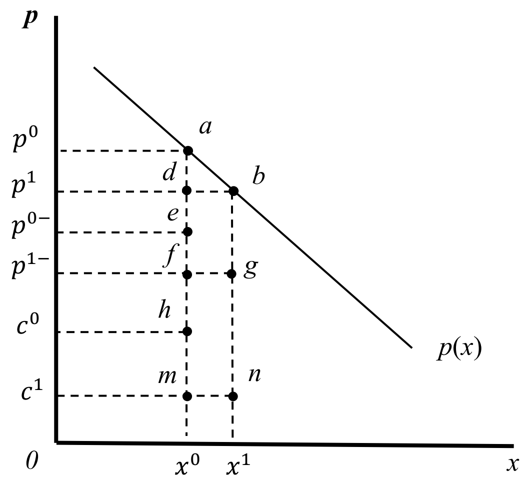
Once the costs and benefits of the project are identified, the practitioner must choose one of the available alternative aggregation methods for their measurement. A clear understanding of the chosen method will prevent common errors that may lead to the overestimation or underestimation of the net benefit.[14] The first aggregation method consists in adding the change in surpluses, as in expression (7). Although it is more informative, its application is difficult in practice given the data usually available and the problems in identifying beneficiaries.[15] The alternative aggregation method is to follow the changes in willingness to pay and resources (ignoring transfers). At first glance, it seems easier, but there are disadvantages associated with its use. The willingness to pay is constant for existing demand, assuming quality in a broad sense to be constant, but there is an increase in willingness to pay of generated demand. In this case, any distortion (e.g., profits or taxes) in secondary markets affected by the change in the primary market must be added, without accounting for any change in the use of resources in secondary markets.

The equivalence of the two aggregation methods is shown with the help of Figure 1, corresponding to an infrastructure project affecting a primary market with the demand function $x = f(p)$ where x is the number of users per year and p is the price. Figure 1 shows the inverse demand function $p(x)$. Marginal costs are constant and equal to c^0 without the project. The initial equilibrium is (p^0, x^0). The market price includes a specific tax (τ), so the price charged by producers (p^-) does not coincide with the price paid by consumers (p), where $p = p^- + \tau$. With the project, the marginal cost goes down to c^1, and the quantity goes up to x^1, so there is a generated demand equal to $(x^1 - x^0)$. Recall superscripts 1 and 0 denote with and without the project.

[14] There are all sorts of measurement/prediction errors, which apply to both methods (Mackie and Preston,1998).
[15] The existence of a fixed factor may completely modify the predicted distribution of the social surplus.

Notice that, although the price goes down, the reduction is lower than the reduction in the marginal cost. Investment costs are ignored for simplicity.

Figure 1.



Assuming no income effects, optimal income distribution and price equal to social marginal costs in the rest of the economy, the change in welfare with the project is the sum of the changes in surpluses of all the agents affected in the primary market, which can be calculated using the standard assumption of a linear approximation between the initial and the final price.

The change in consumer surplus for existing demand (x^0) is equal to the area ($p^0\,adp^1$), and for the new consumer equal to *abd*. The total change in consumer surplus is represented by the area ($p^0\,abp^1$) and measured with the so-called 'rule of a half'):

$$\Delta CS = \frac{1}{2}\left(p^0 - p^1\right)\left(x^0 + x^1\right). \qquad (8)$$

The change in the surplus of the owners of capital (the firm) is represented in Figure 1 by the following change in revenues and costs: a reduction in the revenues of the existing demand equal to the area ($p^{0-}efp^{1-}$), an increase in revenue from the generated demand represented by the area ($fgx^1\,x^0$), the reduction in variable costs of the existing demand ($c^0\,hmc^1$), and the additional costs of serving the generated demand equal to the area ($mnx^1\,x^0$). The total change of the owners' surplus is:

$$\Delta OS = (p^{1-}x^1 - c^1 x^1) - (p^{0-}x^0 - c^0 x^0). \quad (9)$$

The change in taxpayers' surplus is represented by the area $(dbgf)$, and calculated as:

$$\Delta GS = \tau (x^1 - x^0). \quad (10)$$

This increase in tax revenues is not a transfer under the assumption of price equal to marginal cost in the rest of the economy if the specific tax τ also affects the other markets, the value of expression (10) is offset by the loss of taxes in another market unless the project is associated with an increase in productivity or when different economic activities have different tax rates.

Finally, as the other surpluses do not experience any change, the change in social surplus is obtained by adding expressions (8), (9) and (10):

$$\Delta CS + \Delta OS + \Delta GS =$$

$$= (c^0 - c^1)x^0 + \frac{1}{2}(p^0 - p^1)(x^1 - x^0) + (p^{1-} - c^1)(x^1 - x^0) + \tau (x^1 - x^0). \quad (11)$$

Rearranging and simplifying in (11), the change in willingness to pay and resources is obtained:

$$\frac{1}{2}(p^0 + p^1)(x^1 - x^0) - c^1 x^1 + c^0 x^0 . \quad (12)$$

Expressions (11) and (12) are equivalent and are represented in Figure 1 by the areas $abnm$ and $c^0hmx^0c^1$.

The social opportunity cost of resources

Shadow pricing consists of applying conversion factors to market prices to approximate the social opportunity cost. This adjustment only applies to the change in willingness to pay and resources approach. When a project is implemented, society forgoes other goods, as resources divert from other uses. This is the social opportunity cost of the project (C_j): [16]

$$C_j = \sum_{k=1}^{s} p_k dx_k, \quad (13)$$

[16] See Johansson (1993) and de Rus (2021). This section deals with inputs that can be purchased in markets. Non-market resources are not discussed here.

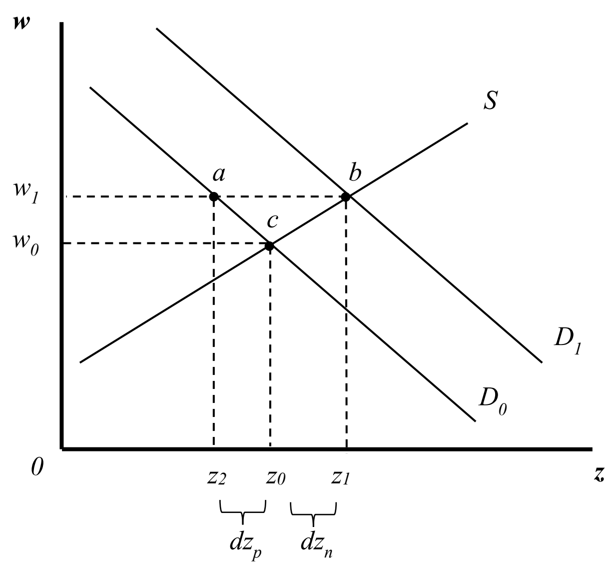
with $s \leq n$ goods or services, assuming only two inputs (z_1 and z_2) that are fully utilized to produce and consume goods, $x_k = f_k(z_1, z_2)$, and assuming also that market prices are equal to the marginal value of the goods diverted to the project. Recalling that any profit-maximizing firm uses additional units of inputs until its market price (w) equals the value of its marginal product ($w = p_k \frac{\partial x}{\partial z}$), through the total differentiation of the production function ($dx_k = \frac{\partial x_k}{\partial z_1} dz_1 + \frac{\partial x_k}{\partial z_2} dz_2$) expression (13) can be expressed as:

$$C_j = \sum_{k=1}^{s} (w_1 dz_1 + w_2 dz_2), \tag{14}$$

which is a more practical way to work out the project's cost as it is easier to calculate the quantities and prices of the inputs required.

The validity and usefulness of expression (14) for identifying and assessing the costs of a project are subject to two underlying assumptions: all the changes in input markets are marginal and input markets are perfectly competitive, without distortions such as indirect or income taxes. This is the case represented in Figure 2 in the initial equilibrium (w_0, z_0)

Figure 2.



When the effect of the project in the factor market is not marginal and the demand for the input shifts from D_0 to D_1, the input price goes up to w_1 and two effects are affecting the opportunity cost of the input allocated to the project: (i) the private demand for the input goes down until w_1 is equal to the value of the marginal productivity and (ii) the increase in the input price increases the quantity supplied. Now, we can calculate the opportunity cost of the input. The project needs *dz* units of the input. This quantity required by the project has two components: new supply (dz_n) that is offered at the new equilibrium input price, and a quantity diverted from the private sector (dz_p), which shifts to the project at the higher price w_1, as represented in Figure 2 at the new market clearing price w_1. The opportunity cost of the new supply (dz_n) is represented by the area cbz_1z_0 and the quantity of the input diverted from private firms (dz_p) is represented by the area acz_0z_2. The shadow price of the input can be calculated as:

$$\frac{1}{2}(w_0 + w_1)dz \; . \tag{15}$$

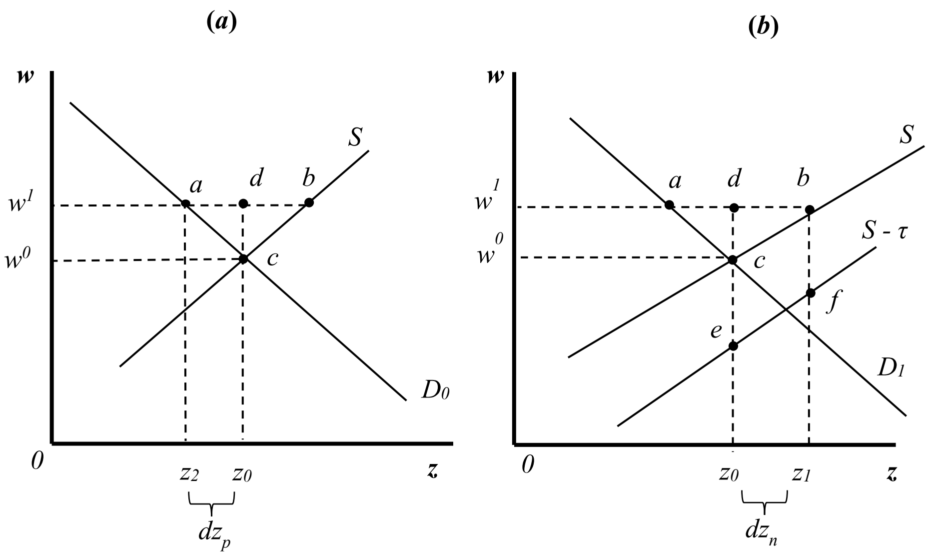
In a more realistic context of project appraisal (e.g. existence of subsidies or taxes, or high unemployment), the previous expression is modified to account for the distortions.

Let's consider a specific tax (τ) in Figure 3. Initially, without the project, the input market is in equilibrium, with the supply (*S*) and demand (D_0) determining the input price w_0 and quantity z_0. The existence of τ introduces a distinction between the market supply function (*S*) and the opportunity cost of the input supplier, $S - \tau$. The function $S - \tau$ shows the social marginal value of producing the input and the demand function is the value of the marginal productivity of the input for the firm. At the equilibrium input price (w_0), the value of the marginal productivity of the input for the firm is equal to the opportunity cost of the input supplier for the marginal unit of input plus the tax.

With the project, the demand for the input shifts from D_0 to D_1, the input price goes up to w_1 and the private demand for the input goes down until w_1 is equal to the value of the marginal productivity of the input. The increase in the input price also has the effect of increasing the quantity of the input offered at this price, and the equilibrium quantity goes up. Now, we can calculate the opportunity cost. The project needs *dz* units of the input. This quantity required by the project has two components: additional production (dz_n) at the new equilibrium price, and quantity diverted from the private sector (dz_p), which shifts to the project at the higher price w_1. The opportunity cost of dz_n is the social marginal cost of producing the input (the value of leisure in the case of labour). The input suppliers receive $w_1 dz_n$, represented by the area dbz_1z_0 in Figure 3(b), but the social opportunity cost is lower (area efz_1z_0) and can be calculated as:

$$\left[\frac{1}{2}(w_0 + w_1) - \tau\right] dz_n. \tag{16}$$

Figure 3.



The opportunity cost of the input quantity already used in the private sector (dz_p), shifts to the project at the higher price w_1, is acz_0z_2. However, the social opportunity cost of these units is higher than the expression (16) and equal to the lost value of their marginal productivity in the private sector (including the tax) when the quantity dz_p shifts to the project. The input supplier receives $w_1 dz_p$, but the social opportunity cost is lower (area acz_0z_2) and can be calculated as:

$$\frac{1}{2}(w_0 + w_1)dz_p\ . \tag{17}$$

In the case of the existence of specific taxes levied on the product market, the shadow price of the deviated input includes the additional specific tax (θ), as the profit-maximizing firm must equalize the wage and net value of the marginal productivity of the input. The shadow price is, in this latter case:

$$\left[\frac{1}{2}(w_0 + w_1) + \theta\right] dz_p. \tag{18}$$

The practitioner should be aware that, depending on the method used, the opportunity cost is different. In the case of adding the change in surpluses, the private opportunity cost is what matters, and the shadow price should be ignored, whereas the social opportunity cost must be used when the approach followed is the change in willingness to pay and resources.

The shadow price of public funds

Governments usually finance the payment of projects cost with tax revenues. This is the case for example, of some public goods, some private goods like a free sports facility or, even when the users pay, some projects require additional financial support, as is the case of a natural area with an entry fee insufficient to cover the total cost. Unfortunately, tax collection has efficiency costs, i.e., is not a mere transfer of income between consumers, producers, and the government.

The excess tax burden or deadweight loss of the tax is the net value of the production lost with the introduction of the tax, and hence constitutes an opportunity cost of the project. The social cost of public funds is $SCF = R + EB$, where R is the tax revenue and EB is the tax excess burden.

For example, consider a project whose investment cost (I) occurs only in year 0 (when the government charges an indirect tax in a market unrelated to the project) and produces a constant annual benefit (without charging anything for the good) during the T years of project life. Assuming a real discount rate equal to zero, NPV is equal to:

$$NPV = -\lambda_g I + T\,\Delta CS, \tag{19}$$

where λ_g is the shadow price of public funds.

Then, if the deadweight loss is equal to 20 per cent of the tax revenue, the marginal cost, the shadow price (or shadow multiplier) of public funds is equal to 1.2, and the cost of the project is equal to $1.2I$. Note that, for NPV greater than zero, $\frac{T\Delta CS}{I} > \lambda_g$, i.e., for a project funded by taxes to be socially profitable, the social benefit obtained per unit of money invested must be greater than the opportunity cost of the public funds.

A more general expression for a revenue-generating project (partially financed by taxes) is the following:

$$NPV = -\lambda_g I + \sum_{t=1}^{T} \frac{\Delta CS_t + \lambda_g \Delta PS_t}{(1+i)^t}, \tag{20}$$

where i is the social discount rate and PS is the producer surplus.

Expression (20) shows that the shadow price of public funds should be applied to both costs and revenues because the annual net revenue reduces the need for public funding and therefore the need for taxes ($\lambda_g(1 + i)^{-t}$ is the present value of 1 euro collected by the project).

Finally, the social marginal cost of public funds (*SMCF*) is obtained by taking the first derivative of *SCF* with respect to *R*:

$$SMCF = 1 + \frac{dEB}{dR}. \tag{21}$$

The deadweight loss (*dEB/dR*) is positive and increases with the size of the tax, i.e., the *SMCF* increases when additional tax revenues are required for the financial support of new projects. Finally, we must also highlight that this implies a high benchmark for the number and size of public projects passing the test of a positive NPV, as the marginal benefit of additional projects requiring financing is expected to diminish, while the *SMCF* is expected to increase.

2.5 Beyond direct effects

The purpose of CBA is to estimate the net welfare effect of public policies and projects. As noted, the practitioner can focus on the analysis of the primary market or in a group of strongly interrelated markets, under the assumption that what happens in other markets does not affect welfare when the rest of the economy is sufficiently competitive or, even when significant effects are present, they can be presumed approximately similar to those associated to the counterfactual.

Indirect effects and wider economic impacts need some market distortion to play a role in the economic appraisal of projects. The treatment of the indirect effects is similar for any secondary market affected by the project (Harberger, 1965; Mohring, 1971). Moreover, indirect effects can be positive or negative depending on the sign of the distortion and the cross elasticities. Nevertheless, even with distortions, when optimal pricing is applied in secondary markets, there are no additional benefits (or costs).

The existence of a wedge between price and marginal cost in other related markets may change the value of the project in any direction, though the usual criticism is that the traditional approach of measurement (changes in surpluses in the primary and closely-related markets) seriously underestimates the social benefits of many projects. For example, many promoters of public infrastructure investment argue that there exist other benefits, beyond direct user benefits, such as changes in productivity and industry reorganization, so it is critical to avoid the potential underestimation of transport improvements, including some of these alleged additional benefits.

Moreover, gains in productivity derived from industry reorganization are not, in principle, additional benefits. This is a well-known result in economics. Although transport cost reductions, for example, may allow firms to reorganize plants, inventories and warehouses that lead to productivity gains, these effects have already been measured with the transport demand (Mohring and Williamson, 1969). What we need for the existence of additional benefits, and not merely double-counting or transfers, is the presence of market distortions, a wedge between price and marginal costs, such as agglomeration economies following changes in proximity (Venables, 2007) or the benefits of urban redevelopment in the presence of a market failure (Laird and Venables, 2017).

The defence of infrastructure investment for economic development based on the results of the econometric aggregate approach and impact studies is rather discredited today (Gramlich, 1994), though promoters still use the argument of infrastructure investment as a sufficient condition for economic development by ignoring endogeneity, or the difficulty of disentangling relocation and growth in the estimates ("much of the estimated effect of transportation costs and infrastructure on the spatial organization of economic activity is probably due to reorganization rather than growth" Redding and Turner, 2014). In this sense, Laird *et al*. (2014) warn of the use of expenditure and costs instead of genuine benefits. They mention the recent shift by planners in the United Kingdom, using changes in gross value added, including wages, as a benefit.

Two different sources of wider economic benefits are associated with land use and the labour market following the impact of a transport improvement. First, a reduction in transport costs may boost private investment and be a cause of the redevelopment of a zone in a city. In the case of a change in land use, the benefits can come from the greater attractiveness of the new area (increase in consumer surplus), or when the existence of the developer's market power, or a coordination failure by firms, is removed, thanks to the transport improvement (Laird and Venables, 2017). Second, the impact on the labour market might be another source of wider economic benefits, though the risk of double-counting is high: the increase in productivity due to an increase in labour density is already measured as agglomeration economies, as well as the creation of new jobs through shadow pricing when measuring the opportunity cost of inputs.

Criticisms of CBA as a method for the social appraisal of projects come from two different perspectives. One is technical and identifies weaknesses in the methodology that aims to estimate the impact of public projects on social welfare. The other is essentially political. The CBA emphasizes the net welfare consequences of the project that the government proposes and ignores the rhetoric of the promoters arguing about the impacts of the project on job creation, regional development, or multiplier effects. Effects that in some cases are inexistent, relocation or double-counting; or do exist but are not incremental, i.e., they are common to the project and its alternative. This is the reason why robust appraisal of projects requires a previous analytical framework to assess the project with consistent rules.

The practical rules of measuring the direct effects of a project on the primary market, ignoring the effects on other markets, are general equilibrium rules when there are no distortions in the rest of the economy (Harberger, 1965; Johansson, 1993). As said, CBA is incremental and adding indirect effects and multipliers to the rest of the economy is incorrect if there are no distortions, and unnecessary if other alternative projects are also similarly affected by such effects. Even with price changes in secondary markets, market demand in the primary market (without distortions) already incorporates all the effects in the rest of the economy (Sudgen and Williams 1978, Mohring 1993, Boardman *et al*., 2018).[17] As an illustration, Figure 4 shows the case of a project reducing the cost of good *x* (primary market), which affects the market of good *y* (secondary market). In this case, the indirect effect in the secondary market is due to the substitutability in demand between both goods.

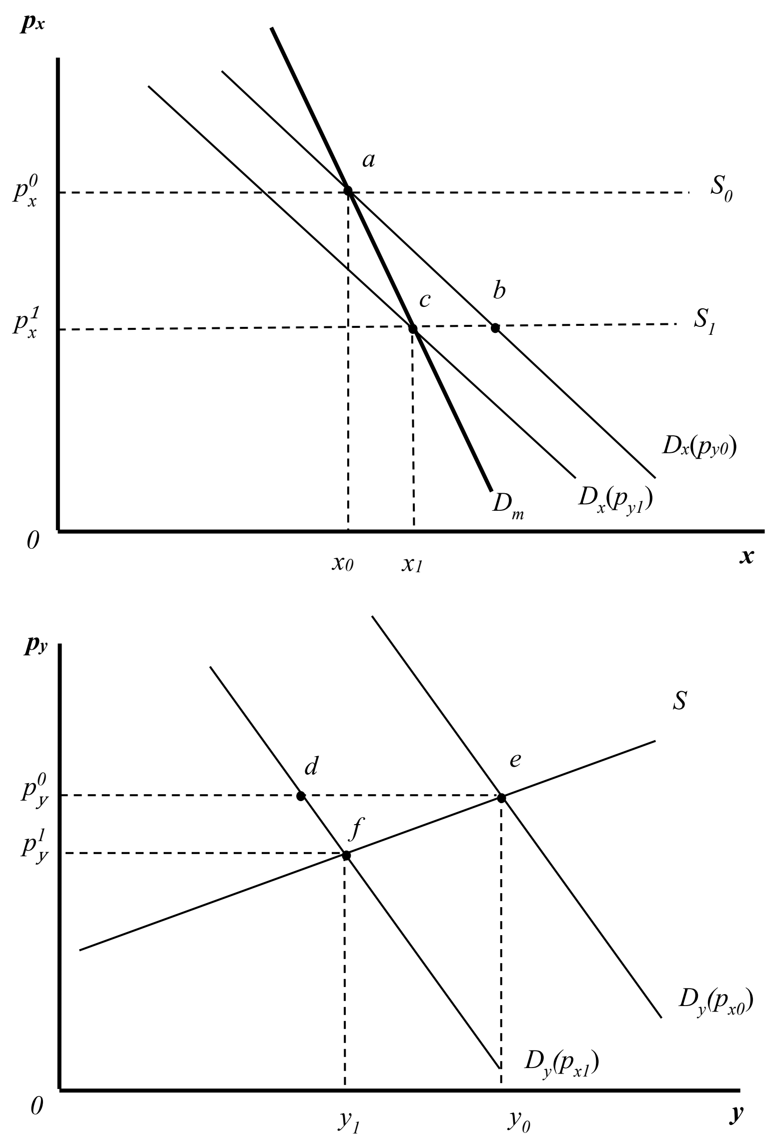
The project reduces the cost of producing good *x* and its price goes down from p_x^0 to p_x^1. The social surplus is equal to the area $p_x^0 ab p_x^1$. The strongly interrelated market of

[17] Kotchen and Levison (2022) analyse the benefits and costs of regulation in the case of undistorted secondary markets. They develop a tool that the practitioner can use to evaluate the magnitude of secondary-market effects in particular applications, showing how they are likely to be relatively small in most circumstances, and providing evidence supporting this conclusion.

good y is affected by this price reduction, shifting the demand from $D_y(p_{x0})$ to $D_y(p_{x1})$. It is important to note that the positions of the demand in both markets reflect the existence of both goods and the changes in their prices. When the price of x goes down, some consumers of y then prefer to buy the substitute - and the demand of y shifts to the left. This fact causes a gain for consumers that continue consuming y equal to the area $p_y^0 dfp_y^1$, but the producers lose the area $p_y^0 efp_y^1$ and hence welfare loss represented by the area *def* should be subtracted from the area $p_x^0 abp_x^1$ in the primary market.

The good news is that the partial equilibrium demand schedules ($D_x(p_{y0})$ and $D_y(p_{x0})$) are not observable and the estimated quantity changes in the market of good x include additional shifts in demand, as represented by $D_x(p_{y1})$. The observed quantities x_0 and x_1 are general equilibrium quantities measured with the equilibrium demand scheduled D_m. The practitioner measures the increase in welfare with elasticities corresponding to this observed demand and therefore the area is $p_x^0 acp_x^1$ (approximately equal to the gain in consumer surplus represented by the area $p_x^0 abp_x^1$ minus the area *def*).

Figure 4.



A public policy consisting of the construction of a hydroelectric complex that lowers the price of energy will have different indirect effects on other markets and an income multiplier effect on the rest of the economy, but only the net difference to other competing projects matters for project appraisal. The point is to be clear about what we are looking for. If what we want to know is the impact that this investment has on gross added value or employment, a CGE model might be appropriate. If we are trying to decide which project contributes most to social welfare, we could, in principle, use the same CGE model, but designed for the appraisal of welfare changes (and for the type of project under evaluation), and subtract the induced effects common to the counterfactual. CBA does this directly and, as may be expected, at a significantly lower cost.

Another reason why CBA has been criticized as an incomplete methodology is the evidence of agglomeration economies associated with large infrastructure projects that increase accessibility to large cities. Public policies such as investment in subways and high-speed lines that reduce the cost of travel, usually attract workers and companies from the periphery to the city centres. The increase in the density of workers increases productivity, a benefit that conventional CBA does not capture by not accounting for these productivity increases derived from concentration, which also includes additional tax collection as a benefit (Venables, 2007).[18]

This omission is not just present in the CGE model, but a problem of both. A general equilibrium model cannot foresee such effects unless this nonlinear relationship between the concentration of workers and average productivity is explicitly incorporated into the model.

The misplaced temptation to incorporate these additional effects into any project that increases proximity must be replaced by an effort to obtain a more precise understanding of what the project is expected to solve (and how it will do so). The significance of these additional benefits is context specific. Moreover, following the same reasoning, reducing the density of workers in areas where firms and workers were initially located can reduce productivity and therefore generates negative dynamics in those areas losing employment and economic activity, which represent an additional cost to be included in the appraisal. It may also be the case that the reduction in transport costs will increase dispersion. This is more likely for interurban projects if certain local factors are present, including land prices and significant wage differentials between areas (see Duranton and Puga, 2004; Graham, 2007; Venables, 2007).

The narrative of the promoters (public agencies or interest groups) of a public policy must be very precise, describing the objective of the public action, the problem to be solved and why a particular line of action is superior to others. Furthermore, the project's rationale should be explained in the context of a specific program of

[18] The three sources of wider economic benefits (imperfect competition, tax revenues arising from labor market impacts and agglomeration economies) have not received the same attention in the economic evaluation of projects. The focus has been directed at agglomeration economies because they are considered to be the main source of wider economic benefits and because their econometric estimation is easier (see Graham and Gibbons, 2019).

government planning. For example, it is not uncommon to see the justification of projects based on agglomeration economies, that favour the concentration of economic activity, while overlooking its consequences on territorial imbalances.

2.6 Conclusions

The economic appraisal of projects can contribute to increasing social welfare. The rationale of CBA is to choose the best projects from a social perspective. The CBA of any project is context specific. The project's objective should be clear, as well as explain how the public intervention is expected to affect the economy. Practical CBA applications need to be based on the identification of quantity changes in the primary markets, and the fact that only the existence of distortions in the rest of the economy can generate additional welfare changes.

Indirect and induced effects in the rest of the economy have zero social value in the absence of market failures. Indirect effects (beyond the main group of strongly interrelated markets) may be ignored when the project is not going to produce large price changes in the rest of the economy and there are no significant distortions; or even when they are large in absolute terms, are not expected to be significantly different compared with the counterfactual.

A project must be judged by its potential to improve the health status of the population, increase human capital, or have other positive real economic effects. Including multiplier effects in the net present value confuse the social appraisal of projects with impact studies and may also conceal poor value for money. Multiplier effects can be ignored if the magnitude of any distortion associated with these effects is similar for both the project and the alternative. The absolute value of the project's multiplier effect is not incremental and therefore irrelevant to the estimation of the project's net welfare value.

A project with negative social NPV reduces social welfare. Adding the multiplier effect is not going to change its net social value. Nevertheless, when choosing between mutually exclusive projects, both with positive net present value, and when there is evidence of a significantly different multiplier effect between them, the net difference of these effects should be included. Even in this case, only the price-marginal cost gap is relevant. The distinction between redistribution and growth (i.e. gross and net effects) is crucial. CBA aims to calculate the net welfare effect of a project. The inclusion of transfers and gross benefits artificially inflates the value of a project. CBA is strictly constructed on an incremental basis, and double-counting must be avoided.

In contexts of high unemployment, it is easy to forget that any welfare effect of unemployment reduction must be net of its social opportunity cost. The way CBA deals with job creation is through shadow pricing. The value of these accounting prices varies substantially with the specificities of the labour market. In the case of high unemployment, the successive round of effects (employment multiplier) might imply additional benefits related to the creation of additional jobs, but the distinction of net effects (both net of opportunity cost and net compared to the alternative) is crucial to avoid grossly overestimating a project's welfare effect.

Finally, regarding equity, a useful way to deal with distributional issues is to show how different groups are affected by the project. Another is to use a specific social welfare function. Clearly illustrating how different groups are affected should be a part of project appraisal. The difficulties in identifying the final beneficiaries and spatial distribution of efficiency gains, when multiple equilibria are possible, require further work.

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3 An overview of CGE models

Federico Inchausti-Sintes
Eric Tchouamou Njoya

3.1 An introduction to Computable General Equilibrium Models

3.1.1 Introduction

Computable General Equilibrium (CGE) models seek to understand the effect of external shocks in the economy through the simultaneous equilibrium that occurs in the markets. Its main advantage lies in its capacity to comprise the linkages among all sectors. Thus, whenever a sector is shocked by any policy or market situation, then CGE models can estimate a new equilibrium that is produced simultaneously, in all sectors. It provides the expected changes in prices and quantities across all sectors. Moreover, from these new equilibria, all kinds of macroeconomic and microeconomic indicators may be built, such as Gross Domestic Product (GDP), employment, or equivalent variation measures.

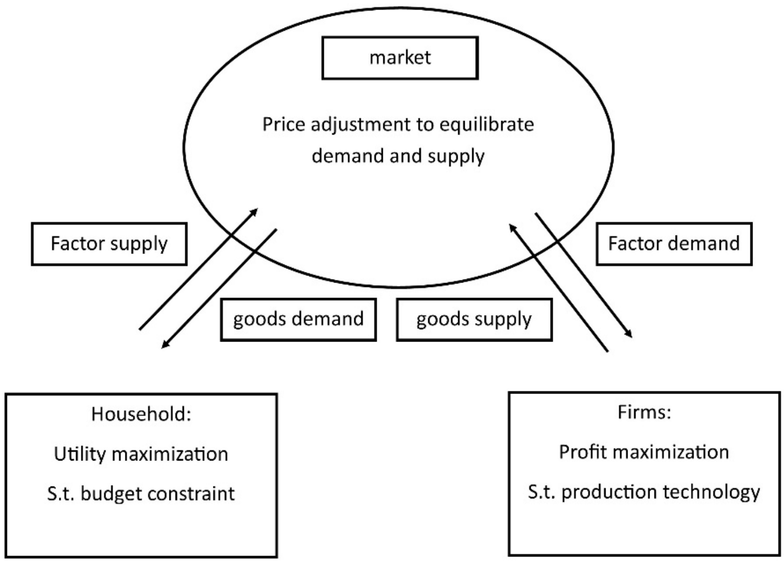
CGE models are based on statistical datasets such as Input-Output Tables (IOT), Social Accounting Matrices (SAM) or Satellite Accounts. Thus, the models are built upon a solid basis of real datasets. However, CGE requires further assumptions to estimate the models. More precisely, the modeler needs to define the functional forms chosen for production, demand or supply, as well as the elasticities behind such functions. Moreover, the modeler also needs to define a model closure to be able to estimate the model. Such decisions condition the results obtained; it is important to anticipate the way this may occur and proceed accordingly.

This paper provides an overview of the theoretical underpinnings of the CGE model as well as other relevant impact assessment models. It focuses on the market closure implications to anticipate its relevance for project appraisal and any divergence with respect to Cost-Benefit Analysis (CBA).

3.1.2 The foundations of the CGE model

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 (SAM) in order to derive policy insights". While the model has traditionally been regarded as a *black-box* because of its complexity, it has the advantage of being able to deal with the whole economy by following the circular flow of income and expenditure (Wing, 2004) (see Figure 1).

Figure 1. Economic structure of a CGE model



Source: Hosoe, Gasawa and Hashimoto (2010)

A basic CGE model implies the existence of a representative household[1] who owns the factors of production (labour and capital). These factors are demanded by firms to produce goods and services that are demanded by the representative household and by the rest of the economy's sectors as inputs. Finally, the representative household demands goods and services constrained by their income (rent from factors of production). Hence, by developing these economic interactions, the change that takes place in one sector or economic agent causes an economic change in other sectors affecting the prices, quantities, or incomes of the economy. Thus, it not only account for *direct effects*, but also *indirect and multiplier effects*.

[1] The existence of a representative household allows welfare analysis to be conducted in CGE through the calculus of the equivalent variation (See Hosoe, Gasawa & Hashimoto, 2010).

This basic structure can be extended to include other economic agents (additional representative households or the government), the investment, or imports and exports (open economy). However, all these extensions must work under the circular flow of income. For instance, if an additional representative household is considered, then the model must specify its endowment of factors and the kinds of goods demanded. Moreover, it should be noted that the total supply of factors of both households must be demanded by firms, and that the goods of the economy demanded by both agents must be produced by the firms (or imports) of the economy. Finally, both households decide their demand of goods constrained to their disposable income (rent of factors).

Mathematically, the circular flow of income and expenditure can be summarized by the following three conditions: zero benefit, market clearance conditions, and income balance (Böhringer, et al, 2003; Hosoe, et al, 2010). Following the notation considered by Böhringer, et al, 2003, 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:

3.1.3 Zero benefit condition

Firms supply goods and services to the market. In order to do so, they combine capital, labour and intermediate goods to produce. In this process, the firms pay wages to workers, rents to capital owners and intermediate demand to other firms. The value of inputs per activity must be equal to or greater than the value of outputs.

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

where $\pi_j(p)$ represents the benefit by activity j, $R_j(p)$ and $C_j(p)$ are the unit cost functions and unit revenues functions by activity j, respectively, and p is a non-negative vector of prices for all goods and factors.

$$C_j(p) \equiv min\left\{\sum_i p_i \frac{\partial \pi_j(p)}{\partial p_i} \mid f_j(.) = 1\right\}$$

$$R_j(p) \equiv max\left\{\sum_i p_i \frac{\partial \pi_j(p)}{\partial p_i} \mid g_j(.) = 1\right\}$$

3.1.4 Market clearance conditions

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. The supply of any commodity must equal or exceed consumers' demand:

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

where y_j represents the supply of good by activity j. $\sum_h w_{i,h}$ 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 institution h given prices p and income M. $d_{i,h}(p, M_h)$ stands for the final demand obtained from the maximization problem of the representative household:

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

Finally, $U_h(x)$ denotes the utility function of household h.

3.1.5 Income balance conditions

Households are endowed with income obtained from firms as workers and capital owners. The households employ this income to demand goods and services as well as investment. The income (value of the endowment) of each institution (households, mainly) h must be equal or exceed the final demand, so that:

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

$\sum_i p_i w_{i,h}$ represents the value of the endowment for institutions h, and $\sum_i p_i d_{i,h}$ represents the value of the final demand of institutions h.

The aforementioned conditions provide a consistent framework for the economic analysis of policies with sectoral changes, linkage effects and welfare evaluation. These equations need to be calibrated according to a SAM (see section 3.2.2) to replicate an initial equilibrium (see applications in Appendix 1). Finally, these conditions must be complemented with the *model/ macro closure*[2]. Basically, from a modelling perspective, the macro closure ends up assuming which variables are endogenous or exogenous (Hosoe, et al, 2010). In this regard, there are three key variables or decisions to be made when closing the model: investment, government and 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)* must 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 considered when addressing the government and current account closure. For instance, some governments may face a binding budget restriction *(D)*. In this case, it is reasonable to assume a fixed budget where expenditure and income vary in consequence. Finally, the current account closure implies determining savings, investments, or the current account. In general, most CGE models assume a fixed current account while they opt for a savings-driven or an investment-driven closure. This closure is common for small economies where foreign credit may be limited (Gilbert and Tower, 2013). In any case, there is no ideal macro-closure, as it relies on the kind of policy simulation carried out.

The structure of a CGE model can be relaxed or the SAM enriched to address different issues such as externalities, non-market goods or obtain a higher sectoral disaggregation. In this sense, the inclusion of natural resources in traditional IOT has allowed the widespread development of environmental analysis using CGE models (Bergman, 2005; or Britz and Hertel, 2011). For instance, CGE models have been especially fruitful when modeling a CO2 emissions trading scheme (Böhringer, 2002: or Wing, 2006). SAM can also be expanded to deal with several economies, known as

[2] The model closure is specifically addressed in section 3.4.

multi-regional models (Aguiar, Narayanan and McDougall, 2016) and spatial markets interactions (Mercenier et al., 2016).

The main assumptions of a standard CGE model can be summarized as follows:

- Circular flow of income and expenditure.
- Secondary production allowed.
- A minimum of one representative household.
- Non-capacity constraints.
- Constant return to scale.
- Perfect market competition.

As said, the latter 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 and Van Leeuwen, 2010; or Boeters and Savard, 2011). Moreover, the behaviour of consumer and firms can be modeled according to four different kinds of function:

- Leontief (elasticity of substitution equals zero)
- Cobb-Douglas (elasticity of substitution equals 1)
- Constant elasticity of substitution (CES) (elasticity of substitution different from 1)
- Stone-Geary (elasticity of substitution different from 1)

The latter also allows for income elasticity different from 1, but at the cost of generating non-homothetic preferences.

On the other hand, there are two main approaches when programming a CGE model: i) maximizing representative household utility where the remaining conditions operate as constraints (Hosoe, et al, 2010; or Gilbert and Tower, 2013) or ii) solving the problem as a system of equations where variables and equations form a Mixed Complementarity Problem (MCP), by avoiding any maximizing behaviour (Böhringer, et al, 2003) (see applications in Appendix 1). Further, Rutherford (1999) developed a straightforward subsystem (MPSGE) to program CGE models in MCP syntax[3]) (see applications in Appendix 1).

3.2 An overview of other impact assessment models

3.2.1 Input-Output tables

Input-Output Analysis (IOA) is a methodology that precedes the CGE model, and was first developed by Leontief (1936, 1941). The methodology can quantify 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 and Blair, 2009). Similar to CGE, the IO methodology relies on the same 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, they are also capable of capturing direct, indirect, and multiplier effects.

However, IOA cannot tackle simultaneous changes in prices and quantities, as done in CGE. In fact, the methodology can only distinguish between the demand and price model. Traditional IOA can be characterized by the following and more restrictive assumptions:

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

However, some of these assumptions can be relaxed to encompass more realistic economic behaviour. For instance, Miyazawa (2012) provides a comprehensive explanation by including more than one representative consumer in an IO framework. On the other hand, Raa (2006) analyzes the inclusion of secondary production and

3 See Markusen (1995) for self-study examples in a Mathematical Programming System for General Equilibrium Analysis (MPSGE).

Cobb-Douglas production technologies, while explaining the conceptual boundaries for the inclusion of increasing economies to scale in IOA. According to Raa (2006), IO models can be translated into linear programming, allowing the introduction of capacity constraints in the production system to be addressed. Most of the current developments in IOA have been focused on dealing with environmental aspects (Miller and Blair, 2009; Wiedmann, Minx, Barrett and Wackernagel, 2006; Wiedmann, 2009; Raa, 2006; or Lenzen, 1998). In sum, IOA is also equipped to quantify the economic impact of an economic policy on the economy, as done in CGE. Nevertheless, it is based on more restrictive assumptions.

Input-Output Tables (IOT) form the main dataset to develop a CGE model because they follow the circular flow of income. These tables are usually elaborated by the Office for National Statistics and are publicly available. They are a natural extension of the national accounts (the production and consumption accounts) and emphasize intersectoral relationships. The national accounts follow standard international procedures for their development and international comparison (SNA, 1993). Three main blocks can be distinguished in IOT:

1. Intermediate demand block (intersectoral/inputs demand).
2. Final demand block (household consumption, government consumption, investment, and exports by goods).
3. Primary inputs block (remuneration of labour and capital and employees by sectors).

Table 1 shows the general structure of an IOT, the intermediate demand block, with the sectors in rows and columns, representing the intermediate demand ($id_{i,j}$) of each sector, i.e., the production of each sector that is demanded by the others to produce their goods. The final demand column represents the share of the sectoral production that is demanded for consumption (representative household and the government), investments, or exports. Finally, the total demand by goods (intermediate and final demand) equates the total production by sector ($\sum_{j=1}^{n} id_{i,j} + fd_i = X_i$). Similarly, the total sectoral production (X_i) equates the value of the factors demanded as inputs

($\sum_{j=1}^{n} id_{j,i} + salaries_i + c\_capital_i = X_i$) ensuring that the circular flow of income holds. Finally, the last row includes the number of employees by sector.

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	$salaries_1$	………	$salaries_n$		
cost of capital	$c\_capital_1$	………	$c\_capital_n$		
Total production	x_1	………	x_n		
Employment	L_1	………	L_n		

3.2.2 Social Accounting Matrix (SAM)

The IOT 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). However, they lack a more comprehensive characterization of the households and/or government (Miller and Blair, 2009). The SAM bridges this gap by including transfers among institutions, social transfers and direct taxation to households and firms; as well as 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 SAM enrich or complement the IOT by characterizing the successive income distributions that take place in the economic system (Breisinger, Thomas and Thurlow, 2009). Table 2 shows the structure of a standard SAM. The IOT is highlighted in blue, while the remaining 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 and Blair, 2009; Breisinger, et al, 2009).

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)

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

The secondary income process predominantly comprises the government. The government collects the money required for public spending through direct and indirect taxation but also for paying subsidies and any other social provision. The role of the government generates a second income distribution that allows calculation of the gross national disposable income. At the same time, the latter 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. This economic activity is registered in the accumulation account (capital and financial accounts). The inclusion of the aforementioned aspects together with the IOT comprise the SAM. Obviously, the SAM provides a richer set of information about economic relations than the IOT.

3.2.3 Satellite accounts

Satellite accounts deal with activities that are insufficiently covered by the standard national accounts. For instance, satellite accounts have been built for tourism (TSA, 2008; Frechtling, 1999 and 2010), culture (FCS, 2009; Throsby, 2008) and the environment (SEAA, 2012; Muller, Mendelsohn and 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) and 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. For instance, the Tourism Satellite Account has been conceived to distinguish consumption incurred by residents and tourists. This is the only way to understand the role of tourists in a multisector framework such as the IOT. More precisely, it disentangles the production by goods into tourism and non-tourism activities and distributes total non-resident consumption into the different goods categories of the IOT (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 understand the contribution of any tourism subsector, such as maritime tourism (Diakomihalis, 2007). Moreover, both tourism and environmental accounts can be combined to shed light on the consequences of tourism activities in the environment (Collins, Jones and Munday, 2009). On the other hand, the environmental account has been mostly developed to extend the IOT (Liang, et al, 2017), generating the so-called energy environmental IOT (Burniaux and Truong, 2002).

3.3 Further extensions to the CGE models

3.3.1 Dynamic Computable General Equilibrium

A SAM provides a snapshot of an economy in one period. Nevertheless, many economic policies take place over several periods/years. CGE models can be adapted to evolve over time. Such adaptation implies the following variables and parameters and their respective assumptions: economic growth (g), capital depreciation (δ), interest rate (r) and the initial stock of capital (K_0). These parameters and variables have to be set according to certain equations in order to assure a steady state economic growth, i.e. that the circular flow of income and expenditure holds over time. Following Paltsev (2008), a dynamic CGE model can be introduced as follows:

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

$$K_0 = \frac{VK}{\delta + r}$$

At the same time, the stock of capital multiplied by ($\delta + g$) must equal the initial investment level (I_0). In general, the initial investment level is obtained from the IOT:

$$I_0 = (\delta + g)K_0$$

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

$$K_{t+1} = K_t(1 - \delta)K_t + I_t$$

where I_t represents the investment level in period t. The remaining conditions of a standard CGE model holds in each period. Finally, the general structure of a dynamic model is as follows:

$$max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^{t} U(C_t)$$

$s.t.$:

$$C_t = F(K_t, L_t) - I_t$$

$$K_{t+1} = K_t(1-\delta)K_t + I_t$$

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

A last key assumption concerns the behaviour of the representative households. Depending on the kind of assumption, dynamic CGE models[4] can be split into forward-looking (Ramsey, 1928) and backward-looking models (or recursive-dynamic models). The main difference between them is their representation of future expectation. In the former, agents/households have perfect expectations, whereas in the latter, they form their expectations in the decision-making moment. Forward-looking models imply deeper changes in the economic structure than backward-looking models (Babiker, Gurgel, Paltsev and Reilly, 2009).

3.3.2 Dynamic Stochastic Computable General Equilibrium (DSGE)

Dynamic CGE models can also encompass stochastic analysis. Although they can be regarded as an extension to traditional CGE models, they have followed a different theoretical and applied approach more focused on macroeconomic analysis (Wickens, 2011; Junior, 2016; or Walsh, 2017). 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

[4] See Dixon and Rimmer (2010) or Fougére, Mercenier and Mérette (2007) for applications of dynamic CGE models.

minimizing behaviours, first order conditions and rational expectations, instead of *ad hoc* aggregated macroeconomic models. However, the widespread development and application of DSGE occurred when frictions were included in the model, which allowed for more realistic economic situations, in so-called New Keynesian models. In this sense, DSGE models can encompass complex economic behaviour such as sticky prices and salaries (Smets and Wouters, 2003), risk premium (Adolfson, Laséen, Lindé and Villani, 2007), dollarization (Castillo, Montoro and Tuesta, 2013), or policy analysis (Del Negro and Schorfheide, 2013; or Hohberger, Priftis, and Vogel, 2020), among other topics.

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. Most authors in applied studies opt to work in logarithms (*log-linearization*) to reduce complexity between economic variables (highly non-linear models) and more easily achieve a mathematical solution (DeJong and Dave, 2011). 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 can estimate these parameters econometrically by including time series data. Briefly, the parameters can be estimated following two main approaches: the Kalman filter and a Bayesian estimation (Fernández-Villaverde, Rubio-Ramirez and 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, 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 (Smets and 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 allows for econometric testing of economic theories.

3.4 The implications of alternative model closures in CGE

3.4.1 The concept of model closure

As stated by Gilbert and Tower (2013), a model is mathematically “closed” when we have enough independent equations to explain the endogenous variables. Further, the selection of exogenous and endogenous variables also determines the computability and complexity of the model (Hosoe, et al, 2010). As noticed by Decaluwé and Monette (1988), Sen (1963) was one of the first who shed light on this issue by showing the complexity of simultaneously determined several economic variables in one single model. Nevertheless, from an economic perspective, the distinction between exogenous and endogenous variables goes beyond its mathematical tractability. The model closure directly alters the economic adjustment of the model and hence, the policy conclusions (Taylor and Lysy, 1979). Specifically, it affects key aspects of a project, such as its financing, which can be done through direct taxation, indirect taxation, private savings, or debt raised from international capital markets. Each aspect has different implications for income redistribution and the economy’s future dynamics.

Model closure is relevant because it affects the social welfare measures taken in a CGE model. To date, the literature on CGE has addressed the issue of model closure focusing on its macroeconomic impact and sectoral implications, rather than its effect on welfare (Sen, 1963; Decaluwe and Monette, 1988; Dewatripont and Michel, 1987; Rattsø, 1982; Robinson, 2006; Adelman and Robinson, 1988; Doi, 2006; Hosoe, et al, 2010 or Gilbert and Tower, 2013). In some of these cases, they do not even explicitly model a representative household - the so-called macro CGE models (Sen, 1963; Dewatripont and Michel, 1987; Rattsø, 1982; Robinson, 2006) - but assume non-homothetic preferences in household behaviour, which impede welfare comparisons (Adelman and Robinson, 1988). In other cases, they describe the theoretical macroeconomic implications of adopting some of the closures (Doi, 2006; Hosoe et al, 2010 or Gilbert and Tower, 2013).

Thissen (1998) briefly introduces Sen´s model mathematically as follows:

$$Y = f(K, L) \qquad (1.a)$$

$$w = \frac{\partial f(K,L)}{\partial L} \qquad (2.a)$$

$Y = rK + wL$ (3.a)

$S = S_p rK + S_w wL$ (4.a)

$I = I^*$ (5.a)

$S = I$ (6.a)

Equation (1.a) denotes the production function where K denotes capital, and L denotes labour, which comprise the factors of production. Equation (2.a) represents the demand of labour from production Y, equation (3.a) denotes the income constraint of this economy where income depends on rents from capital (rK) and labour (wL), with r and w representing the rent of capital and wage, respectively. The income constraint also equates total production Y. Savings in this economy are assumed endogenously (equation 4.a) and are represented as a share of their respective income (S_p and S_w) which, in a closed economy setting, equates to investment (equation 6.a). Finally, equation 5.a assumes that the level of investment in this economy must match some sort of optimal investment equilibrium (I^*).

Overall, the model consists of six equations and five endogenous variables. As explained by Thissen (1998), this model can be mathematically solved by dropping equation five. Since Sen (1963), different model closures have emerged and nowadays they are generally classified into the following blocks:

- **savings-investment** identity.
- **current account balance** (open-economy setting).
- **government behaviour**.

Some authors, such as Gilbert and Tower (2013), define the previous blocks more compactly as macro-closures[5]. While, simultaneously, they distinguish other closures that are more focused on factor markets, micro-closures. For instance, whether prices of capital and stock of capital are assumed exogenous or endogenous; or especially the existence of unemployment in the model. Any of the previous closure blocks are ultimately linked to each other. For instance, the government's role in raising or lowering taxes affects disposable household income, which influences both

[5] Thissen (1998) provides additional model closures, but focused on macro CGE models.

consumption and investment. On the other hand, assuming a fixed level of current account deficit/surplus or allowing it to vary (endogenously) will also determine the total level of savings of the economy.

Following the above literature review on model closures, this section turns to an explanation and simulation of the main closures (savings-investment, government behaviour and current account balance) and micro-closures (unemployment). The shock in all models is the same and entails an increase in the capital endowment of 10%[6].

3.4.2 A brief literature review

This section reviews CGE models built to examine the welfare impact of policies or projects. We do not intend to provide a complete review of all possible CGE models with a welfare measure, but rather highlight selected models and examine their treatment of the closure. CGE models have been widely used in recent decades to model socially relevant questions. It has been argued that CGE models are not very useful unless the modeller pays attention to specific details, such as the level of sectoral and household disaggregation, assumptions made about the specification of key relationships, and the extent to which it represents a good approximation of the studied economy (De Maio, Stewart and Van Der Hoeven, 1999).

Thus, CGE models are often criticized for their reliance on the assumptions made in developing them. A key issue concerns the closure of the model, namely macro-economic, factor market, and foreign exchange account closures. Zalai and Révész (2016) rightly point out that despite the early warnings, the issue of model closure has been largely neglected in CGE studies. Taylor (2016) argues that while sectoral disaggregation is central to CGE analysis, the sectoral outcome of the model depends strongly on the closure of the model. Although it has long been established that model closure affects it qualitative outcomes (Taylor and Lysy, 1979; Rattsø, 1982; Adelman and Robinson, 1988; De Maio et al, 1999; Taylor, 2016), most models do not test the sensitivity of their results to model closure.

[6] All closures have been modeled in Mixed Complementarity Format (MCP) (Böhringer, et al, 2003). Under this format, the profit condition shows a complementarity condition with the activity variables, the market clearance condition with the price variables and the budget constraint with the income level.

De Maio et al, (1999) review CGE models developed to analyze the impact of adjustment policies on the poor in Africa and point out that macroeconomic and distributional outcomes of the models reflect assumptions made about the parameters, behavioural assumptions, and closure. The authors indicate that a CGE model is useful only if the assumptions reflect the realities of the economy concerned.

Dewatripont and Michel (1987) investigate the microeconomic foundations of the closure problem using a simple temporary competitive equilibrium model with a perfect foresight assumption. The authors demonstrate the implications of price expectations for the construction of a temporary equilibrium framework. Kilkenny and Robinson (1990) show that despite the relatively small role of agriculture in the U.S. economy, the nature of the impact of changes in agricultural policies depends, among others, on the degree of factor mobility and microeconomic closure assumptions.

Cloutier et al, (2008) provide a review of how the closure has been modelled in empirical CGE studies on the welfare implications of trade liberalization in developing countries. They argue that most studies have concluded that trade liberalization implied a positive effect on the overall welfare of an economy. However, equally, other studies found no aggregate welfare effect. Cloutier et al, (2008) pointed out that it is useful when evaluating findings to carefully examine the assumptions employed in the models concerning closure rules and market structure. The authors found that most models surveyed are closed in the (Neo) classical way, assuming fixed investment, endogenous wages, exogenous labour and full employment. Most importantly, despite its fundamental role in the construction and simulation process, some studies failed to provide sufficient guidance about how the model is closed.

Various authors have carried out comparative analyses of alternative macro and factor market closures, such as Taylor-Lysy (1979), Rattsø (1982), and De Melo and Robinson (1989). Adelman and Robinson (1988) construct a CGE model to estimate the distributional impact of macroeconomic adjustment programmes in developing countries. Their model incorporated different closures, namely neo-Keynesian, neoclassical, alternative macro closures for the balance of trade, and a variety of structuralist macro closure rules. The authors concluded that, the functional distribution (i.e. distribution between profit earners and wage earners), but not the size distribution of income, was sensitive to macro closure rules, and that the balance-of-trade closure was at least as important in determining distributional outcomes as the savings-investment closure.

Bourguignon, Branson and de Melo (1989) construct a CGE model that incorporates a financial sector with a treatment of asset markets that closely correspond to the stylized description of developing countries financial markets. They use the model to examine the effects of stabilization and structural adjustment mechanisms in emerging economies and conclude that the distribution of income and wealth is likely to be affected by alternative financial market closures. Rattsø (1982) claims that rather than building a general model and applying it to all sorts of policy-experiments, “the particular economic problems should inform both model-closure and model-formulation”. The importance of simulating CGE models is confirmed by Decaluwé and Monette (1988), who demonstrate that disturbances stemming from the supply or demand side of the economy may have different quantitative and qualitative impacts depending on the choice of a particular closure rule.

Most CGE models developed to examine welfare implication have focused on trade policies. However, there has been in recent years a growing volume of CGE models about the welfare impact of, for example, externalities and climate policy regimes (Juana, Strzepek and Kirsten, 2008; Twimukye and Matovu, 2009; Devarajan, Go, Robinson and Thierfelder, 2011; Pradhan and Ghosh, 2012; Dennis, 2016; Maddah, Berijanian and Ghazizadeh, 2018) or tourism expansion (Blake, Arbache, Sinclair and Teles, 2008; Wattanakuljarus and Coxhead, 2008; Li, Blake, and Thomas, 2013; Pratt, 2014; Njoya, Semeyutin, and Hubbard, 2020). A review of these studies reveals that the majority of them undertook a sensitivity test to explore the robustness of the model findings to key parameters and elasticities, concluding that the results in different sensitivity analyses do not differ significantly (in magnitude and direction) from those in the base case (Li, Blake and Cooper, 2011; Dennis, 2016). However, like in most CGE models, these studies did not incorporate an analysis to assess the sensitivity of the findings to different closure rules.

3.4.3 A formal analysis of the different *closures*

Investment-savings closure

Let's assume a closed economy, with one representative household, two factors (capital (K) and labour (L)) and two goods (X_1, X_2). Equations (1) and (2) denote the zero-profit condition equating total costs ($C_{Xi}(P_l, P_k)$) and total incomes P_{Xi} at their respective initial values ($\bar{X}_i$)[7]. Equation (3) represents the "zero-profit" condition of the representative household, where the total level of expenditure ($E(P_{x1}, P_{x2})$) equates welfare price index (P_w) with an initial value of $\bar{W}$. In equation 4, the investment decision is introduced in a similar way to the previous equations, with $I(P_{x1}, P_{x2})$ being the investment function and P_{inv} the price of the total investment; with an initial value of $\bar{I}$.

This economy faces a fixed level of capital ($\bar{K}$) and labour ($\bar{L}$), which are demanded as factors of production to produce X_1 and X_2 as shown in equations (5) and (6), where $\bar{X}_{i,k}$ and $\bar{X}_{i,l}$ denotes the initial demand of each sector (X_1 and X_2) concerning each factor (K, L). Both goods (X_1 and X_2) are finally consumed ($\bar{W}_{x1}\frac{\partial E(P_{x1},P_{x2})}{\partial P_{x1}}W$ and $\bar{W}_{x2}\frac{\partial E(P_{x1},P_{x2})}{\partial P_{x2}}W$) or invested ($\bar{I}_{x1}\frac{\partial I(P_{x1},P_{x2})}{\partial P_{x1}}I$ and $\bar{I}_{x2}\frac{\partial I(P_{x1},P_{x2})}{\partial P_{x2}}I$) according to equations (7) and (8), where $\bar{W}_{x1}, \bar{W}_{x2}, \bar{I}_{x1}$ and $\bar{I}_{x2}$ denotes the initial demand from household and investment concerning each good, respectively.

As shown in equation 10, the level of investment and consumption rely on household endowment, which is formed by the incomes obtained from labour ($w\bar{L}$) and capital ($r\bar{K}$) minus total savings ($\bar{S}$) available in this economy that is assumed fixed **(savings-driven closure**). As can be appreciated in equation (10), the existence of savings in this economy detracts final consumption from the representative households affecting the welfare (W) that can be attained (equation 9).

Finally, equation 11 equates investment (I) and savings ($\bar{S}$).

$$\bar{X}_1 C_{X1}(P_l, P_k) = P_{X1}\bar{X}_1 \qquad (1)$$

$$\bar{X}_2 C_{X2}(P_l, P_k) = P_{X2}\bar{X}_2 \qquad (2)$$

$$\bar{W} E(P_{x1}, P_{x2}) = P_w \bar{W} \qquad (3)$$

[7] Variables with an upper bar denotes initial values. See table A.1 to see the initial values of all models.

$$\bar{I}I(P_{x1}, P_{x2}) = P_{inv}\bar{I} \quad (4)$$

$$\bar{K} = \sum_i \bar{X}_{i,k} \frac{\partial C_i(P_l, P_k)}{\partial P_k} X_i \quad (5)$$

$$\bar{L} = \sum_i \bar{X}_{i,l} \frac{\partial C_i(P_l, P_k)}{\partial P_l} X_i \quad (6)$$

$$\bar{X}_1 X_1 = \bar{W}_{x1} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x1}} W + \bar{I}_{x1} \frac{\partial I(P_{x1}, P_{x2})}{\partial P_{x1}} I \quad (7)$$

$$\bar{X}_2 X_2 = \bar{W}_{x2} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x2}} W + \bar{I}_{x2} \frac{\partial I(P_{x1}, P_{x2})}{\partial P_{x2}} I \quad (8)$$

$$\bar{W}W = \frac{M}{P_w} \quad (9)$$

$$M = r\bar{K} + w\bar{L} - \bar{S} \quad (10)$$

$$I = \bar{S} \quad (11)$$

The 11 endogenous variables are: $X_1, X_2, P_{x1}, P_{x2}, P_k, P_l, P_w, P_{inv}, W, I, M,$ for 11 equations. Thus, the model is "closed". Alternatively, total savings can be assumed endogenous by modifying the following equations in the model: First let's assume that total savings (S) vary according to the new equation (12) where $(1 - \alpha)$ represents the share of total income (M) devoted to savings. As a result, equation (9) and (10) are rewritten as shown in equation (13) and (14), respectively. Now both investments and savings are endogenously determined within the model.

On the other hand, it should also be noted that if we now fix investment ($\bar{I}$) while keeping savings endogenous, then the model would also be closed (investment-driven closure).

$$S = (1 - \alpha)\frac{M}{P_{inv}} \quad (12)$$

$$W = \alpha \frac{M}{P_w} \quad (13)$$

$$M = r\bar{K} + w\bar{L} \quad (14)$$

The differences in results when adopting one of these two savings rules can be better appreciated when simulating both models. Assuming Cobb-Douglas cost functions

($C_i(P_l, P_k) = P_l^{\gamma_i} P_k^{1-\gamma_i}$) for the production of both goods, investment ($I(P_{x1}, P_{x2}) = P_{x1}^{\beta} P_{x2}^{1-\beta}$) and household expenditure ($E(P_{x1}, P_{x2}) = P_{x1}^{\mu} P_{x2}^{1-\mu}$). The parameters of the models were calibrated according to the values shown in Table A.1 (see Appendix II).

As shown in Table 3, the economic impact varies in magnitude in both closures. For instance, the variation in sectoral production (X_1 and X_2) is 1.116 and 1.076 in both cases, respectively. Further, as expected, the capital-intensive sector (X_1) most benefits from the rise in capital endowment in both closures. And the price of capital reduces because of the rise in the supply of capital. Moreover, the variation in prices shows small differences in both cases. However, the largest differences emerge when analyzing the change in welfare and investment. Assuming a fixed level of savings allows for higher welfare gains (1.191), while assuming savings endogenously detract consumption attaining lower welfare gains (1.095), but increasing investment (1.095).

Table 3. Results of investment-savings closure (deviations from the initial equilibrium)

	Exogenous-savings	*Endogenous-savings*
X_1	1.116	1.116
X_2	1.076	1.076
W	1.191	1.095
I	1	1.095
P_{x1}	0.973	0.977
P_{x2}	1.009	1.013
P_k	0.904	0.908
P_l	1.085	1.090
P_h	0.991	0.995
P_{inv}	0.991	0.995

Government closure

The government fulfils the role of collecting taxes (both indirect and direct) while providing public goods and social transfers to households. Depending on which of these mechanisms are determined "outside" or "within" the model affects the economic adjustment and the results. These variables may also vary to achieve some level of surplus/deficit. Additionally, this closure may also interact and affect the investment-savings closure in two ways: firstly, indirectly by changing the endowment of the representative households, which, in the last term, will also affect the level of welfare. Secondly, directly, by allowing the government to invest. In any case, the government behaviour assumed will entail economic adjustments, which finally affect the outcome of the economy.

The government is introduced into the economy as follows:

$$\bar{G}G(P_{x1}, P_{x2}) = P_{x1}^{\alpha} P_{x2}^{1-\alpha} = P_G \bar{G} \tag{15}$$

$$GOV = i_{taxes} + transfers + surplus \tag{16}$$

$$\bar{X}_1 X_1 = \bar{W}_{x1} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x1}} W + \bar{I}_{x1} \frac{\partial I(P_{x1}, P_{x2})}{\partial P_{x1}} I + \bar{G}_{x1} \frac{\partial G(P_{x1}, P_{x2})}{\partial P_{x1}} G \tag{17}$$

$$\bar{X}_2 X_2 = \bar{W}_{x2} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x2}} W + \bar{I}_{x2} \frac{\partial I(P_{x1}, P_{x2})}{\partial P_{x2}} I + \bar{G}_{x2} \frac{\partial G(P_{x1}, P_{x2})}{\partial P_{x2}} G \tag{18}$$

$$M = r\bar{K} + w\bar{L} - \bar{S} + transfers \tag{19}$$

$$\bar{X}_1 C_{X1}(P_l, P_k) = P_l^{\gamma_i} P_k^{1-\gamma_i} = (P_{X1} + i_{taxes})\bar{X}_1 \tag{20}$$

$$\bar{X}_2 C_{X2}(P_l, P_k) = P_l^{\gamma_i} P_k^{1-\gamma_i} = (P_{X2} + i_{taxes})\bar{X}_2 \tag{21}$$

Equation (15) denotes the expenditure function of the government, where $\bar{G}$ and P_G represent the initial level of government expenditure and prices, respectively. The initial market clearance condition (7) and (8) must be redefined to accommodate the demand of goods from the government, equations (17) and (18). The government demands these goods, provides social transfers to households ($transfers$) and collects indirect taxes (i_{taxes}), according to equation (16). The production of goods X_1 and X_2, equations (1) and (2), needs to be modified to account for the indirect tax burden, equations (20) and (21). Finally, household endowment is also extended to include the social transfers

($transfers$) (equation, 21). Initially, indirect taxes are endogenous while transfers and surplus are fixed (**exogenous-transfers**).

Next, let's assume that the government decides to vary the social transfers ($transfers$) (**endogenous-transfers**) to keep the government surplus constant, as shown in equation 22. Alternatively, the surplus may also be assumed endogenously, yielding different results:

$$transfers = i_{taxes} - surplus \quad (22)$$

Table 4. Results of investment-savings closure (deviations from the initial equilibrium)

	Exogenous-transfers	*Endogenous-transfers*
X_1	1.059	1.059
X_2	1.039	1.039
W	1.081	1.064
G	1.098	1
I	1	1
P_{x1}	0.991	0.991
P_{x2}	1.010	1.010
P_k	0.953	0.953
P_l	1.049	1.049
P_w	1	1
P_{inv}	1	1
$transfers$	1	1.098
$surplus$	1	1

As shown in Table 4, both closures, Exogenous-transfers and Endogenous-transfers, lead to equivalent economic adjustments in terms of production and prices, but they differ in the change in welfare, 1.081 and 1.064, respectively. As can also be appreciated, with fixed transfers, increases in tax collection also increases government consumption (1.098). However, by allowing transfers to vary, the level of consumption remains constant for the government.

Current-Account closure

The last macro closure refers to the consequence of adopting an open-economy framework. In this case, the main issue of concern relates to the existence of foreign deficit or surplus and the way of financing it. Moreover, it should be remembered that this deficit/surplus is directly linked to the level of savings in the economy, i.e., now in an open-economy situation, total savings is disentangled into domestic (S_d) and foreign savings (S_f) extending the investment-savings closure ($I = S_d + S_f$). At the same time, the government closure can also be affected when assuming public foreign deficit/surplus. The standard closure assumes a fixed current account surplus/deficit, while the exchange rate, imports and exports vary to match the initial surplus/deficit. This closure is widely used in small open economies where international prices are assumed exogenous and the availability of foreign savings is limited (Hosoe, et al, 2010; and Gilbert and Tower, 2013). Additionally, this closure also enhances the welfare analysis because it prevents from welfare changes caused by variations in the net foreign position (borrowing/lending from abroad). The open economy is modelled using equations (1) to (11) and adding the following equations (23-26) (exogenous current-account):

$$\bar{A}_i A_i = \bar{A}_i m_i^{\alpha_i} d_i^{1-\alpha_i} \; ; \text{ where } \; i = X_1, X_2 \tag{23}$$

$$\overline{EX}_{x1} P_{x1} = Pfx\overline{EX}_{x1} \tag{24}$$

$$\overline{EX}_{x2} P_{x2} = Pfx\overline{EX}_{x2} \tag{25}$$

$$M = r\bar{K} + w\bar{L} + \overline{deficit} \tag{26}$$

Equation (23) allows for imperfect substitution between imports (m_i) and domestic (d_i) goods/services (Armington, 1969) where α_i and $(1 - \alpha_i)$ represent the share of imports and domestic goods, respectively. Equations (24) and (25) denote the share of domestic production (X_1 and X_2) that is devoted to exports. Pfx denotes the real exchange rate, and $\overline{EX}_{x1}$and $\overline{EX}_{x2}$ the respective initial values of exports. Income constraint is also modified to encompass the inclusion of the current account deficit that is assumed fixed ($\overline{deficit}$) (equation, 26). The positive sign of the deficit denotes that the rest of the world is financing the economy. The adjustment of income constraint would be the same in the case of the current account surplus, but with a negative sign ($M = r\overline{K} + w\overline{L} - \overline{surplus}$), which implies that the economy is financing the rest of the world.

Combining equations (23-26) with equation (27) allows for endogenizing the current account deficit that was held constant in equation (26) (endogenous current-account). ∂_{x1} and ∂_{x2} denote the share of exports in the total production for X_1 and X_2, respectively. ini_{def}, ini_{x1}, ini_{x2}, ini_{m1}, ini_{m2} denote the initial values of the current account deficit, the initial domestic production of good X_1 and X_2, and the initial imports of X_1 and X_2, respectively.

$$f_{deficit} ini_{def} = (ini_{x1}\partial_{x1}X_1 + ini_{x2}\partial_{x2}X_2) - ini_{m1}\alpha_{x1}A_{x1} - ini_{m2}\alpha_{x2}A_{x2} \quad (27)$$

Finally, including equation (28) means that any change in savings is financed through foreign savings:

$$capflow\ Pfx = f\_deficit\ P_i \qquad (28)$$

According to Table 5, the largest changes are in prices, foreign deficit ($f\_deficit$) and real exchange rate. The presence of an endogenous current account implies that the foreign deficit rises due to the increase in the capital endowment. However, the change in welfare and investment remains the same when assuming financing investment with foreign savings. However, in the latter case, the economy is more expensive (P_w=1.028) than in the other two closures.

Table 5. Results of current-account closure (deviations from the initial equilibrium)

	Exogenous current-account	*Endogenous current-account*	*Endogenous current-account**
X_1	1.061	1.061	1.061
X_2	1.036	1.036	1.036
W	1.044	1.049	1.049
I	1.044	1.049	1.049
P_{x1}	0.979	0.979	1.012
P_{x2}	1.010	1.010	1.044
P_k	0.952	0.949	0.981
P_l	1.047	1.043	1.078
P_w	0.999	0.995	1.028
P_{inv}	0.999	0.995	1.028
$f\_deficit$	1	1.049	1.049
$capflow$	-	-	1.049
$real\_exchange\_rate$	1.004	0.995	1.028

*By financing investment through foreign savings

Unemployment closure

This closure is sometimes denoted as a micro closure. The existence of unemployment can easily be included in the CGE framework by extending income constraint as follows:

$$M = r\overline{K} + \frac{w\overline{L}}{1-U0} - \left(\frac{w\overline{L}}{1-U0}\right)Un \qquad (29)$$

$$P_l = P_w \qquad (30)$$

Equation (29) represents the income balance constraint, where Un is the variable that denotes unemployment level and $U0$ represents the initial unemployment level. Equation (30) denotes the price of labour (P_l) and assume that workers are willing to work when the variation of salaries equates the variation of the final price (P_w). Finally, the variable Un acts as a complementary variable of this equation[8]. It should be noted that the investment is omitted from this model for the sake of clarity. Thus, the model with an unemployment closure is based on equations (1) to (9), but omitting equation (4) and detracting the investment demand from equations (7) and (8). Now both goods are demanded as follows:

$$\bar{X}_1 X_1 = \bar{W}_{x1} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x1}} W \qquad (31)$$

$$\bar{X}_2 X_2 = \bar{W}_{x2} \frac{\partial E(P_{x1}, P_{x2})}{\partial P_{x2}} W \qquad (32)$$

Table 6. Results of unemployment closure (deviations from the steady state)

	Full employment	*Unemployment*
X_1	1.059	1.100
X_2	1.039	1.100
W	1.049	1.100
P_{x1}	1.040	1
P_{x2}	1.060	1
P_k	1.001	1
P_l	1.101	1
P_w	1.050	1

As shown in Table 6, there are significant changes in production and welfare when assuming unemployment. The increase in capital endowment together with the

[8] An alternative common way of modeling unemployment is assuming a wage curve (Blanchflower & Oswald, 1995).

unemployment facilitate a multiplier effect. On the other hand, prices vary sharply with full employment.

3.5 Conclusion

The economic results of a CGE model will vary depending on the kind of closure assumed. These differences can be more marked when addressing real economies. However, there is no one-size-fits-all model closure since each relies on the kind of economic situation that best describes the particular simulation. For instance, assuming a fixed current account is widely-used in small open economies, where international prices are assumed as given, and the availability of foreign savings are limited.

Since the model closure conditions the results of the CGE model, then it may also condition any related result from the model, such as GDP or Equivalent Variation. The latter matters for the project appraisal, and if it varies with the model closure it may be a source of divergence with respect to Cost-Benefit Analysis.

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3.6 Appendix I

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 as
the *consumption.
*it is not relevant in partial equilibrium, but is important in a general equilibrium
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 (welfare 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;
```

3.7 Appendix II

Table A.1: Calibrated initial values of the CGE model*

	Investment-savings-closure	*Government-closure*	*Current-account closure*	*Unemployment closure*
γ_{x1}	0.6	0.6	0.6	0.6
γ_{x2}	0.4	0.4	0.4	0.4
β_{x1}	1	1	1	1
μ_{x1}	0.5	0.5	0.5	0.5
μ_{x2}	0.5	0.5	0.5	0.5
β	0.5	0.5	0.5	0.5
∂_{x1}	-	-	0.40	-
∂_{x2}	-	-	0.40	-
α_{x1}	-	-	0.45	-
α_{x2}	-	-	0.45	-
$\overline{EX}_{x1}, ini_{x1}$	-	-	40	-
$\overline{EX}_{x2}, ini_{x2}$	-	-	40	-
$\bar{m}_{x1}, ini_{m1}$	-	-	50	-
$\bar{m}_{x2}, ini_{m2}$	-	-	50	-
ini_{def}	-	-	20	-
$f\_deficit$	-	-	1	-
$capflow$	-	-	1	-
$\overline{X_1}$	100	100	100	100
$\overline{X_2}$	100	100	100	100
$\bar{I}$	100	100	100	-

*initially all prices are equal 1.

Table A.1 (continue): Calibrated initial values of the CGE model

	Investment-savings-closure	*Government-closure*	*Current-account closure*	*Unemployment closure*
$\bar{W}$	100	120	120	200
$\bar{M}$	100	120	120	100
$\bar{K}$	100	100	100	100
$\bar{L}$	100	100	100	100
$\bar{G}$	-	20	-	-
$\overline{GOV}$	-	20	-	-
$\overline{transfers}$	-	20	-	-
$\overline{\iota_{taxes}}$	-	20	-	-
∂_{x1}	-	-	40	-
∂_{x2}	-	-	40	-
α_{x1}	-	-	0.45	
α_{x2}	-	-	0.45	
A_{x1}	-	-	110	-
A_{x2}	-	-	110	-
m_{x1}	-	-	50	-
m_{x2}	-	-	50	-
d_{x1}	-	-	60	-
d_{x2}	-	-	60	-
$deficit$	-	-	20	-
$U0$	-	-	-	0.1
U	-	-	-	0.1

4 On the evaluation of large projects in closed and open economies

Per-Olov Johansson

4.1 Introduction

There has been some controversy how to design a cost–benefit analysis of projects so large that they cause significant price changes in other sectors of the economy. Such projects include high-speed rails, new airports and ports, and tax reforms. The favored approach 'collapses' all price effects into the primary market. As pointed out by Bullock (1993), it is easy to get lost when trying to provide a proof of the approach. He also asserts that previous authors have considered a closed economy and demonstrates that the proof fails if there are traded goods.

The purpose of this paper is to provide a simple derivation of a "short-cut" that collapses the evaluation of a megaproject to a single market. Bullock's open-economy result is reconsidered, and it is shown that the short-cut indeed holds under flexible exchange rates. As a by-product, the paper also demonstrates how to account for distortionary taxation, that is, the deadweight loss of taxation.

In addition, another approach, involving line integrals, is developed. It allocates gains and losses to different stakeholders. It contradicts claims that double counting results if gains and/or losses outside the primary market are accounted for. For example, it is often claimed that adding property values to time savings in the evaluation of, say, a new high-speed rail causes a kind of double counting. However, if properly designed the evaluation avoids the double-counting problem and provides some insights with respect to the distributional impacts of a large project.

An advantage of using CBA techniques to evaluate large projects is that they need no detailed and restrictive assumptions about utility and production functions. Rather, the project under scrutinization can often be modelled in detail. This contrasts with computable general equilibrium (CGE) techniques, which draw on more standardized sectors. A drawback of CBA is the problem of capturing distortions 'elsewhere' in the economy. However, it should be mentioned that there are attempts to use cost–benefit techniques to evaluate Big projects. The most noteworthy example is probably provided by Florio (2019) who suggests the use of CBA to evaluate Big Science like large particle accelerators, outer space probes, and genomics platforms.

The rest of the paper is structured as follows. Section 4.2 outlines the basic model. In Section 4.3 this model is used to derive a large-project evaluation rule that allocates benefits and costs to different agents. Section 4.4 turns to an approach which collapses all effects but distortions into a single market. It is demonstrated that the rule of half can be applied in a way that significantly simplifies the evaluation. Section 4.5 extends the rule to an open economy. Section 4.6 provides a sketch of a CBA of a high-speed rail, HSR. A few conclusions and an Appendix are added. The Appendix also provides a numerical general equilibrium model which sheds additional light on the results stated in the main part of the paper and could be interpreted as an extremely simple variation or embryo of a CGE.

4.2 The Basic Model

The focus in this paper is on a representative household. In a capitalist economy, this household, owns all firms, supplies labor, pays taxes, and consider all prices as exogenous. (It would just add clutter to have, say, H > 1 identical households). The household is assumed to be equipped with well-behaved ('textbook') preferences. The well-behaved direct utility function is denoted $u = u(x, \Gamma - L)$, where x denotes a vector of commodities, Γ denotes the time endowment, and *L* denotes the supply of homogeneous labor. Therefore, the indirect utility function is also well-behaved and serves as the social welfare function in this economy.

However, instead of using this function to derive project evaluation rules, the augmented expenditure function is employed. This function is defined as follows:

$$E(p, w, m, V^0) = e(p, w, V^0) - m, \tag{1}$$

where p denotes a 1×n vector of consumer relative prices, w denotes the wage rate, $e(.)$ denotes the 'pure' expenditure function, m denotes a lump-sum income, and V^0 denotes the initial level of utility. The lump-sum income, consisting of the sum of profit incomes plus a lump-sum surplus or deficit from the government, is exogenous from the household's point of view but is endogenous from the point of view of the economy. Assuming there is a representative firm in each sector of the economy, the sum of profit income is denoted $\pi(q,w)$, where q denotes producer prices. In a multi-household context, this approach, drawing on the concept of compensated equilibrium, avoids the

Boadway-paradox according to which those gaining from a non-marginal redistribution can always compensate those who lose, even if the economy is taken from one (Marshallian) first-best general equilibrium allocation to another one. Refer to Boadway (1974).

The government earns income from taxation of commodities and runs a firm producing the first commodity. This firm is used to generate cost–benefit rules, while all other governmental activities are suppressed. Commodity taxes are ad valorem and could be interpreted as a value-added tax, VAT, accompanied by extra taxes on some commodities, such as energy, and subsidies to some commodities, such as agricultural products. Any public sector surplus or deficit, denoted T, is returned to or paid by the household in a lump-sum fashion.

4.3 The General Project Evaluation Rule

The focus of this paper is on large projects. How large is a large project? The typical project addressed in many manuals is implicitly infinitesimally small. This assumption imply that any resulting price adjustments can be ignored, at least if markets are perfect. Nevertheless, a typical feature of transport sector projects is that they are assumed to be non-marginal, hence generating changes in consumer and producer surpluses, not only in the market under evaluation but often also in the markets for substitute modes. In addition, changing property values are interpreted as representing capitalization of primary changes in travel times and so on. This suggests that not only direct travel costs/prices change more than marginally. Therefore, it seems legitimate to derive cost–benefit rules that can handle price changes also in secondary and other markets.

Consider now a large change in the government's provision of the first-sector commodity. This causes (Hicksian) general equilibrium relative producer prices to change from (q^0, w^0) to (q^1, w^1). The associated compensating variation, denoted CV, is defined as follows:

$$CV = m^1 - m^0 + e(p^0, w^0, V^0) - e(p^1, w^1, V^0). \qquad (2)$$

This sign convention implies that CV is positive if the project causes lump-sum income to increase or expenditure $e(.)$ to fall. Equation (2) provides a simple and straightforward cost–benefit rule. However, the expenditure function is not directly observable, implying that we must find other ways to estimate CV.

One approach is to 'disaggregate' equation (2) in the following way:

$$CV = \sum_{i=1}^{n}[\pi^i(q^1,w^1)-\pi^i(q^0,w^0)]+t\cdot[q^{D1}\cdot x(p^1,w^1,V^0)-q^{D0}\cdot x(p^0,w^0,V^0)]- \\ \int_c [x(.)dp+L(.)dw]+[q_1^1\cdot g_1^1-C(q^1,w^1,g_1^1)]-[q_1^0\cdot g_1^0-C(q^0,w^0,g_1^0)], \quad (3)$$

where t denotes a tax vector, q^D denotes a diagonal matrix of producer prices,[1] x denotes (Hicksian) demand for commodities, L denotes supply of labor, a subscript c refers to the path taken in evaluating the line integral in the second line of the equation, g_1 denotes the supply of the public sector firm behind the considered change, and $C(.)$ denotes its conditional cost function. This approach can compactly be summarized as follows.

1. Use the profit functions to estimate the sum of changes in private sector producer surpluses.

2. Based on the compensated (Hicksian) demand functions for taxed commodities, estimate the change in tax revenue.

3. Add changes in compensated consumer surpluses and labor producer surplus, as developed in what follows.

4. Add the change in producer surplus of the public sector firm, covered within the two final square brackets in equation (3), using its conditional cost function to estimate costs.

The line integral in equation (3) deserves a comment. There is, in principle, an infinite number of paths that are permissible, provided the expenditure function is well-behaved. They all result in one and the same total change in compensated consumer surplus. However, they generate different individual surpluses, depending on where in the evaluation chain a market appears. One path is to evaluate the area to the left of the sector 1 compensated demand curve between initial and final levels of p_1, holding all other prices, including the wage, at their initial levels. Next, holding $p_1 = p_1^1$, evaluate the change in the compensated consumer surplus in sector 2, holding the remaining prices at their initial levels. Then, holding the two first prices at

[1] Let t be a 1×n vector, q^D be a n×n diagonal matrix with producer prices in the main diagonal and zeros elsewhere, and x a n×1 vector (and any sign indicating transposed vectors is suppressed). Then their product reduces to tax revenue.

their final levels, evaluate the sector 3 surplus, and so on. Finally, given $p = p^1$, evaluate the compensated labor producer surplus change as w is changed from w^0 to w^1; this kind of evaluation is illustrated graphically in Figure 2 in Section 4.6, which is devoted to an outline of a CBA of a HSR. Reversing the order of integration will change individual surpluses, in general, but results in the same total compensating variation. Recall that commodity 1 now is evaluated conditional on all other prices being held at their final rather than at their initial levels causing the compensated demand curve to have a different position and slope, in general. Informative analyses are provided by Hoehn and Randall (1989) and Carson et al. (1998) how the magnitude of an individual surplus is affected by where in the evaluation sequence it is evaluated.

It is important to underscore that one can 'disaggregate' the total surplus in the way illuminated by equation (3), and that the same rule applies if a private-sector project is considered. In a multi-household economy this approach provides a simple distributional analysis where gains and losses are allocated to different stakeholders. Sometimes, the literature gives the impression that the approach outlined here implies double counting of benefits and/or costs, but as long as the conditions for path independency are satisfied, the approach results in one and the same CV independently of the route or path taken. For example, a transport investment could result in both lower travel costs and affect property values. Then these effects could be accounted for in the way suggested by equation (3) without causing a double-counting problem. This is further illuminated in Section 4.6, where a HSR is evaluated.

The reader could also 'convert' changes in profits to producer surplus measures measured as areas to the left of supply and demand curves between initial and final producer prices. Then, evaluate the conditional cost functions as line integrals, just as done above for $e(.)$. This could be a wise strategy if the investigator wants to illuminate how different markets are affected by the project. A useful simplification in empirical applications is provided by separable production functions, such as Cobb-Douglas, where the different cost items are additive, that is, only depends on the own factor price and the scale of operations.

4.4 A Short-Cut

There is another approach to CBA, discussed by Just et al. (1982) and further developed by Bullock (1993), who (among other things) addresses inconsistencies in Just et al. (1982, Appendix D); Just et al. (2004) addresses the concerns raised by Bullock (1993). However, here we provide a slightly different proof. Suppose that we can solve the general equilibrium producer prices as functions of the exogenous production g_1 of the public sector firm (suppressing other parameters of the problem, for example tax rates). Then, $q_i^* = f^i(g_1)$ for i = 1,…, n-1, arbitrarily using commodity n as numéraire (with producer price equal to unity and consumer price equal to $1 + t_n$) , and $w^* = h(g_1)$, where an asterisk refers to an equilibrium level.

Consider the market for commodity i. Assume for notational simplicity that the commodity is not used as an input in production. Regardless of this last assumption, the direct effect of a small, induced price adjustment vanishes from the evaluation of the project:

$$[x_i^s(q^*, w^*) - x_i(p^*, w^*)]dq_i^* = 0, \tag{4}$$

where $p_i^* = (1+t_i)\cdot q_i^*$, and the price change is "driven" by a change in g_1. The simple reason why the net effect equals zero is that supply x_i^s equals demand x_i in equilibrium, and in equation (4) they appear with opposite signs. Next, consider a discrete or large change in g_1. Provided prices continue to clear markets throughout the change, the equality of the two terms within square brackets in equation (4) will hold. Tax revenue is also affected, and this effect is accounted for below.

Summing across markets, and integrating with respect to g_1, the cost–benefit rule reduces to:[2]

$$CV = \int_{g_1^0}^{g_1^1} [q_1^*(g_1) - C_{g_1}^g(q^*(g_1), w^*(g_1), g_1)]dg_1 + TW, \tag{5}$$

where $q^*(g_1) = [f^1(g_1), \ldots, f^{n-1}(g_1), 1]$, $C_{g_1}^g(.)$ denotes a marginal cost, and TW is a short-cut for the total of sector-specific tax wedges. Because the TW-term is a bit involved it is developed in the Appendix. It may come as a surprise that the project is

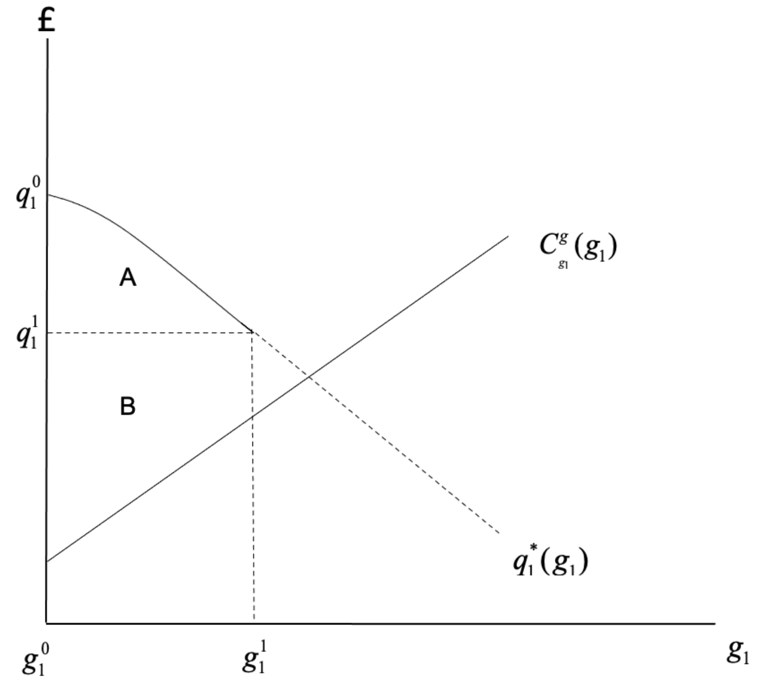
[2] In the Appendix it is shown how a short-cut for changes in tax rates to finance the project could be added to equation (5).

evaluated at producer prices. However, the impact on tax revenue is contained in the *TW*-term. In the special case where the net change in demand for the commodity under evaluation equals the change in g_1, one could deduct $t_1 \cdot q_1^* dx_1 = t_1 \cdot q_1^* dg_1$ from the (marginal) tax wedge term and multiply q_1^* by $(1 + t_1)$ in equation (5), that is, value the project at consumer price, and replace *TW* by the remaining parts of *TW*. However, in general one would expect the net change in demand to differ from the change in g_1, unless the public sector firm has a monopoly, as in Section 4.6, where a CBA of a HSR is outlined.

A graphical illustration of the integral in equation (5) is provided by Figure 1. The benefits are evaluated as an area under the equilibrium price path and the increase in costs as an area under the marginal cost curve. The difference between benefits and costs is captured by area A plus area B. (An optimally designed project would be such that the equilibrium price equals marginal cost, at least if $TW = 0$, while $TW \neq 0$ suggest that we are in a second-best world.)

Figure 1

Benefits and costs captured in the market for commodity 1.



In the absence of distortions, equation (5) illustrates results derived by, among others, Bullock (1993), Just et al. (1982, 2004), and in a more graphical fashion by Bailey (1954) and Mohring (1993).[3] However, note that *CV* in equation (5) equals *CV* in equations (2)-(3). They just draw on different ways of evaluating the change in going from g_1^0 to g_1^1; equation (3) draws on a line integral plus discrete changes, while equation (5) involves a line integral expressed as a definite integral. This equality provides an important and useful insight for practical evaluations. Recall warnings that one risk double-counting of benefits and/or costs if one does not proceed as in equation (5). To illustrate, suppose the first market in equation (3) is a travel market under evaluation, the second market is the market for a competing transport mode, and the third market is the property market. If no other markets are significantly affected, then area A + B plus *TW* corresponds to the *sum* of the terms in equation (3) over the three

[3] Further references are Brännlund and Kriström (1996) and Johansson and de Rus (2018).

markets. Recall that the curve in Figure 1 is an *equilibrium path*, not the (initial or final or some intermediate) demand curve for the considered transport mode. To further illustrate, suppose the supply of properties is completely inelastic. Then, according to equation (3) a property price increase simply represents a redistribution. Whether the gain to property owners corresponds to an area in the figure is out of the scope of the paper to investigate. Nevertheless, noteworthy is that some infrastructure investment, for example new highways, possibly mostly move development around a region such that infrastructure-induced development is close to a zero-sum game (Ewing, 2008).

A neat approximation of area A + B is provided by the rule of half:

$$CV \approx \frac{1}{2}(q_1^0 + q_1^1)\Delta g_1 - C_{g_1}(g_1^0)\Delta g_1 + TW, \tag{6}$$

where $\Delta g_1 = g_1^1 - g_1^0$ (and the marginal cost estimate possibly is replaced by a more exact estimate). Thus, the approximation is based on a straight line between the initial and final price-quantity configurations in the figure. A kind of upper bound for the benefits is obtained by shifting the price curve upwards by the tax on the commodity, i.e., by valuing benefits at the consumer price (but to avoid double counting the added effect should be deducted from the *TW*-term). If the initial and final price quantity combinations, that is, g_1^0 and g_1^1 are available (and the difference between Marshallian and Hicksian equilibria is negligible), it is a straightforward exercise to approximate area A + B in Figure 1.

Nevertheless, a caveat is in order. The pre-project demand curve for the commodity might be quite different from the equilibrium path for q_1. Hence, an ex-ante evaluation of equation (5) based on the initial demand curve would result in a biased estimate, in general. Thus, equation (5) must be applied with great caution. The same holds true when using survey techniques, such as contingent valuation and discrete choice experiments, to estimate the WTP ex ante for a project. In terms of Figure 1, the estimated WTP, holding all other prices at their initial prices, could be quite different from the area under the equilibrium path. This is worth observing in empirical evaluations. The same caveat applies for ex post evaluations, where estimates are based on *final*, rather than initial, equilibrium prices.[4]

Equation (5) provides no simple quick fix, not even in an otherwise perfect economy. In fact, if only the initial (final or with the project) demand curve for the examined commodity is available, equation (3) might provide a safer evaluation route; recall that the line integral permits a path such that the considered commodity is placed at the beginning (the end) of the evaluation sequence, that is, evaluated at initial (final) prices, as illustrated below equation (3). In theory at least, this provides an exact evaluation route.

4.5 The Short-Cut in an Open Economy

Bullock (1993) points at an important shortcoming of equation (5). The equation only holds if all commodities are nontraded. In an open economy facing a fixed exchange rate, as is the case also for many countries within currency areas, one would expect Bullock's claim to hold. The large project will add to or deduct from a country's current account. Thus, like distortive taxes, a current account-effect is not covered by areas under the equilibrium path in equation (5); the equality in equation (7) below does not hold under a fixed exchange regime.

However, over the longer run one cannot rule out that trade flows adjust to achieve balance in the current account. With respect to multinational projects, the question also arises whether they should be assessed at the national or at a larger level. This important question relating to who "stands" in an evaluation is not addressed here.

In any case, matters are different under flexible exchange rates. Suppose for notational simplicity that just two commodities are traded, and that there are no intermediate uses of these commodities. There is a domestic excess supply of one commodity, that is, net export, while there is domestic excess demand for the other commodity, that is, net import. Because the exchange rate is flexible, the following holds:

[4] A simple numerical illustration based on CES preferences for three commodities overestimates the "true" area under the q_1^*-curve by 15 percent if based on the initial demand function for the considered commodity. The ex post curve, estimable once a project is running, underestimates the true area by around 6 percent, a quite decent outcome.

$$\varepsilon \cdot [q_1^w \cdot (g_1 + x_1^s - x_1) + \cdot q_2^w (x_2^s - x_2)] = 0, \tag{7}$$

where ε denotes the exchange rate, and a superscript w refers to a world market price in foreign currency. Equation (7) provides the current account expressed in domestic currency. When prices adjust, the current account in foreign currency multiplied by $d\varepsilon$ replaces the equilibrium conditions (4) for the traded goods. Hence, if the considered large change in g_1 impacts on net export, the exchange rate will adjust to clear the current account. Solving the exchange rate (simultaneously with other prices and wages) as a function of g_1 provides an equilibrium path for ε holding the current account in balance as g_1 is adjusted. Therefore, equation (5) is still valid (but the *TW*-term might be affected, depending on how traded goods are taxed).

However, if the project, here g_1, is so large that it impacts on a world market price, that is, affects the country's terms of trade, matters are different. In terms of equation (4), the change in the world market price is not multiplied by an equilibrium condition, but typically by an excess demand or an excess supply. This impact is not covered by equations (5)-(6).[5] Nevertheless, the approximation in equation (6) provides a cheap, cost-effective first-aid kit that is useful for obtaining a rough assessment of the social profitability even of complex megaprojects. Although a market good has been used here to illustrate the approach, it is equally applicable if the project provides a public good or is aimed at reducing emissions of damaging climate gases, for example.

4.6 A Sketch of an Evaluation of a New HSR

This section provides an illustration of the two approaches outlined in Sections 4.3 and 4.4 by outlining a CBA of a hypothetical high-speed rail. A HSR consists of infrastructure and rolling stock that allows the movement of passenger trains capable of speeds above at least 200-250 km per hour (according to the definition applied by the EU). This technology competes with road and air transport over distances of 400-600 km, and in which it is usually the main mode of transport. For short trips, the private vehicle has a comparative advantage, and for long distance travel, air becomes the ultimate transport mode.

[5] Such effects are covered by equation (3) and could be added to equations (5)-(6), at least in theory. Suppose, for simplicity, that the considered firm has virtually no impact on ε and is a (not necessarily profit-maximizing) monopolist. Then the consumer surplus gains made by foreigners when q_1^w falls as g_1 is increased, converted to domestic currency, should be deducted from equation (5).

A rigorous economic appraisal would compare several relevant “do something” alternatives with the base case, as discussed in de Rus (2011). These alternatives include upgrading the conventional infrastructure, management measures, road, and airport pricing or even the construction of new road and airport capacity. However, for the limited purposes of this section it is sufficient to restrict attention to two transport modes, the new or planned HSR and an existing transport mode. For this reason, the demand functions for the first two commodities are modified to read:

$$x_i(.) = x_i[(1+t_1)\cdot q_1 + tc_1 \cdot w, (1+t_2)\cdot q_2 + tc_2 \cdot w, p_3, \ldots, p_n, w, V^0], \qquad (8)$$

where $i = 1, 2$, q_i denotes the pre-tax monetary cost (pre-tax fare), tc_i denotes the time a trip by transportation mode i requires, and, for simplicity, time is valued at the ruling market wage; refer to de Rus (2011) for discussion of typical approaches used in the practical evaluation of projects. Adding $tc{\cdot}w$ to the fare paid by a traveler, one obtains the generalized travel cost, denoted $p_i^G = (1+t_i)\cdot q_i + tc_i \cdot w$. We interpret x_1 as high-speed rail demand, while x_2 denotes demand for a substitute transportation mode (such as a ‘conventional’ train, car, bus or aircraft). By assumption, $tc_1 < tc_2$, and both commodities are non-essential in the sense that one can survive without consuming them. Demand for a non-essential commodity equals zero if its price becomes sufficiently high.

The easiest way to provide an overview of a CBA of a new HSR is by using the indirect utility function of a representative individual. The *CV* for the project is implicitly defined by the following equation:

$$V[(1+t_1)\cdot q_1^1 + tc_1 \cdot w^1, p_2^{G1}, p_3^1, \ldots, p_n^1, w^1, m^1 - CV] = V[0, p_2^{G0}, p_3^0, \ldots, p_n^0, w^0, m^0], \qquad (9)$$

where a superscript 1 (0) denotes general equilibrium prices and incomes with (without) the considered HSR. This approach illuminates that *CV* is a function of the time cost. The higher tc_1 (and w^1), ceteris paribus, the lower is the WTP. Similarly, the higher the fare, the lower is *CV*. Moreover, the agent need not consider the modes equivalent from a quality perspective (comfort, noise, and so on). Her preferences are reflected in the slopes and positions of the demand functions and hence in the magnitude of *CV*. Finally, general equilibrium induced adjustments in other prices and incomes affect the WTP; climate and other environmental impacts will be addressed below. Unfortunately, utility functions are not observable. Therefore, we return to our monetary approaches.

4.6.1 The Demand Side Approach

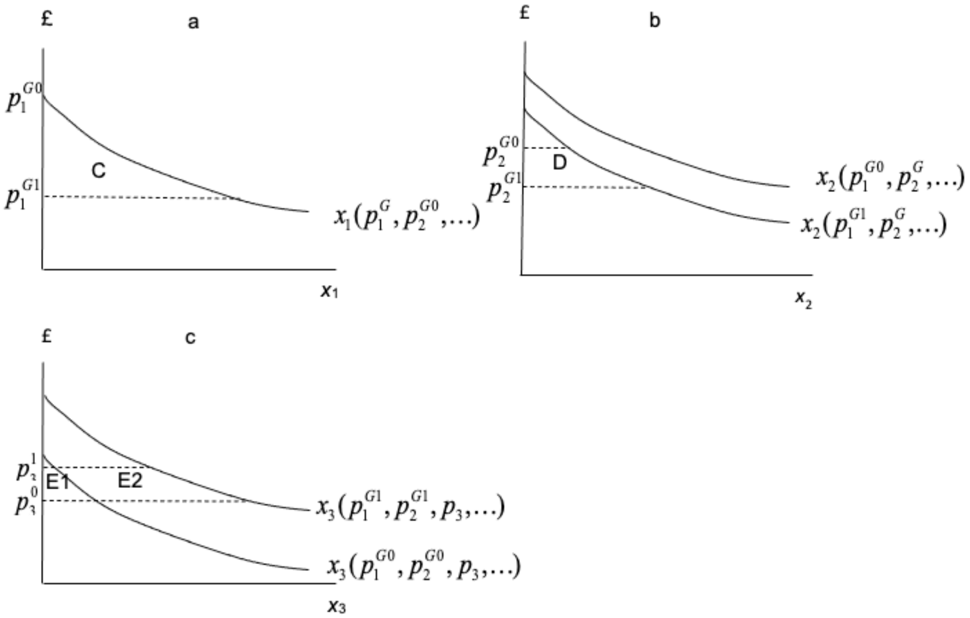
The only variable cost item in equation (8) is the pre-tax fare, although, from a general equilibrium perspective, also w is endogenous. The high-speed rail demand curve is pictured in Panel a of Figure 2.[6] Given the time cost of a trip (and preferences), there is a fare such that the generalized travel cost becomes so high that demand equals zero. This choke price is denoted $p_1^{G0}(=(1+t_1)\cdot q_1^0+tc_1\cdot w^0)$ in Figure 2 and mimics the pre-HSR situation. Although fixed, the time cost affects the position of the demand curve. The lower the time cost, the farther to the north-east is the demand curve situated. This feature is obvious from equation (8). If the generalized travel cost faced by HSR travelers equals p_1^{G1}, they earn a Hicksian consumer surplus (or a compensating variation) equal to area C in Figure 2. This assumes that this market is the first in the evaluation chain, implying that all other prices are kept constant at their initial levels. In a multi-household society where preferences differ across travelers, and each traveler undertakes one trip, they are ranked according to WTP. The marginal traveler is willing to pay no more than p_1^{G1} in terms of the generalized travel cost or $(1+t_1)\cdot q_1^1$ in terms of the fare.

Turning to the second market, pictured in Panel b of Figure 2, due to the reduction of p_1^G the demand curve for x_2 is assumed to shift to the left. Overall, there is a reduction in the equilibrium generalized travel cost p_2^G, and the gain in Hicksian consumer surplus equals area D in Figure 2. Finally, there is a third affected market where the introduction of the new transport mode causes the equilibrium price to increase. It could be a local housing market that is facing an increase in demand due to the HSR. In any case, the change in Hicksian consumer surplus is evaluated conditional on the first two prices being held at their final levels, that is, $p_i^G=p_i^{G1}$ and $p_2^G=p_2^{G1}$. The resulting loss of Hicksian consumer surplus is captured by area E = E1 + E2 in Panel c of Figure 2.

[6] Alternatively, one could draw the demand curve with the fare $(1+t_1)\cdot q_1$ on the vertical axis. This is equivalent to a parallel downward shift of the demand curve by $tc_1\cdot w^0$.

Figure 2

Panel a: HSR market; Panel b: Market for another transportation mode; Panel c: A third affected market.



As clarified in the discussion of line integrals in connection to equation (3), the considered evaluation sequence is one out of many possible paths. For example, we could evaluate the change in the third market given that the other prices are held at their initial levels, then evaluate the second market given p_3^1 and p_1^{G0}, and so on. This will affect the magnitudes of the individual Hicksian surpluses but leave the total surplus, that is, area C + D + E in Figure 2, unchanged.

To arrive at a complete evaluation, one would have to add possible changes in Hicksian consumer surpluses in other markets, any producer surplus change in the labor market, changes in profit incomes, tax revenue, and the profit of the public sector firm assumed to construct and operate the HSR; see points 1-2 and 4 following equation (3). It should be noted that if one replaces the (perfect competition) profit functions in equations (3) by profit expressions, the approach is compatible with imperfect competition, for example, monopolies, oligopolies and monopsonies. That clarification justifies the absence of supply curves in Figure 2. Climate issues will be addressed below.

4.6.2 The Short-Cut Approach

Turning to the short-cut approach, the supply of the first commodity is still denoted g_1. The pre-tax or producer fare q_1 adjusts to maintain equilibrium between demand and provision (ceteris paribus) throughout the shift from $g_1 = g_1^0 = 0$ to $g_1 = g_1^1$. Therefore, the approach stated in equation (5) is applicable also for the evaluation of the HSR. It might come as a surprise that the time cost does not explicitly enter the evaluation. However, the equilibrium fare q_1^* is a function of tc_1 and tc_2 (while w is endogenous and evaluated along its equilibrium path as g_1 adjusts). Hence, in terms of Figure 1, the slope and position of the equilibrium price path depends on the magnitude of the time parameters. A reduction (increase) of tc_1 (tc_2) would cause an upward shift in the equilibrium path.[7] One could also value the HSR at end-user fares by shifting $t_1 \cdot q_1 dg_1$ from *TW* to the integral in equation (5); recall that the public sector firm is the sole supplier so its supply equals demand in equilibrium.

[7] See the Appendix for the evaluation of a change in the travel time of an *existing* HSR.

Because the two evaluation approaches considered in this section provide two different and permitted paths for the evaluation of the considered project, they result in the same overall *CV*. A third way, drawing on the (unobservable) indirect utility function, is provided by equation (9). A simple numerical general equilibrium model illustrating the equivalence of the three approaches has been posted on ResearchGate (Johansson 2021) and is added to the appendix. This model also suggests that a CGE can be used to undertake general equilibrium CBA.

4.6.3 The CBA

Drawing on equation (3) in de Rus (2011) the cost–benefit analysis of the HSR can compactly be summarized as follows:

$$\begin{aligned} CV^{PV} &= \int_{\tau=\tau^0}^{\tau^E} CV(\tau)\cdot e^{-(r_\tau-\gamma_\tau)}d\tau - I + SV(\tau^E) = \\ &\int_{\tau=\tau^0}^{\tau^E}\Big[\int_0^{g_{1\tau}^1}[q_{1\tau}^*(g_{1\tau}) - C(q_\tau^*(g_{1\tau}), w_\tau^*(g_{1\tau}), g_{1\tau})]dg_{1\tau} + TW_\tau\Big]\cdot e^{-(r_\tau-\gamma_\tau)}d\tau - I + SV(\tau^E), \end{aligned} \tag{10}$$

where CV^{PV} denotes the total present value WTP for the HSR, τ^0 denotes the date when the railway becomes operational, τ^E denotes the time horizon, r_τ denotes the time τ real discount rate, γ_τ denotes time τ growth of benefits and costs, *I* denotes the present value at time zero of the investment cost, and *SV*(.) denotes any present value at time zero of remaining infrastructure and rolling stock at the time operations cease. Any distortions other than taxes are ignored as are any annual fixed maintenance and operating costs, that is, annual costs that are independent of the magnitude of $g_{1\tau}^1$. The discount rate would typically be assumed to be constant over time or decreasing (hyperbolic discounting). The formulation in equation (10) admits discussion of the optimal timing of the investment. For example, initially demand could be so low that annual benefits do not cover annual costs. If so, it is socially profitable to delay the investment until this condition is met.

A remaining issue relates to emissions of climate gases (ignoring here other emissions that harm living organisms). Even if the steel, concrete, and so on, needed for the construction of the rail and the electricity needed during the phases of construction and operation are covered by the European Union's system for emission trading (EU ETS), the HSR could have an impact on global emissions. After the 2018 reform of the system, the supply of permits is *endogenous*, implying that a project causing emissions of greenhouse gases might increase, leave unchanged, or even reduce total emissions; refer to Johansson (2020) for details and further references. On the other hand, if there is a tax on climate gases reflecting the global marginal damage caused by additional emissions, there is no need to adjust the CBA. Refer to Jorge-Calderón and Johansson (2017) for details. However, even in such an ideal case, there is a caveat. The substitute transport mode(s) need not be covered by the same policy instruments. For example, aircraft emit water vapor at high altitudes, creating condensation trails contributing to climate change. These impacts are not covered by EU ETS. In addition, parts of the equipment needed for the considered transport modes may be imported from countries lacking effective policy instruments.

4.6.4 Lessons from the HSR-Example

An import lesson from this exercise for applied studies is that the ex-ante demand curve for x_1 in Figure 2 cannot be given an interpretation as an equilibrium path, that is, $q_1^*(.)$ in general. Recall that such an interpretation ignores the induced adjustments in the rest of the economy. The exception occurs in the unlikely event that the HSR leaves prices in all other markets unaffected. Then, the $q_1^*(.)-$curve can be interpreted as the inverse demand curve for x_1. A possible catcher in the rye when several prices adjust is as follows. Suppose that we have somehow estimated the general equilibrium with the HSR. Then the fare-quantity combinations (q_1^1, x_1^1) and $(q_1^0, 0)$ can be used to provide a linear approximation of area A+B in Figure 1. This is an application of the rule of half stated in equation (6). However, if the $q_1^*(.)-$curve is non-linear, the rule might provide a poor answer. For example, in the simple numerical general equilibrium model in the Appendix, the rule of half overestimate *CV* by 25–30 percent.

A second lesson is that solving for the generalized travel cost instead of the fare and integrating p_1^{G*} over g_1 is possible but roundabout. To arrive at the desired result, one must evaluate the time cost along its equilibrium path and deduct the resulting amount from the integral of p_1^{G*}. This claim is supported by the numerical general equilibrium model in the Appendix. The same result applies in a partial equilibrium context where the time cost is assumed to be constant.

Another lesson is that one can disaggregate benefits and costs as suggested by Figure 2 and in more detail by equation (3). However, it is important to realize that there are strict mathematical rules for such a distributional analysis. One cannot simply base the analysis on initial or estimated final demand and supply curves. The evaluation must be based on the concept of a line integral. This approach is easily extended to account for market power. The short-cut approach, on the other hand, is more challenging from a technical point of view, at least if there is market power in secondary markets; the supply by the firm in the primary market is exogenous in the current paper. Hence, the firm can be modelled as acting as a monopolist at one extreme or as if there was perfect competition at the other.

Finally, it has been assumed that any surplus (deficit) caused by the HSR is returned to (collected from) households in a lump-sum fashion. This is the standard assumption employed in CBA. However, in the Appendix we have extended the short-cut approach to CBA to the perhaps more realistic case where an ad valorem tax is increased to finance any deficit partially or fully.

4.7 Conclusions

The purpose of this paper has been to derive cost–benefit rules for large projects. Two different but consistent general equilibrium approaches have been used. One approach disaggregates benefits and costs across different markets. The approach draws on strict mathematical rules. What one must evaluate is a line integral. This means that there are many different paths to choose among. All result in one and the same total outcome. This approach functions even when there are distortions such as taxes and market power.

The other approach aims at capturing the effects of even a megaproject in the market for the transport mode under investigation. This works nicely if all markets are perfect. It becomes more involved if there are distortions like taxes and market power or if the project has a noticeable impact on world market prices. Still, applying the rule of half, it points at a simple tool for a rough evaluation of a large transport project. The obvious but costly alternative would be to use a computable general equilibrium model.

We have also extended the approach to an open economy showing that it works under flexible exchange rates. However, if the project is so large that it affects world market prices in foreign currency, a term reflecting the change must be added. The reason is that foreigners have no standing in the typical CBA. An exception is provided by analysis at an international level, for example, the European Union or, in the case of climate change where, typically, a global perspective is applied.

Another extension is provided by using a distortive tax to finance the project. This is of relevance for many large-scale transport investments undertaken by national governments; lump-sum taxation need not be available. The paper also provides a sketch of a CBA of a high-speed rail. Among other things, it points at the danger of using the ex-ante demand function for travels as a proxy for the equilibrium fare path. Such an approach could result in a seriously biased estimate of the WTP for trips. The paper also points at a possible simple catcher in the rye. Given an estimate of the fare-demand combination, the rule of half can be used to obtain a rough estimate of the WTP for a new HSR.

The analysis in the current paper is based on the concept of the compensating variation holding agents at their initial or pre-project levels of utility. It would be possible to instead base the analysis on the equivalent variation, where agents are held at their final or with-project utility levels (as is typically the case in computable general equilibrium models). Mäler (1985) has suggested that the choice of compensated money measures should in some cases be influenced by distributional considerations, provided society prefers a more even to a more uneven income (or welfare) distribution. Suppose that initially, before a reasonably small project is undertaken, society is indifferent to small changes in income distribution. Then equivalent variation, which is based on pre-project conditions (prices, incomes, and so on), is the relevant measure. On the other hand, if it is judged that income distribution with the project is such that small changes in income distribution would not affect social welfare, then the CBA of the project should be based on the compensating variation measure; this measure is defined in terms of final levels of incomes, and so on. The reader is referred to Mäler (1985) for further details.

Nevertheless, in a real-world evaluation, a more detailed distributional analysis than the one suggested above might be required. A first step in such an analysis is to distribute benefits and costs across stakeholders. This provides the decision-maker with basic information of the considered project's/policy's distributional impact. Some influential international manuals on project evaluation, such as the ones by the EU and the (Green Book of the) UK, also recommend the use of specific social welfare functions, where the social welfare weight attributed to a special (possibly regional) group depends on the group's income per capita or per (standardized) household. The reader is referred to Johansson and Kriström (2016, Section 7.5) for a discussion of how these manuals handle distributional issues, and to European Commission (2014) and HM Treasury (2020) for further details.

Appendix

The tax wedge term *TW* in equation (5) corresponds to a definite integral with integrand equal to:

$$MTW = \sum_i [\sum_{j\neq n} t_i \cdot q_i^*(.) \frac{\partial x_i(p^*, w^*, V^0)\cdot(1+t_j)}{\partial q_j}] + \sum_i t_i \cdot q_i^*(.) \frac{\partial x_i(p^*, w^*, V^0)}{\partial w} = \sum_i t_i \cdot q_i^*(.) \frac{\partial x_i^*(g_1, V^0)}{\partial g_1}, \quad \text{(A.1)}$$

where *MTW* denotes the marginal tax wedge evaluated at general equilibrium prices, and all constants (tax rates and so on) except initial utility are suppressed in the second line. Thus, integrate the sum with respect to g_1 from g_1^0 to g_1^1 along the optimal price paths, which are functions of g_1, noting that one can exploit the fact that $dq_i^* = (\partial f^i(g_1) / \partial g_1) dg_1$ and $dw^* = \partial h(g_1) / \partial g_1) dg_1$. The result of this definite integral is denoted *TW* in equation (5).

Finally, consider the possibility that the project is partially financed by an increase in an ad valorem tax, for example, the one on x_i. One could view the tax rate as a function of the size of the considered project: $\alpha_i \cdot g_1^j = t_i^j$, where α_i is a constant such that $\alpha_i \cdot g_1^j = t_i^j$ for j = 0, 1. This produces a new set of general equilibrium prices as functions of g_1. Straightforward but tedious calculations reveal that, in addition to the integral of (A.1), one must add the following definite integral to equation (5):

$$\int_{g_1^0}^{g_1^1}[\alpha_i \cdot g_1 \cdot q_i^*(.)\frac{\partial x_i(q_1^*(.)(1+t_1),\ldots,q_i^*(.)(1+\alpha_i \cdot g_1),\ldots)}{\partial t_i}+ \sum_{j\neq i} t_j \cdot q_j^*(.)\frac{\partial x_j(.)}{\partial t_i}]\cdot q_i^*(.)\alpha_i dg_1, \tag{A.2}$$

where $\partial x_i(.)/\partial t_i$ denotes a substitution effect, $\partial x_j(.)/\partial t_i$ a cross-substitution effect, and the integrands can be (seemingly) simplified in the same way as is done in the second line of equation (A.1). The first term accounts for the change of "value" of the tax wedge in the market facing the tax increase (most easily seen by replacing the ad valorem tax by a unit tax, causing q_i^* to vanish from the expression). The second term accounts for the change in the value of the cross-substitution terms.

As equation (A.2) reveals, there are parallel expressions involving cross-substitution effects in the remaining markets. The magnitude of the terms in equation (5) are also affected because the equilibrium paths for prices are changed when they are functions of both g_1 and the new parameter $\alpha_i \cdot g_1$. It seems difficult to account for this type of tax funding of a project without access to a CGE model or a simulation model. However, in principle, (A.2) can be transformed to a 'non-marginal' cost of public funds which is easier to estimate.

To assess the value of a change in the travel time of a trip with an *existing* HSR, let us consider the Lagrange function for the expenditure minimization problem:

$$\mathcal{L}(.) = p \cdot x - w \cdot L + \lambda \cdot [V^0 - U(x, \Gamma - L - tc \cdot x)], \tag{A.3}$$

where $p = [(1 + t_1)\cdot q_1,\ldots, (1 + t_n)\cdot 1]$, λ denotes a Lagrange multiplier, and in the main text tc equals zero except for x_1 and x_2. Taking the partial derivative of $\mathcal{L}()$ with respect to tc_1 yields $\lambda \cdot U_\ell \cdot x_1$, where a subscript ℓ refers to leisure time. In optimum, $\lambda \cdot U_\ell = w$. Hence, $\partial e(.)/\partial tc_1 = w \cdot x_1(.)$. Integrating $-w^*(tc_1)\cdot x_1(.)$ between initial and final travel times, holding g_1 constant (or replaced by a supply function), yields the general equilibrium adjustment in Hicksian consumer surplus associated with a change in the travel time tc_1. Note that $q_1,\ldots, q_{n-1}$ and w are now functions of tc_1 and hence adjust as tc_1 changes such that equilibrium is maintained throughout in all markets. The numerical illustrations in the Appendix consider a simultaneous change in capacity and travel time of an existing HSR, where travel time is affected by, say, bottlenecks or traffic jams.

The rest of this Appendix provides a numerical illustration of many, but not all, results presented in the section on a high-speed rail. A simple Stone-Geary type of quasi-linear utility function is postulated because transportation is hardly an essential commodity (in contrast to, for example, air to breath). A trip is assumed to require *tc* time units, and there are just two modes of transportation. The first mode is initially not available, but it is evaluated using cost–benefit techniques.

The direct utility function is as follows:

$$U = \delta \cdot \ln(x_1 + 1) + \ln(x_2 + 1) + \ln(\Gamma - \delta \cdot tc_1 \cdot x_1 - tc_2 \cdot x_2 - L) + x_3 \qquad \text{(A.4)}$$

where $\delta = 1$ if provision of the first commodity is strictly positive and $\delta = 0$ otherwise, and x_3 denotes the numéraire. Demand functions are defined as follows:

$$\begin{aligned} x_i(.) &= \frac{1 - q_i - tc_i \cdot w}{q_i + tc_i \cdot w} \qquad i = 1,2 \\ x_3(.) &= \delta \cdot T + \pi_2 + w \cdot L - \delta \cdot q_1 \cdot x_1 - q_2 \cdot x_2 \end{aligned} \qquad \text{(A.5)}$$

where $T = q_1 \cdot g_1 - w \cdot (g_1)^2$, and $\pi_2 = (q_2)^2/(4 \cdot w)$. Thus, the first commodity is provided by the government. Any ad valorem taxes are suppressed here. Note that travel time is valued at the wage rate.

Supply of labor is defined as follows:[8]

$$L(.) = \Gamma + \delta \cdot tc_1 + tc_2 - \frac{1}{w} - \delta \cdot \frac{tc_1}{q_1 + tc_1 \cdot w} - \frac{tc_2}{q_2 + tc_2 \cdot w} \qquad \text{(A.6)}$$

Note that the functions in equations (A.5)-(A.6) will look the same if the analysis is based on the expenditure function; recall that preferences are quasi-linear.

Equilibrium conditions for the two transport markets and the labor market are used in the numerical exercise:

[8] Evaluated at the equilibrium prices for $g_1 = 2$, it holds that $\partial L(.)/\partial tc_i < 0$.

$$\frac{1-q_1-tc_1\cdot w}{q_1+tc_1\cdot w}=\delta\cdot g_1$$
$$\frac{1-q_2-tc_2\cdot w}{q_2+tc_2\cdot w}=\frac{q_2}{2\cdot w} \qquad \text{(A.7)}$$
$$\Gamma+tc_1+tc_2-\frac{1}{w}-\frac{tc_1}{q_1+tc_1\cdot w}-\frac{tc_2}{q_2+tc_2\cdot w}=\delta\cdot(g_1)^2+\frac{(q_2)^2}{4\cdot w^2}$$

These can be solved to obtain $q_i^*=q_i^*(g_1)$ and $w^* = w^*(g_1)$; the functions and their graphs for the first market and the labor market are shown at the end of the paper (holding tc_1 = 1/10). Obviously, these equilibrium paths are functions of tc_1 and tc_2, in addition to g_1. However, the functions are reported for $tc_2 = 4/10$.

Consider now a shift of g_1 from $g_1^0=0$ to $g_1^1=2$ with $tc_1 = 1/10$, $tc_2 = 4/10$, and Γ=24. The general equilibrium price vector changes from $[q_1^0\approx 0.9943, q_2^0\approx 0.273, w^0\approx 0.057]$ to $[q_1^1\approx 0.326, q_2^1\approx 0.293, w^1\approx 0.069]$.[9] Thus, the increased demand for labor increases the equilibrium wage rate. In turn, this causes the equilibrium (ticket) price of the second commodity to increase. The initial market prices (q_1^0, w^0) are such that demand for trips on the high-speed rail equals zero.

The indirect utility function can be used to assess the social profitability in a quite simple way and is here used as a kind of consistency check. The compensating variation is implicitly defined by the following equation:

$$\ln(x_1^1+1)+\ln(x_2^1+1)+\ln(\Gamma-tc_1\cdot x_1^1-tc_2\cdot x_2^1-L^1)+x_3^1-CV=U^0 \qquad \text{(A.8)}$$

where a superscript 1 (0) refers to the final (initial) equilibrium levels, and initial utility is $U^0 \approx 4.073$. One finds that $CV \approx 0.834$.

Next, proceed sequentially as in equation (3) in the main paper to obtain:

[9] All *CV*-estimates reported below are based on approximations of prices to (up to) 16 decimals. Thus, using the approximate prices stated here need not exactly replicate the reported results.

$$CV = -\int_{q_1^0}^{q_1^1} \frac{1-q_1-tc_1\cdot w^0}{q_1+tc_1\cdot w^0}dq_1 - \int_{q_2^0}^{q_2^1} \frac{1-q_2-tc_2\cdot w^0}{q_2+tc_2\cdot w^0}dq_2 +$$
$$\int_{w^0}^{w^1}\left[\Gamma + tc_1 + tc_2 - \frac{1}{w} - \frac{tc_1}{q_1+tc_1\cdot w} - \frac{tc_2}{q_2+tc_2\cdot w}\right]dw + \Delta T + \Delta\pi^2 \approx$$
$$0.434 - 0.045 + 0.083 + 0.376 - 0.014 = 0.834$$

(A.9)

Note that one could as well integrate over generalized travel costs $x_i = (1-p_i^G)/p_i^G$, where $p_i^G = q_i + tc_i \cdot w$, as is done in the main paper, and obtain the same result.

Finally, use the equilibrium paths for q_1 and w as in equation (5) in the main paper to obtain:

$$CV = \int_{g_1^0}^{g_1^1}[q_1^*(g_1) - w^*(g_1)\cdot 2\cdot g_1]dg_1 \approx 1.086 - 0.252 = 0.834 \quad \text{(A.10)}$$

The (disgusting!) functions $q_1^*(.)$ and $w^*(.)$ are shown at the end of this paper, but their graphs, also shown, are smooth. If we instead had solved market equilibria using the generalized travel cost, we would simply have obtained the inverse demand function for x_1, i.e., $p_1^G = 1/(1+x_1)$. Then one must evaluate the time cost along the path for the wage rate and deduct the resulting amount to arrive at the desired result (1.0986 – 0.0122 – 0.252 ≈ 0.834).

The rule of half does not perform excellently in this case:

$$CV \approx \frac{1}{2}\cdot(q_1^1 + q_1^0)\cdot x_1^1 - w^0\cdot(g_1)^2 \approx \frac{1}{2}\cdot(0.326+0.994)\cdot 2 - 0.0575\cdot 4 = 1.09 \quad \text{(A.11)}$$

where $x_1^1 = g_1^1 = 2$ in equilibrium. The fit improves slightly to around 1.044 if the final equilibrium wage rate is used. This poor performance is obvious from inspection of the non-linear graph of the q_1^* - function shown below.

The exercise undertaken in this paper demonstrates that one can use different approaches to assess the social profitability of an investment. It should also be noted that we do not explicitly have to estimate the value of the gain in travel time when the HSR is introduced. However, *CV* decreases (increases) as tc_1 (tc_2) increases. Nevertheless, such an approach does not reflect the social value of a reduction in travel time. To see why, differentiate the indirect utility function or the expenditure function with respect to tc_1 to obtain:

$$dV(.) = -de(.) = dCV^{tc_1}(tc_1, \bar{g}_1) = -w \cdot x_1(.)dtc_1 = -w \cdot \left(\frac{1 - q_1 - tc_1 \cdot w}{q_1 + tc_1 \cdot w} \right) dtc_1 \quad \text{(A.12)}$$

Thus, utility (expenditure) decreases (increases) as the travel time marginally increases. To evaluate a discrete change, use equation (A.7) to solve q_1, q_2, and w as functions of tc_1 for fixed g_1, i.e., $g_1 = \bar{g}_1$, and integrate (A.12) between initial and final levels of tc_1. Alternatively, replace a fixed g_1 in equation (A.7) by a supply function for the HSR. Note that one must solve (A.7) also for q_2 although it does not appear in (A.12). This is so because in the general equilibrium CBA of the change in travel time, q_1, q_2 and w adjust to maintain balance between supply and demand in markets; holding q_2 constant would result in a disequilibrium in the market for the second commodity (and q_1 and w would not follow their general equilibrium paths).

Let us also briefly consider a joint change in capacity and travel time for an existing HSR, where travelers are delayed due to more traffic causing traffic jams or bottlenecks are eliminated reducing travel times. A first variation is to add the integrated right-hand side expression in equation (A.12) to equation (A.9), recalling that one must decide where to place the integral in the evaluation chain because (A.9) is still a line integral (and the equilibrium prices will be different when both g_1 and tc_1 change).

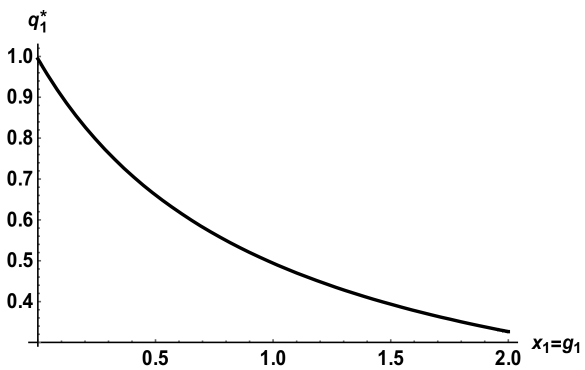
A second variation is to evaluate equation (A.10), holding tc_1 at its initial level. Next holding g_1 at its final level, evaluate equation (A.12) for the discrete change in travel time. Thus, we now evaluate a line integral. Hence, we could reverse the order of integration and arrive at the same overall compensating variation. Thus, the short-cut approach becomes a line integral in this more complex case.

A third variation assumes that the travel time is a function of capacity. Suppose that $tc_1 = 3/10 - (1/10) \cdot g_1$, i.e., $dtc_1 = -(1/10)dg_1$. Then the following expression is added to the integrand in equation (N.7):

$$-w \cdot \left(\frac{1 - q_1 - tc_1 \cdot w}{q_1 + tc_1 \cdot w} \right) \cdot \left(-\frac{1}{10}\right) \quad \text{(A.13)}$$

where $tc_1 = 3/10 - (1/10)\cdot g_1$. Suppose that g_1 increases from $g_1 = 1$ to $g_1 = 2$, while the travel time reduces from 2/10 to 1/10. The initial general equilibrium price vector equals $[q_1^0 \approx 0.488, q_2^0 \approx 0.2784, w^0 \approx 0.060]$ while the final one is the same as previously. Then $CV \approx 0.2118$, $CV^{\Delta g} \approx 0.1979$ if evaluated conditional on $tc_1 = 2/10$, and $CV^{\Delta tc} \approx 0.0139$ if evaluated conditional on $g_1 = 2$. These results are obtained by using the equilibrium paths for prices stated at the end of the paper. It is left to the reader to verify that the indirect utility function generates $CV \approx 0.2118$.

$$q_1^*(.) = \frac{1}{4}(\frac{4}{1+g_1} - 5tc_1 + \frac{60tc_1}{-117+5g_1(g_1+tc_1)} + \frac{30tc_1}{-601+25g_1(g_1+tc_1)} +$$
$$30tc_1\sqrt{-\frac{(121-5g_1(g_1+tc_1))^2(-1819+75g_1(g_1+tc_1))}{(601-25g_1(g_1+tc_1))^2(117-5g_1(g_1+tc_1))^2}} +$$
$$tc_1\sqrt{}(25+300(\frac{1}{601-25g_1(g_1+tc_1)} - \frac{2}{-117+5g_1(g_1+tc_1)} -$$
$$\sqrt{-\frac{(121-5g_1(g_1+tc_1))^2(-1819+75g_1(g_1+tc_1))}{(601-25g_1(g_1+tc_1))^2(117-5g_1(g_1+tc_1))^2}}) +$$
$$400\left(\frac{2}{-117+5g_1(g_1+tc_1)} + \frac{1}{-601+25g_1(g_1+tc_1)} + \sqrt{-\frac{(121-5g_1(g_1+tc_1))^2(-1819+75g_1(g_1+tc_1))}{(601-25g_1(g_1+tc_1))^2(117-5g_1(g_1+tc_1))^2}}\right)^2))$$



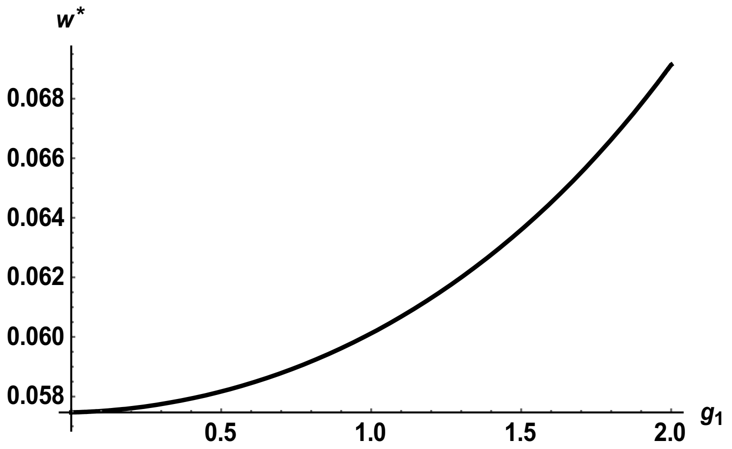
$$w^*(.)=\frac{5}{4}(1-\frac{12}{-117+5g_1\left(g_1+tc\ \right)}-\frac{6}{-601+25g_1\left(g_1+tc_1\right)}-$$

$$6\sqrt{-\frac{\left(121-5g_1\left(g_1+tc_1\right)\right)^2\left(-1819+75g_1\left(g_1+tc_1\right)\right)}{\left(601-25g_1\left(g_1+tc_1\right)\right)^2\left(117-5g_1\left(g_1+tc_1\right)\right)^2}}-$$

$$\frac{1}{5}\surd(25+300(\frac{1}{601-25g_1\left(g_1+tc_1\right)}-\frac{2}{-117+5g_1\left(g_1+tc_1\right)}-$$

$$\sqrt{-\frac{\left(121-5g_1\left(g_1+tc_1\right)\right)^2\left(-1819+75g_1\left(g_1+tc_1\right)\right)}{\left(601-25g_1\left(g_1+tc_1\right)\right)^2\left(117-5g_1\left(g_1+tc_1\right)\right)^2}})+$$

$$400\left(\begin{array}{l}\dfrac{2}{-117+5g_1\left(g_1+tc_1\right)}+\dfrac{1}{-601+25g_1\left(g_1+tc_1\right)}+\\ \sqrt{-\dfrac{\left(121-5g_1\left(g_1+tc_1\right)\right)^2\left(-1819+75g_1\left(g_1+tc_1\right)\right)}{\left(601-25g_1\left(g_1+tc_1\right)\right)^2\left(117-5g_1\left(g_1+tc_1\right)\right)^2}}\end{array}\right)^2))$$



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5 East is east and West is west? A gentle introduction to links between CGE and CBA

Bengt Kriström

5.1 Introduction

A well-known Kipling poem includes the line *East is east and West is west and never the twain shall meet?* Is the same negative sentiment true for CBA (Cost-Benefit Analysis) and Computable General Equilibrium Models (CGE)? This note suggests these two approaches are closely related, which is not quite evident from the literature on the two approaches. In fact, the literatures seem to develop in parallel, with little or no signs of cross-fertilization. Both approaches belong to the applied economists standard toolkit. CBA appears to be ideally suited for small projects, while CGE-models are typically applied to large-scale problems, not seldom involving a country or a set of countries.

In a way, CGE appears to be a way of getting out of the textbook Marshallian straitjacket, so where is the common ground? Fundamentally, both approaches aim at shedding light on whether or not a change of resource-use is for the better. Furthermore, they are based on the same theoretical underpinnings, a general equilibrium model. Most importantly, CBA is based on the theory of welfare measurement in general equilibrium and CGE is a useful way to empirical implementation of this theory.

Perhaps the most significant advantage in tying the approaches together is that the economics involved becomes more transparent. The complexity of any CGE-model used in professional contexts typically forces the user to a significant amount of arguing by analogy. There is little hope that the results produced by a large-scale model can be "understood" in any detail. Still, the typical large-scale CGE-model produces results that often appear congenial to economic intuition. Experience suggests that CGE-results at odds with basic economic intuition is a warning sign. Needless to say, the complex non-linearities of a general equilibrium model can be a challenge to economic intuition, especially for large changes. True, "anything can happen" in the most general settings. Even so, there seems to be merit in being able to predict key results of a typical CGE model-run, necessarily under some simplifying assumptions. This is the objective here and we will focus on deriving linear welfare measures in general equilibrium, using the principles of CBA. Specifically, we derive nonparametric welfare measures – linear welfare indices – and compare them with exact measures obtained from CGE model runs[1].

In order to compare the approaches, we need to agree on the objectives. For CBA, it is quite clear: CBA is a consistent methodology for assessing the welfare consequences of a project. A project is a perturbation of the economy. For CGE, one objective that has been offered is that it is a way to convert abstract models of general equilibrium theory into a practical tool for policy analysis. This is a bit too vague, perhaps, so I am going to sharpen this to add that the ultimate objective of a CGE is to assess the welfare change due to a policy. Consequently, my view is the objective of CBA and CGE is ultimately identical. What is more, both approaches derive from the same theoretical base.

Perhaps the bifurcation of the two literatures into two seemingly parallel strands can be explained by a view that the objectives are considered to be fundamentally different. CBA is, perhaps, considered to be useful for "small" projects, while it cannot be used in "large-scale" evaluations. There is some truth in the latter assertion, but this is mainly because of computational complexity, not because the approaches are fundamentally different.

A key issue that I deal with already here is "secondary market effects". A very useful aspect of CGE-modelling is that the complex market interactions are handled upfront; these are integral to the set-up of an equation system that is ultimately solved. But this does in no way mean that secondary market effects are disregarded in CBA, even though the approach is usually considered (in the textbook examples) a partial equilibrium approach. The fact of the matter is that CBA deals with the secondary market effects by definition; it is a general equilibrium approach. Indeed, depending on the project, general equilibrium welfare theory offers extremely useful simplifications. After all, the objective is to compute welfare change, the difference between utility in the status quo and the counterfactual. A correct measure is only obtained if the theory correctly represents the project.

[1] Traditionally, the change in GDP was computed and used in both CBA and CGE. The change in GDP is a linear welfare index as shown e.g., in intermediate microeconomics textbooks.

Let us now turn to a brief look at the two approaches.

5.2 CBA and CGE

Cost-Benefit analysis (CBA) is a prime candidate for project appraisal, a methodology that has been developed since the 1930s, when it was first used (in a rudimentary way) in the US. Standard intermediate textbooks include Sugden & Williams (1978). More advanced treatments are in Lesourne (1974) and Johansson & Kriström (2016). The more advanced treatments specifically begin with a general equilibrium model and derives monetary measures of welfare change in this setting.

Computable General Equilibrium (CGE) is a numerical implementation of general equilibrium analysis, routinely used by consulting firms, governments and academic economists to shed light on complex policy changes in a comprehensive manner. Textbooks include Shoven & Walley (1992) and Ginsburg & Keyzer (2002)[2]. Advances in computation and data availability have made it routine to solve multi-regional models that includes e.g., detailed carbon emission accounting. Such models are routinely combined with detailed micro-data on e.g., household expenditure patterns.

5.3 Welfare measurement

Chetty (2009) argues that there are two basic approaches to welfare evaluation; the structural approach and the reduced-form approach. He develops "sufficient statistics" in a general framework, that combines these two approaches. This is quite similar to what I do here: I derive cost-benefit rules in general equilibrium and show how these can be used as non-parametric first-order estimates of what one obtains from a large-scale Computable General Equilibrium (CGE) model. In a way, the theory allows us to "peek into the black box".

Table 1 in Chetty (2009) summarizes studies on taxes, social insurance and behavioral models, that uses structural and reduced forms, in some cases "sufficient statistics" are derived. Chetty gives the example of Feldstein, who shows "*...how the marginal welfare gain from raising the income-tax rate can be expressed purely as a function of the elasticity of taxable income even though taxable income may be a complex function of choices such as hours, training, and effort*".

[2] A list of readings on CGE-modelling is available at https://www.gtap.agecon.purdue.edu/resources/cge_books.asp

Chetty's (2009) obtains formulas that provide simple ways to compute deadweight loss of taxation allowing for optimization errors. The objective here is more modest, whence we derive welfare change formulas that can be viewed as perturbations of an underlying Arrow-Debreu type of model.

5.4 CBA and CGE – a comparison

In a typical CBA, a public firm extracts resources from the economy within a project, e.g., an infrastructure investment. The project is a perturbation of the economy. Any changes of an equilibrium must come from exogenous forces. This means that the public firm is considered to be an exogenous parameter that "generates" the change.

The project passes a cost-benefit test if utility is higher with the project, compared to the utility in the status quo. To derive such a test, a cost-benefit rule is a way of delineating the benefits and the costs that arise due to the project. In the typical case, it is a linear welfare index, so that the inputs and the output quantities used by the project are scaled by suitable prices. These prices can be observed market prices or shadow prices. The approach here is based on observable prices, for an alternative see Dreze & Stern (1982) that is based on shadow prices.

In the case of a CGE-model, we interpret baseline economic data (typically from the national accounts) as a general equilibrium. The CGE-model parameters are ordinarily obtained by calibrating preference and technology to this observed "point". There are other ways to obtain the preference and technology parameters, but the conceptual idea remains the same.

First of all, the calibrated model should replicate the benchmark. This means that all the accounting identities hold and that the conditions for equilibrium are fulfilled. The calibrated CGE-model is then perturbed by changing some exogenous parameters, such as taxes, and the new equilibria are then compared to the benchmark. The sense in which the new equilibria are better or worse than the status quo is often summarized by measures such as equivalent variation (EV).

As noted, a traditional linear welfare index is the change in GDP, an idea used both in CBA and CGE. This idea has a backing in theory, but the change in GDP is typically not an exact welfare measure. Therefore, CGE-models now routinely report EV.

While CBA is typically considered to be a method that looks at "small projects", there is no such limitation from a theoretical point of view. A CGE typically involves "large" projects, which in terms of welfare measurement means that a line-integral needs to be assessed when computing e.g., EV. The difference between a "small" and "large" project is subtle. For the purposes of this paper, if the welfare consequences of a project are well-approximated by a first-order Taylor approximation of the indirect utility function, then it is "small". If not, it is "large". The "small" project involves marginal price changes, while the "large" allows for non-marginal changes. This definition is somewhat arbitrary, but is sufficient for this paper.

Next, we derive cost-benefit rules for the simple possible general equilibrium model. The idea is that we can use these rules to get an idea of the welfare measures obtained from a CGE-model [3]. A key insight in the CBA-literature on general equilibrium welfare measurement is that the competitive economy allows for extremely useful simplifications, when deriving welfare measures. Thus, while a project might change the quantities and prices in all markets in an arbitrarily large economy, it is often sufficient to look at the market where the change originated. For example, introducing a tax on one good and returning the revenues will change welfare, but it is often sufficient to look at the market where the change took place. The Marshallian welfare analysis is a good approximation even in general equilibrium for this case. For a proof of this assertion, see Johansson & Kriström (2016).

Of course, if we are in a 2nd-best or even 3rd-best world, intuition is hampered by the complexity of the evaluation. 2nd-best theory tells us that projects that returns the economy to the production frontier are not necessarily preferred to an allocation inside the production boundary. Such cases can be handled by both methods, but will necessarily involve additional assumptions. For example, if there is unemployment, the wage does no longer measure the opportunity cost, and we need to proceed in ways to cater for this fact. Indeed, if there are different levels of unemployment in different sectors, the situation is considerably more complicated. My experience is that both CBA and CGE analysts use perfect competition as a useful benchmark, adding complexity when the case under study requires it. In my illustrations, I will keep it as simple as possible.

[3] In a companion paper, I go through the same mechanics for a tax-swap case

5.5 Cost-benefit rules in general equilibrium

The workhorse that we use to link CBA and CGE are general equilibrium cost-benefit rules. These are explained in advanced textbooks, such as Johansson & Kriström (2016). Because these may be unfamiliar, we will explain them at some length using the simplest possible model. We will then run the same analysis through a numerical CGE-model.

5.5.1 The simplest case: The exchange economy

It will be useful to derive cost-benefit rules in an exchange economy. To avoid complications when it comes to aggregating welfare change over households, we proceed as if there is only one household. Let $V(p, m)$ be an indirect utility function, where p is a price-vector and m is income. Classic microeconomic theory tells us that V is (given standard assumptions on the direct utility function) continuous and quasiconvex in p,m, decreasing and strictly quasiconvex in p, increasing in m, zero degree homogenous in p, m and Hotelling's lemma (Roy's identity) holds.

Let i index goods and $i \geq 2$, with corresponding endowments $e_i \geq 0$ and demands x_i^d, where $x_i \leq e_i$ in equilibrium. When $x_i^d > e_i$, the individual is a net buyer and conversely if the person is a seller. Because there is only one person involved, this is somewhat artificial. But no essential economic insights are obtained by adding additional indices.

Income is $m = \sum p_i \cdot e_i = \sum p_i x_i$. Consider the welfare impact of the perturbation $de_j > 0, de_i = 0$ for some $j \neq i$. Totally differentiating the indirect utility function, using Hotelling's lemma and then dividing through by $\lambda = \frac{\partial V}{\partial m}$ yields

$$\frac{dV}{\lambda} = dEV = \sum (e_i - x_i^d) dp_i + p_j de_j \tag{1}$$

Thus, when $de_j = 0$, we are in a first-best general equilibrium allocation with supply equal to demand in all markets. It also follows that we do not need to consider what happens in each of the markets. In equilibrium, these effects net out and we are left with the value of the change of the endowment.

Suppose that $e_1 = e_2 = 12$ and $p_1 = p_2 = 1$ in the initial equilibrium. If the direct utility function is $x_1 \cdot x_2$, we have $v = \frac{m^2}{4 \cdot p_1 \cdot 1} = \frac{(p_1 e_1 + e_2)^2}{4 \cdot p_1 \cdot 1}$ so that the perturbation $de_1 > 0, de_2 = 0$ yields

$$\frac{dv}{\lambda} = p_1 \cdot de_1 = 1 \cdot de_1 \tag{2}$$

which is quite intuitive. Let the consumer have an endowment of 12 apples and 12 pears and perturb the economy by adding an apple to his endowment. Given Cobb-Douglas utility, budget shares will be constant, so that with constant prices $x_1^d = x_2^d = \frac{25}{2} = 12.5$. In other words, half of the endowment increase is consumed and half of it is traded to make room for the consumption of one extra half of a pear. Therefore, it seems reasonable to assert that the value to this consumer of the perturbation is proportional to the change in the endowment, valued at initial prices.

Utility increases from 144 to 156.25 (if the consumer chooses to eat the apple without trading, utility would increase to $13 \cdot 12 = 156$). To convert the welfare change to money we divide by the marginal utility of money, which is $\frac{1}{2} \cdot 24 = 12$ in the status quo. Therefore, marginal willingness to pay is 1.02 at the status quo parameter values. EV, the exact value, is 1. The linear measure faces the problem that the “exchange rate” is not constant throughout the change, i.e., the marginal utility of money changes from 12 to 12.5. If we choose a middle value of 12.25 for this changing parameter, our linear index would give a value of 1, which is the correct value. Of course, in practice we do not know the “correct” utility function and can take the view that our linear index is a non-parametric approximation to the true welfare change.

5.5.2 A CGE-model

Let us further illustrate the ideas above, using a standard Cobb-Douglas (CD) style CGE- model, with 2 sectors using capital (*K*) and labor (L). Thus, preferences and technology are CD. Assume that we initially observe in sectors 1,2 a total of $12 = \overline{K} = K_1 + K_2$ and $12 = \overline{L} = L_1 + l_2$. In the ex ante equilibrium, assume that $K_1 = 8, L_1 = 4$, i.e. sector 1 is capital intensive and vice versa. Furthermore, initially, demand is $x_1 = 12, x_2 = 12$ so that income is 24, prices are set to 1 in the initial equilibrium. In a CGE-model, the technology and preference parameters are then calibrated so that we can replicate the status quo with this data. This is particularly easy when we have a Cobb-

Douglas economy. We need to decide upon a numeraire, a choice that will make no difference in this case.

In line with the above, consider the perturbation $d\overline{K} > 0, d\overline{L} = 0$. We evaluate the reform using EV. In the standard theory, EV is implicitly given by

$$V(p^1, m^1) = V(p^0, m^0 + EV) \tag{3}$$

Because it is more convenient to work with expenditures and cost-functions in CGE, define $\Delta m = m^1 - m^0$, and $EV = \Delta m + e(p^0, u^1) - e(p^1, u^1)$, where $e(\bullet)$ is the expenditure function and u^1 is the utility level in the ex post situation. Add and subtract $e(p^0, u^0)$ and assume that the utility function is homothetic and let $u^0 = 1$ to find that

$$EV = m^0 \cdot (u^1 - 1) \tag{4}$$

so that EV is just a scaled version of income in the status quo, proportional to the utility change. EV is reported directly in standard programs such as MPSGE.

We will compute EV and the linear approximation for a series of small projects. The computer code using MPSGE is in the appendix. If the utility function is $u = x_1 \cdot x_2$, we can solve for EV in equation (3), to obtain

$$EV = m^1 - \frac{m^0}{\sqrt{p_1^1}} \tag{5}$$

where $m^i, i = 0{,}1$ is the income at the status quo and the new prices (with the numeraire $p_2 = 1$). It is an exact money measure of the underlying utility change.

Recall that the numeraire is x_2 and that preferences as well as technology are homothetic. We thus expect consumption of both goods to increase, the more so in the capital-intensive sector; the relative price of good 1 is expected to increase, since it is produced in the relatively labor-intensive sector. All these intuitions are borne out by the simulation.

The results of the simulation is recorded in table 1.

Table 1. Simulation results a 2-by-2-by-1 Cobb-Douglas general equilibrium model, with $\overline{K} = \overline{L} = 12$ *and* $x_1^d = x_2^d = 12$ *in the initial equilibrium. The perturbation is* $\Delta\overline{K} = 12 \cdot (1 + indx/100)$*, indx=1..10.*

indx	scale	$\frac{dV}{\lambda}$	EV	% error EV	Δp_1
1	1.00	–	–	–	–
2	1.01	0.12	0.120	0.249	0.003
3	1.02	0.24	0.239	0.495	0.007
4	1.03	0.36	0.357	0.739	0.010
5	1.04	0.48	0.475	0.980	0.013
6	1.05	0.60	0.593	1.220	0.016
7	1.06	0.72	0.710	1.457	0.020
8	1.07	0.84	0.826	1.691	0.023
9	1.08	0.96	0.942	1.924	0.026
10	1.09	1.08	1.057	2.154	0.029

For small changes of $\overline{K}$, which in this example is up to a 9% increase, the "non-parametric" welfare measure appears to do reasonably well. It also appears that the linear approximation is an upper bound, which is quite intuitive. This assertion can be demonstrated by using a first-order approximation of the expenditure function, to obtain the inner and outer Hicksian bounds.

5.6 Conclusion

The point of these examples is that we can get some intuitive ideas about what to expect from a CGE-model, when looking at a certain policy. Note how the equilibrium assumptions simplifies the analysis. While labor and capital were exogenous in the second example, there was no need to keep track of the prices of capital and labor adjustments. Had we assumed flexible labor and capital markets, our final welfare measure would not change.

When we ran the CGE-model, there was no need for approximations, the line-integral is computed internally. We could easily have obtained EV for a non-marginal project by integration when we developed the CBA rules. It would again have resulted in substantial simplifications that helps intuition.

Finally, I have intentionally left out a series of contentious issues, since my point is to suggest that "east really is close to west", CGE and CBA really are tightly related. It follows almost immediately that we can extend the simple (2-by-2-by-1) model in various directions. As noted, in a companion paper, I look at the Bovenberg -de Mooij (1994) model of modelling "double-dividend" in general equilibrium. In this case, we start with a tax-ridden economy and perturb the taxes so that tax-revenue is the same in the counterfactual, increasing a tax on a bad and lowering it on a good. What Bovenberg -de Mooij (1994) obtains is a cost-benefit rule in general equilibrium (although they do not use this name). If we are able to assume that the most important change of a project will remain isolated in a certain sector of the economy, the multi-market welfare measurement is useful. Here part of the economy is left exogenous and one can proceed with the same basic idea as above, see Just et al (2005). There are many other extensions to dynamics, uncertainty, distributional issues and so on analyzed e.g. by Johansson & Kriström (2016). My view is that such analysis can be useful as a precursor to running a large-scale CGE-model, because CBA and CGE originate from the same theoretical root: Arrow-Debreu.

Technical appendix

In this technical appendix, the welfare measure is derived in more detail. In addition, two computer programs for replication of the results are listed.

Welfare measure

We have in equilibrium

$$V(\mathbf{p}^*, m^*) \tag{6}$$

where $m = m^* = p_1 \cdot x_1 + x_2 = \sum \Pi^i + r\overline{K} + w\overline{L}$. Consider the pertubation $\overline{dK > 0}, d\overline{L} = 0$, i.e. an increase of the capital endowment. We assume that the markets are in equilibrium $x_i^d = x_i^s, \overline{K} = K_1 + K_2, \overline{L} = L_1 + L_2$ throughout the change. To convert the induced utility change dV from the perturbation, we convert into money by dividing dV with $\lambda = \frac{\partial V}{\partial m}$

Thus, compute the total differential dV to obtain

$$dV = -\sum \lambda x_i^d dp_i + \lambda \cdot dm \tag{7}$$

according to Hotelling's lemma. Next we need to compute dm, which is endogenous. Thus, consider $d\left(\sum \Pi^i + r\overline{K} + w\overline{L}\right)$ and again employ Hotelling's lemma, to obtain the supply and demand functions on the firm side. The profit-functions can be written as $\Pi^i(p,r,w)$,i=1,2, so that $\frac{\partial \Pi^i}{\partial p_i} = x_i^s$, $\frac{\partial \Pi^i}{\partial w} = L_i^d$ and $\frac{\partial \Pi^i}{\partial r} = K_i^d$. We have

$$\begin{aligned} \frac{dV}{\lambda} &= \sum\left(x_i^s - x_i^d\right)dp_i + \\ &\left(\overline{K} - \sum K_i^d\right)dr + \left(\overline{L} - \sum L_i^d\right)dr + \\ &r \cdot d\overline{K} + w \cdot d\overline{L} \\ &= r \cdot d\overline{K} + w \cdot d\overline{L} \end{aligned} \tag{8}$$

This result is quite intuitive. The first two lines record the equilibrium conditions, where we have assumed the demand is equal to supply for all goods and services. This implies that if markets cannot equilibrate, there is a welfare loss to be added. Furthermore, profit maximization means that price = marginal cost, an equality that holds throughout the change. Consequently, if price is not equal to marginal costs, as in imperfect competition, there is also a welfare loss to be added to the welfare measure.

If $d\overline{K} = d\overline{L} = 0 \rightarrow \frac{dV}{\lambda} = 0$, then the initial equilibrium is Pareto-optimal. If $d\overline{K} > 0 d\overline{L} = 0$, we recover the result in the text. In addition, the result reminds us that prices are endogenous in a general equilibrium model. The partial equilibrium idea of exogenously changing a price and compute its welfare impact has no counterpart in general equilibrium. We can prove this by considering the perturbation $dp_i \neq 0$, which yields $\frac{dV}{\lambda} = 0$ in equilibrium.

Finally, let us consider the approximating features of our linear welfare measure using a heuristic argument. Consider $V(p^1, m^1) - V(p^0, m^0 + EV) = 0 \approx -\lambda x^d \Delta p + \lambda(\Delta m - EV) = 0$ so that $EV = x^d \Delta p + \Delta m$ If we take $\Delta m \approx 0$ for simplicity, then EV is the change in expenditures, conditional on the level of demand. This is an upper bound, since the individual typically will reduce consumption when own-prices change. The gist of this heuristic argument is that a linear welfare measure does not cater for all of the possible adjustment possibilities available to a household.

MPSGE

```
scalar kscale /1/;
parameter reportEV(*,*);

$ontext
$model:simple
$sectors:
w
x1
x2

$commodities:
px1
px2
pk
pl
pw

$consumers:
ra

$prod:x1 s:1
o:px1 q:12
i:pl q:8
i:pk q:(4)

$prod:x2 s:1
o:px2 q:12
i:pl q:4
i:pk q:(8)

$prod:w s:1
o:pw q:24
i:px1 q:12
i:px2 q:12

$demand:ra s:1
d:pw q:24
e:pl q:12
e:pk q:(12*kscale)

$report:
v:l1 i:pl prod:x1
v:l2 i:pl prod:x2
v:k1 i:pk prod:x1
v:k2 i:pk prod:x2
v:x1d i:px1 prod:w
v:x2d i:px2 prod:w
v:welf o:pW prod:W

$offtext
$sysinclude mpsgeset simple
$include simple.gen
SOLVE simple USING MCP;

set scalelevel /1*10/;
loop(scalelevel,
kscale=1+(ord(scalelevel)-1)/100;
$include simple.gen
solve simple using mcp;
reportEV(scalelevel,”dvbyl”)=(12*(kscale-1));
reportEV(scalelevel,”EV2”)=(W.l-1)*24;
reportEV(scalelevel,”dp1”)=(px1.l-1);
reportEV(scalelevel,”scaleupk”)=kscale;
reportEV(scalelevel,”EV% error”
$reportEV(scalelevel,”dvbyl”)=100* (reportEV(scalelevel,”dvbyl”)-
reportEV(scalelevel,”EV2”))/reportEV(scalelevel,”dvbyl”);
display reportEV;
```

R

```
rm(list = ls())
library(readxl)
library(kableExtra)
EV=read_excel(''results.xlsx'')
names(EV)=c(”indx”,”dvbyl”,”EV2”,”dp1”,”scale”,”EV% error”)
EV=EV[,c(1,5,2,3,6,4)]
names(EV)=c(”indx”,”scale”,”dvbyl”,”EV2”,”EV% error”,”dp1”)
kbl(EV,format=”latex”,digits=3)
```

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

Emile Quinet

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:

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

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)

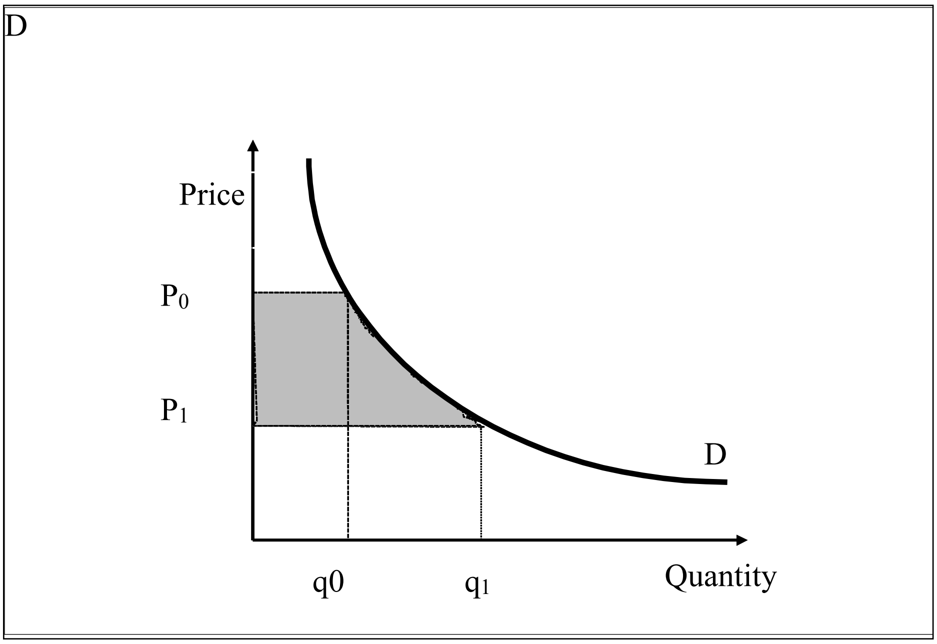
[2] Which is rigorous under some currently-made simplifying assumptions (for example, assuming a quasi-linear utility function) and if only the price of one good changes.

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).

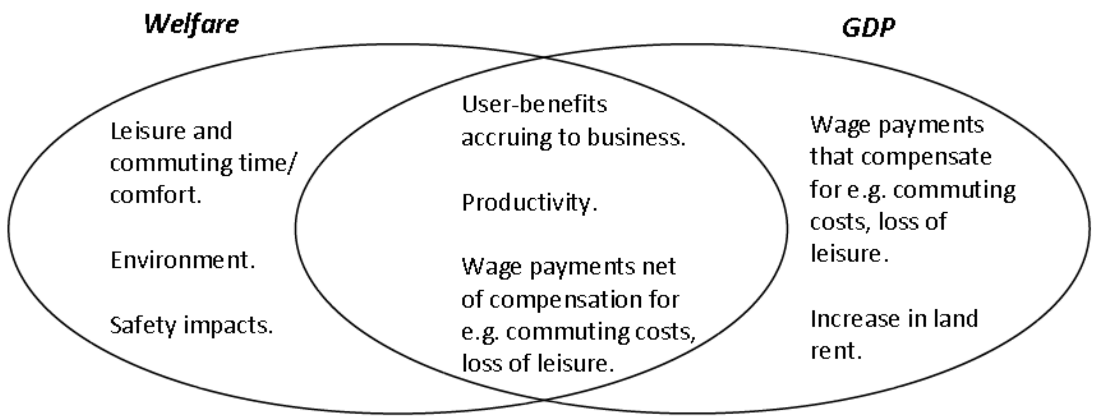
6.3 The shortcomings of current practice of CBA

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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7 On the compatibility between CGE and CBA for project appraisal

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7.1 Introduction

This paper seeks a better understanding of the implications of employing Computable General Equilibrium (CGE) for project appraisal and its compatibility with Cost-Benefit Analysis (CBA). In this sense, it should be remembered that CGE and CBA models draw on the same economic theory, but employ different approaches. CGE models have predominantly focused on quantifying the economic effects of different policies in terms of Gross Domestic Product (GDP), inflation, sectoral changes, government surplus/deficit, unemployment, or current accounts (surplus/deficit); rather than welfare evaluation analysis, as is central in CBA.

This study provides a way to measure welfare impacts with CGE and discusses why and if so, how much, it may diverge with respect to CBA. The following cases are modelled: labour market with voluntary unemployment; labour market with involuntary unemployment, derived demand; derived demand with involuntary unemployment; derived demand with a negative externality; derived demand with non-competitive markets and a final model assuming different CGE *model closures*.

Impact assessment studies such as CGE need to be aware of the multiplier effects caused by any shock in the economy. Such effects need to be evaluated with respect to a counterfactual scenario, otherwise they may provide results with a positive bias in welfare terms. This paper discusses the role played by counterfactual scenarios for project appraisal with CGE. Finally, most of the cases are extended to an open-economy framework to check the consistency of the results and conclusions under this kind of scenario.

The theoretical approach is complemented with numerical examples for each model and extended to open-economy situations. Specifically, six examples are considered: labour market with voluntary unemployment; labour market with involuntary unemployment; derived demand; derived demand with involuntary unemployment; derived demand with a negative externality; and derived demand with non-competitive markets. As expected, the results confirm the theoretical supposition, highlighting that CGE can incorporate any of the opportunity costs stressed by CBA.

The remainder of the paper is organized as follows. Following this introduction, Section 7.2 starts demonstrating (theoretically) that CGE can handle certain market situations stressed in CBA. In Section 7.3, the four market situations (voluntary unemployment, involuntary unemployment, derived demand and externalities) are described; highlighting all aspects that the CGE model should capture from a welfare CBA perspective. In Section 7.4, a theoretical approach is developed to illustrate how show the way CGE can deal with welfare appraisal. Similarly, the main theoretical issues of concern are also addressed here to anticipate economic situations considered in a CGE framework to capture the welfare changes. In Section 7.5, the numerical examples are explained and simulated, together with the CGE counterfactual analysis. In Section 7.6, the relevance of the CGE counterfactuals is explained for welfare appraisal. Finally, the main findings and results are addressed in the divergence analysis section.

7.2 The foundations of the C-Bridge

This section starts "*bridging CBA and CGE"* (C-Bridge) by demonstrating theoretically that CGE can handle the market situations highlighted in CBA. This implies that, among other aspects, all economic changes that concur in the *primary* markets are implicitly included in the final demand of the representative/s household/s. The section demonstrates that the welfare change can be approached by income differences, with and without the project, by employing: *the Income Welfare Approach (IWA)*. Finally, the section highlights and demonstrates a series of theoretical issues of concern when conducting welfare analysis under CGE modelling. Furthermore, the theoretical consequences, in terms of welfare, of assuming multiple households and different *model closures* are explored.

7.2.1 Bridging CBA and CGE: a theoretical model

This section aims to show that the myriad of welfare variations that take place in different markets, as noted by CBA, are all captured in the final demand decision of the representative household when modelling the economy in CGE. Hence, the appraisal followed in CGE models can capture the welfare variations triggered by a project.

We start by eliciting one of the central assumptions in CGE models: the market clearance condition. This assumes that, in equilibrium, the quantities demanded equal the quantities supplied for all i markets, such as:

$$Demand_i = Supply_i \qquad (1)$$

7.2.1.1 Closed economy without government

Let's assume a closed economy without government, one representative household, and two factors of production (K and L), without intermediate demands. The supply-side of the market clearance condition (equation 1) can now be represented more succinctly as $Supply_i = Y_i = F_i(K_i, L_i)$, where the supply/production of good (i) depends positively on the factors of production (K_i and L_i), which are combined according to the technology (F_i), to produce good i. Similarly, the demand-side depends positively on income level (M) and negatively on prices (P_i).

$$D_i(M, P_i) = Y_i = F_i(K_i, L_i) \qquad (2)$$

Assuming that the production function $F_i(K_i, L_i)$ is a homogenous function, then $F_i(K_i, L_i)$ can be decomposed into demand for the factors of production as follows: $tF_i(K_i(r, P_i), L_i(w, P_i)) = \frac{\partial F_i(K_i(r,P_i),L_i(w,P_i))}{\partial K_i} K_i + \frac{\partial F_i(K_i(r,P_i),L_i(w,P_i))}{\partial L_i} L_i$,

where $\frac{\partial F_i(K_i,L_i)}{\partial L_i} = \frac{W}{P_i} = w$ and $\frac{\partial F_i(K_i,L_i)}{\partial K_i} = \frac{R}{P_i} = r$, where W and R denote wages and the cost of capital, respectively, while w and r denote the respective real values, and t the degree of homogeneity. Let's assume for simplicity that $t = 1$. Thus, equation $Y_i = F_i(K_i, L_i)$ can be written as: $Y_i = rK_i + wL_i$ and equation (2) stands now as follows:

$$D_i(M, P_i) = Y_i = F_i(K_i, L_i) = rK_i + wL_i \qquad (2.1)$$

By multiplying both sides of equation (2.1) by the respective market prices and adding over i goods/services, it yields:

$$\sum_{i=1}^{n} D_i(M, P_i)\, P_i = \sum_{i=1}^{n} Y_i\, P_i \quad (3)$$

where $\sum_{i=1}^{n} D_i(M, P_i)\, P_i$ represents the total expenditure (E) and $\sum_{i=1}^{n} Y_i\, P_i = (r \sum_{i=1}^{n} K_i + w \sum_{i=1}^{n} L_i) P_i$ the total income constraint in nominal terms (M). Hence, when the circular flow of income holds, the change that takes place in one market is finally captured in the income constraint of the representative household[1].

Let's take the case of the development of an economic project. We distinguish between two situations: 0 and f, which represent the initial equilibrium without the project (0) and the final equilibrium when the project has been implemented (f). Moreover, let the income level M vary between both equilibria. Now, equation (2.1) can be disentangled as follows:

$$D_i^0(M^0, P_i^0) = r^0 K_i^0 + w^0 L_i^0 \quad (3.1)$$

$$D_i^f\left(M^f, P_i^f\right) = r^f K_i^f + w^f L_i^f \quad (3.2)$$

Adding equations (3.1) and (3.2) by goods yield. the respective Walrasian equilibrium (Varian, 1992) is:

$$\sum_{i=1}^{n} D_i^0(M^0, P_i^0) = \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r, P_i), L_i(w, P_i))}{\partial K_i} K_i^0 + \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r, P_i), L_i(w, P_i))}{\partial L_i} L_i^0 \quad (3.3)$$

$$\sum_{i=1}^{n} D_i^f\left(M^f, P_i^f\right) = \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r, P_i), L_i(w, P_i))}{\partial K_i} K_i^f + \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r, P_i), L_i(w, P_i))}{\partial L_i} L_i^f$$

(3.4)

Multiplying the right-hand side of equations (3.3) and (3.4) by the respective market prices yields expenditure levels, such as: $E_0 = \sum_{i=1}^{n} P_i^0 D_i^0(M^0, P_i^0)$ and $E_f = \sum_{i=1}^{n} P_i^f D_i^f(M^f, P_i^f)$.

Similarly, by multiplying the left-hand side of these equations by their respective prices of factors (wage and price of capital) generate income levels (income constraints), such as: $M_0 = \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r, P_i), L_i(w, P_i))}{\partial K_i} K_i^0 + \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r, P_i), L_i(w, P_i))}{\partial L_i} L_i^0$,

[1] The demonstration can easily be relaxed to include more than one representative household with identical and homogenous tastes. In this case, the welfare variation is obtained by adding the respective equivalent variations. Instead of assuming identical and homogenous tastes, Deaton and Muellbauer (1980) opt for a weaker assumption by considering that all consumers have income-expansion paths that are linear and parallel (Engle´s curves).

and $M_f = \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r,P_i),L_i(w,P_i))}{\partial K_i} K_i^f + \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r,P_i),L_i(w,P_i))}{\partial L_i} L_i^f$.

Finally, subtracting equation (3.3) from (3.4) we obtain that:

$$E_0 - E_f = M_0 - M_f \quad (3.5)$$

In essence, equation (3.5) shows that successive changes that may take place in one market (the primary market) affect the whole economy. And thus, they are included in the representative agent's expenditure functions.

However, the project's magnitude of the project is not the only factor that affects income level in the economy. For instance, the public sector not only demands goods and services, but also collects taxes and transfers social subsidies to households, which affects the income of the economy. Similarly, in an open-economy setting, the economy not only generates an inflow (imports) and outflow (exports) of goods and services with the rest of the world; but also affects the disposal income of the economy by paying and selling such imports and exports, respectively: which, in turn, affects the current account deficit or surplus. Hence, social welfare must be extended to include the aforementioned income effects in the economy.

7.2.1.2 Open economy with government

Now the total demand of the economy is also composed of export demand (X) and government demand (D^G), and household demand (D^H). Similarly, the supply-side is extended because of imports[2] (m). In sum, and differentiating again between the initial and final equilibrium yields the following demand and supply expressions:

$$D_i^0(M^0, P_i^0) = D_i^{H,0}(M^{H,0}, P_i^0) + D_i^{G,0}(M^{G,0}, P_i^0) + X_i^0$$

$$Y_i^0 = F_i^0(K_i^0, L_i^0, m_i^0) = r^0 K_i^0 + w^0 L_i^0 + m_i^0$$

$$D_i^f(M^f, P_i^f) = D_i^{H,f}(M^{H,f}, P_i^f) + D_i^{G,f}(M^{G,f}, P_i^f) + X_i^f$$

$$Y_i^f = F_i^f(K_i^f, L_i^f, m_i^f) = r^f K_i^f + w^f L_i^f + m_i^f$$

Since $D_i^0(M^0, P_i^0) = Y_i^0$ and $D_i^f(M^f, P_i^f) = Y_i^f$, then:

$$D_i^{H,0}(M^{H,0}, P_i^0) = r^0 K_i^0 + w^0 L_i^0 + m_i^0 - X_i^0 - D_i^{G,0}(M^{G,0}, P_i^0) \quad (3.6)$$

[2] It should be noted that upper-case denotes income; whereas lower-case refers to imports.

$D_i^{H,f}\left(M^{H,f}, P_i^f\right) = r^f K_i^f + w^f L_i^f + m_i^f - X_i^f - D_i^{G,f}\left(M^{G,f}, P_i^f\right)$ (3.7)

Adding equations (3.6) and (3.7) by goods we obtain that:

$$\sum_{i=1}^{n} D_i^{H,0}(M^{H,0}, P_i^0) = \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial K_i} K_i^0 + \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial L_i} L_i^0 + \sum_{i=1}^{n} \frac{\partial F_i^0(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial IM_i} m_i^0 - \sum_{i=1}^{n} \frac{\partial F_{EX_i}^0(Y_i)}{\partial Y_i} Y_i^0 - \sum_{i=1}^{n} D_i^{G,0}(M^{G,0}, P_i^0) \qquad (4.1)$$

with $F_{EX_i}(Y_i)$ denoting exports production.

$$\sum_{i=1}^{n} D_i^{H,f}\left(M^{H,f}, P_i^f\right) = \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial K_i} K_i^f + \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial L_i} L_i^f + \sum_{i=1}^{n} \frac{\partial F_i^f(K_i(r,P_i),L_i(w,P_i),IM_i(Pm_i,P_i))}{\partial IM_i} m_i^f - \sum_{i=1}^{n} \frac{\partial F_{EX_i}^f(Y_i)}{\partial Y_i} Y_i^f - \sum_{I=1}^{n} D_i^{G,f}\left(M^{G,f}, P_i^f\right) \qquad (4.2)$$

Multiplying both sides of equations (4.1) and (4.2) by their respective market prices, we obtain the respective expenditure and income functions (income constraints), such that:

$E_0^H = RF_0 + ca_0 - G_0 = M_0$ (4.3)

$E_f^H = RF_f + ca_f - G_f = M_1$ (4.4)

where M_0 is now composed by the rent of labour and capital ($RF_0 = \sum_{i=1}^{n} \frac{\partial F_i^0(K_i,L_i,IM_i)}{\partial K_i} K_i^0 + \sum_{i=1}^{n} \frac{\partial F_i^0(K_i,L_i,IM_i)}{\partial L_i} L_i^0$), the current account position ($ca_0 = \sum_{i=1}^{n} \frac{\partial F_i^0(K_i,L_i,M_i)}{\partial M_i} M_i^0 - \sum_{i=1}^{n} \frac{\partial F_{EX_i}^0(Y_i)}{\partial Y_i} Y_i^0$) and finally, the total public spending ($G_0 = \sum_{i=1}^{n} D_i^{G,0}(M^{G,0}, P_i^0)$). Similarly, RF_f, ca_f and G_f denotes the counterpart of the previous expressions, but in relation to the final equilibrium (f).

Subtracting (4.3) from (4.4) yields:

$E_f^H - E_0^H = (RF_f + ca_f - G_0) - (RF_0 + ca_0 - G_f)$ (4.6)

Equation (4.6) is equivalent to equation (3.5) but assumes an open economy with the government. Hence, as noted, both equations are based on showing that the welfare change enhanced by a project can be calculated by focusing directly on final demand, omitting the successive changes that occurred in the economy's other markets.

7.2.2 Approaching the equivalent variation by income variation: the income welfare approach (IWA)

An additional result in terms of welfare is implicit when analyzing equations (3.5) and (4.6): *"the welfare variation, measured by the equivalent variation, can also be calculated by analyzing the changes that take place in the income constraint"*. The formal demonstration is addressed below.

Proposition: *The Equivalent Variation (EV) can be approached by the difference between the income level before and after the project's implementation, in a general equilibrium framework.*

Proof:

Let's begin by eliciting the mathematical expression of the equivalent variation:

$EV = e(P^0, U^f) - e(P^0, U^0)$

where superscript 0 and f denote the situation with and without the project, respectively, and e represents an expenditure function that depends on prices (P) and utility level (U). Through the circular flow of income, total expenditure equals total income, such that: $e(P^0, U^0) = M^0$ and $EV = e(P^0, U^f) - M^0$.

By taking into account that the expenditure function is separable into prices and utility, then $e(P^0, U^f)$ can be rewritten as $e(P^0)U^f$, such that:

$EV = e(P^0)U^f - M^0$

Both $e(P^0)$, which denotes the consumer price index, and M^0 are known, whereas utility level U^f remains unobservable[3]. Fortunately, its values can be retrieved from a standard maximizing utility problem, where the problem's first-order condition can be written as:

[3] This is also unobservable; however, it is embedded within M^0.

$$\frac{\partial U}{\partial X_i} = \frac{P_{X_i}}{P_U}$$

Adding the first-order condition by goods, it yields:

$$\sum_{i=1}^{n} \frac{\partial U}{\partial X_i} = \sum_{i=1}^{n} \frac{P_{X_i}}{P_U}$$

Since utility is a homogenous function, according to the Euler theorem, we can obtain that: $\sum_{i=1}^{n} \frac{\partial U}{\partial X_i} = \frac{tU}{\sum_{i=1}^{n} X_i}$, where t denotes the degree of homogeneity[4]. Hence, substituting the previous expression $\sum_{i=1}^{n} \frac{\partial U}{\partial X_i} = \sum_{i=1}^{n} \frac{P_{X_i}}{P_U}$ and rearranging it, yields $U = \frac{\sum_{i=1}^{n} X_i P_i}{tP_U}$, which means that the utility level equals expenditure level ($\sum_{i=1}^{n} X_i P_i$) in real terms ($M^f = \frac{\sum_{i=1}^{n} X_i P_i}{tP_U}$). Replacing U^f with the latter expression in the equivalent variation, yields that:

$EV = e(P_0)M^f - M^0$.

Assuming that the initial prices equal 1[5] in the equilibrium, then this implies that $e(P_0) = 1$.

Hence, $EV = M^f - M^0$ [6].

This result coincides with Johansson (2022) when deriving general equilibrium cost-benefit rules for large projects through expenditure functions. Likewise, it is also comparable to the approach used by Johansson and Kriström (2016) when employing the indirect utility function to conduct welfare evaluations in CBA.

Further, it is worth highlighting that the result holds under any economic or market situation (involuntary unemployment, non-competitive markets[7], existence of a

[4] In general, the production function is assumed to be homogenous of degree 1 ($t = 1$).
[5] It should be noted that assuming initial prices different to 1 implies a monotonic transformation of M^f and M^0, but the EV does not vary.
[6] The demonstration can be easily relaxed to include more than one representative household. In this case, the welfare variation is obtained by calculating the total equivalent variation of all households considered. Likewise, when assuming an economy with a public sector, its equivalent variation should also be considered in the total equivalent variation (see Section 7.6).
[7] In essence, involuntary unemployment is already reflecting a non-competitive market situation.

government or an open economy framework, among others), except when assuming negative externalities, as shown below.

7.3 The implications of distortions for the C-Bridge

The presence of distortions in the economy is the main source of potential divergences between CGE and CBA. In this paper we study the distortions caused by voluntary unemployment, involuntary unemployment, derived demand and externalities. We formally extend the analysis by highlighting, and anticipating, the main theoretical issues of concern when dealing with some of these situations in a CGE framework. This Section explains the underpinnings of such distortions.

7.3.1 Derived demand

CBA provides a convenient shortcut when the project under analysis causes a reduction in the cost of an input employed by other sectors in the economy. If the markets operate in a competitive environment without distortions, the analysis should concentrate on the input market to calculate the social welfare; thereby avoiding double-counting (de Rus, 2021). Alternatively, the welfare analysis may focus on output instead of input markets, yielding the same welfare result. However, in real case situations, it is easier to collect information in the input market instead of collecting information in all markets affected by the cost reduction.

The use of the primary market where the first effect of the project occurs is not restricted to the case of an input derived demand. Observed demand in one market concentrates valuable economic information of multiple effects in other markets. For instance, in the case of substitution effects in other markets (secondary markets) with price changes, Boardman, Greenberg, Vining and Weimer (2018) show how observed demand in the primary market correctly captures the substitution effect between the primary market and other markets.

From a CGE perspective, derived demand does not seem to provide any shortcut, since this approach requires the whole economy to be modelled. Besides, regarding welfare, CGE models focus on the output markets (representative household). Thus, once again the question is whether, in the case of derived demand, a CGE model correctly evaluates the welfare impact of a project by concentrating on final demand, or if it eventually results in double-counting by not drawing a distinction between economic impacts and welfare changes.

Derived demand is demand for a factor of production that occurs as a result of the demand for another intermediate or final good. If the project under analysis causes, for instance, a reduction in the cost of an input employed by other sectors in the economy, then the welfare impact can be measured either by focusing on the input market/s or, alternatively, by focusing on the output markets that demand this intermediate good. Otherwise, if both kinds of markets are added (input and output markets), then the welfare evaluation would result in double-counting. This result holds when assuming competitive markets without distortions (taxes or subsidies, for example) in the economy. We can more formally prove this result when addressing a CGE modelization.

Proposition: *In the case of derived demand, welfare variation in the output market equals the welfare variation that occurs in the input market.*

Proof:

Let's assume an economy with Y_i goods/sectors, two factors of production (K and L) supplied inelastically to the market and where the production of one good (Y_Z) is entirely demanded as an intermediate good by other sectors. Thus, the production functions of the economy are: $Y_i = F_i(K, L)$ when $i = Z$, and $Y_i = F_i(K, L, Z)$, otherwise. Finally, let's assume a variation in the production of good Y_Z such as $\Delta Y_Z > 0$, with $\Delta P_Z < 0$. As noted, in order to avoid double-counting, CBA holds that, either, we should focus on the output markets (Y_Y and Y_X), or, the input markets (Y_Z) to compute the welfare variation.

Let's approach the welfare variation by employing the variation of the total surplus (ΔS): $\Delta S = \sum_{i=1}^{n} \int_{P_0}^{P_f} D_i^i(M, P_i)$ where D_i denotes the final demand of good i, which depends positively on income (M) and negatively on its own price (P_i)[8].

[8] Total surplus includes both consumer and producer surplus. It should be noted that in CGE a single representative household/agent is usually assumed.

By the market clearance condition, demand equals supply, so that:

$D_i^i(M, P_i) = Y_i$

And the production Y_i depends on the factors of production and the intermediate good Y_Z:

$Y_i = F_i(K_i, L_i, Z_i)$

According to the Euler equation, the production equation can be written as follows:

$$Y_i = \frac{\partial Y_i}{\partial L_i} L_i + \frac{\partial Y_i}{\partial K_i} K_i + \frac{\partial Y_i}{\partial X_i} Z_i$$

By including this expression in terms of the variations in production (ΔY):

$\Delta Y = \sum_{i=1}^{n} \int_{w_0}^{w_f} D_L^i(I_i, w) + \sum_{i=1}^{n} \int_{r_0}^{r_f} D_K^i(I_i, r) + \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$ where $D_L^i(I_i, w)$ and $D_K^i(I_i, r)$ denotes labour and capital demand from the economic sectors (output markets), which depend positively on the income of each sector (I), and negatively on the prices of both factors, w and r, respectively, and $D_Z^i(I_i, P_Z)$ represents the demand of good Z.

Keeping in mind that $D_i^i(M, P_i) = Y_i$, then, we get that $\Delta S = \sum \Delta S_i = \sum \Delta Y_i$; where ΔS denotes the total surplus variation, ΔS_i represents the total surplus variation by good i and ΔY_i the production variation by good i.

$$\Delta S = \sum_{i=1}^{n} \int_{P_0}^{P_f} D_i^i(M, P_i) = \sum_{i=1}^{n} \int_{w_0}^{w_f} D_L^i(I_i, w) + \sum_{i=1}^{n} \int_{r_0}^{r_f} D_K^i(I_i, r) + \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$$

Use of the total surplus variation relies on assuming the income level as constant, which implies that $\sum_{i=1}^{n} \int_{w_0}^{w_f} D_L^i(I_i, w)$ and $\sum_{i=1}^{n} \int_{r_0}^{r_f} D_K^i(I_i, r)$ equal zero. Hence, the variation in total surplus collapses to:

$$\Delta S = \sum_{i=1}^{n} \int_{P_0}^{P_f} D_i^i(M, P_i) = \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$$

where $\sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$ equals the variation in production of sector Y_Z (ΔY_Z) (input market) such as:

$$\Delta Y_Z = \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$$

Hence:

$\Delta S = \Delta Y_Z$ (ΔS^{output}=ΔS^{input})

Proving that the welfare change can be calculated either by focusing on the output markets (ΔS^{output}) or on the input markets (ΔS^{input}), as stated by CBA. However, this result relies on assuming the income level is constant. When the latter does not hold, its effect in terms of welfare is captured by using the equivalent variation, which is the standard welfare measure in CGE (Hosoe, Gasawa and Hashimoto, 2010).

7.3.1.1 Equivalent variation: conditions for convergence in CBA and CGE

The case of derived demand allows us to highlight the potential welfare equivalence when conducting CBA and CGE. As noted, this measure provides a convenient shortcut when a project triggers no income effect. However, as soon as the project generates the latter, then the Equivalent Variation and Surplus Variations differ[9].

7.3.1.2 Input market multiplicative effect (*Pme*)

Another important result emerges when delving into the case of intermediate demand and analyzing welfare change; not in terms of total surplus variation or production variation, but in terms of the multiplicative effect in welfare.

Specifically, we want to test the following proposition:

Proposition: *In case of intermediate demand, the multiplicative effect observed in the input market coincides with the multiplicative welfare effect triggered in the economy.*

Proof:

[9] Willig (1976) shows under what conditions the magnitude of the error between both welfare measures is not significant.

Let's firstly introduce the new notation, reflecting that the variables are now measured in multiplicative terms, such as: $\tilde{X} = \frac{X_f}{X_0}$ where X_0 and X_f represent initial and final values, respectively.

Considering that, $EV = \Delta M$, in multiplicative terms, we obtain:

$$\widetilde{EV} = \widetilde{M}$$

Similarly, the expression $EV = e(P^0, U^f) - e(P^0, U^0)$ can also be transformed so that:

$$\widetilde{EV} = \tilde{e}$$

Since total expenditure equals total demand, in multiplicative terms, we obtain that:

$$\tilde{e} = \sum_{i=1}^{n} \widetilde{Y_\iota} \widetilde{P_\iota}$$

At the same time, according to the Euler theorem, total production can be decomposed into its factors of production, such that:

$$\frac{\partial Y_i}{\partial L_i}\widetilde{L_\iota} + \frac{\partial Y_i}{\partial K_i}\widetilde{K_\iota} + \frac{\partial Y_i}{\partial X_i}\widetilde{X_\iota}$$

Hence:

$$\sum_{i=1}^{n} \widetilde{Y_\iota}\widetilde{P_\iota} = \sum_{i=1}^{n} \left(\frac{\partial Y_i}{\partial L_i}\widetilde{L_\iota} + \frac{\partial Y_i}{\partial K_i}\widetilde{K_\iota} + \frac{\partial Y_i}{\partial X_i}\widetilde{X_\iota}\right)\widehat{P_\iota}$$

Assuming that, either, there is no variation in the demand of labour and capital in output markets ($\widetilde{L_\iota} = \widetilde{K_\iota} = 0$), or, that total variation is zero ($\sum_{i=1}^{n} \frac{\partial Y_i}{\partial L_i}\widetilde{L_\iota} + \frac{\partial Y_i}{\partial K_i}\widetilde{K_\iota} = 0$) then the equivalent variation collapses to:

$$\widetilde{EV} = \sum_{i=1}^{n} \widetilde{Y_\iota}\widetilde{P_\iota} = \sum_{i=1}^{n} \left(\frac{\partial Y_i}{\partial X_i}\widetilde{X_\iota}\right)\widetilde{P_\iota}$$

Since the production of intermediate good equals its respective demand from output markets, then: $\widetilde{Y_Z} = \sum_{i=1}^{n} \widetilde{X_\iota}$. So that, $\sum_{i=1}^{n} \widetilde{X_\iota} = \sum_{i=1}^{n} \widetilde{Y_\iota}$. This implies that: $\widetilde{Y_Z} = \sum_{i=1}^{n} \widetilde{Y_\iota}$. And finally, that: $\widetilde{EV} = \widetilde{Y_Z}\,\widetilde{P_Z}$[10].

This demonstration considerably simplifies estimation of a project's welfare effect by simply calculating the *Pme* triggered in the market under analysis. However, albeit

[10] See footnote 6.

different to the previous case when neglecting the income effect in the demonstration of variation in intermediate demand, this new result also relies on a key assumption. Specifically, it holds that either there are no variations in the sectoral demand of factors in the output markets ($\widetilde{L_i} = \widetilde{K_i} = 0$), or that the variation exists, but its total net effect is zero ($\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) = 0$). However, what does this assumption imply? and, how realistic is it?

The first case, $\widetilde{L_i} = \widetilde{K_i} = 0$, would be implicit when assuming, for instance, full employment of both labour and capital, and perfect labour mobility. In this situation, $\widetilde{L_i} = \widetilde{K_i} = 0$ holds, meaning that the economic impact of the project in output markets can be omitted from the welfare evaluation and simply focus on the input one. Thus, $\widetilde{EV} = \widetilde{Y_Z}\,\widetilde{P_Z}$holds.

The second case, $\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) = 0$, can be better contextualised when assuming unemployment. On the one hand, it should be noted that now, $\widetilde{L_i} = \widetilde{K_i} = 0$, does not hold, because the output markets are also capable of increasing their production by seeking unemployed workers. On the other, the constraint: $\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) = 0$, has to be reformulated as follows: $\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) + \widetilde{U} = 0$, where $\widetilde{U}$ denotes the multiplicative change in unemployment that takes place in output markets. As can be appreciated, it is reasonable to assume that the employment created by output markets equates to a reduction in unemployment, so that $\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) + \widetilde{U} = 0$. As a result, $\widetilde{EV} = \widetilde{Y_Z}\,\widetilde{P_Z}$ holds again. A similar conclusion is obtained when introducing a government, or assuming non-competitive market conditions.

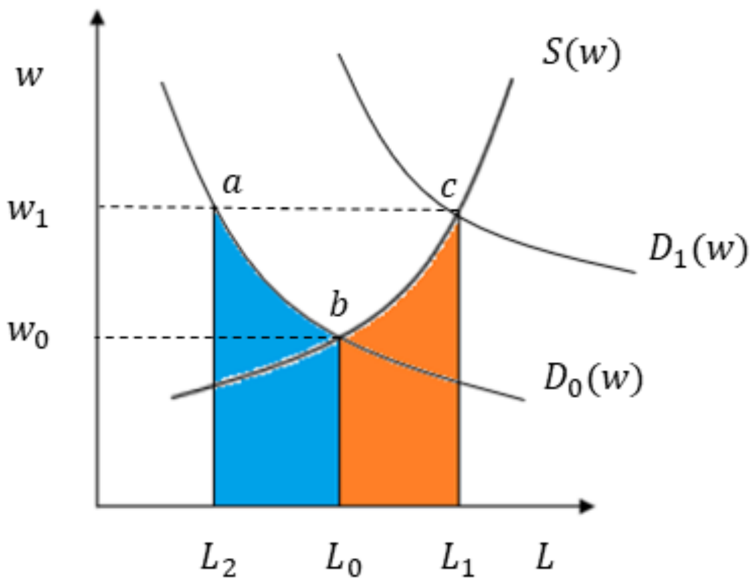
However, $\widetilde{EV} = \widetilde{Y_Z}\,\widetilde{P_Z}$ no longer holds when considering a deficit or surplus in the current account (open economy). In this situation, the economy can expand (deficit) or contract (surplus) resources beyond the constraints of a closed economy. For instance, let's assume a small open economy with a deficit, where output markets demand imports as commodities. Now, $\sum_{i=1}^{n}(\widetilde{L_i} + \widetilde{K_i}) = 0$ is $\sum_{i=1}^{n}\widetilde{L_i} + \sum_{i=1}^{n}\widetilde{K_i} + \sum_{i=1}^{n}\widetilde{m_i} + \widetilde{def} = 0$, where $\widetilde{m_i}$ denotes the multiplicative effect on import demand in the output markets and $\widetilde{def}$ represents the multiplicative effect on the deficit of the economy. Now, if these markets increase their demand for imports ($\widetilde{m_i}$) as a result of the effect of the project in the input market, $\widetilde{def}$ rises as well, causing $\sum_{i=1}^{n}\widetilde{L_i} + \sum_{i=1}^{n}\widetilde{K_i} + \sum_{i=1}^{n}\widetilde{m_i} + \widetilde{def} \neq 0$. Hence, $\widetilde{EV} \neq \widetilde{Y_Z}\,\widetilde{P_Z}$. Summarizing, $\widetilde{EV} = \widetilde{Y_Z}\,\widetilde{P_Z}$ works adequately in any economic situation, except when considering a deficit or surplus in the current account. In this case, $\widetilde{EV} \neq \widetilde{Y_Z}\,\widetilde{P_Z}$.

7.3.2 The labour market: voluntary and involuntary unemployment

In the economic evaluation of projects, resources are valued at the social opportunity cost (de Rus, 2021). In general, as soon as there is competitive market behaviour, the price reflects the social opportunity cost of the resource. However, in cases where the market price does not reflect the opportunity cost, CBA uses shadow prices.

Figure 1 illustrates a competitive labour market. In this example, the project increases the demand for labour from D_0 to D_1, which increases the demand of workers by $L_1 - L_0$ units. The welfare implications for the $L_1 - L_0$ new workers should be evaluated by considering the opportunity cost of their leisure (area bcL_1L_0). On the other hand, the $L_0 - L_2$ workers hired by the project come from other sectors and their opportunity cost should take into account such loss (area: abL_0L_2). The same reasoning is applied when assuming the existence of a factor supplied perfectly inelastically to the market, such as land.

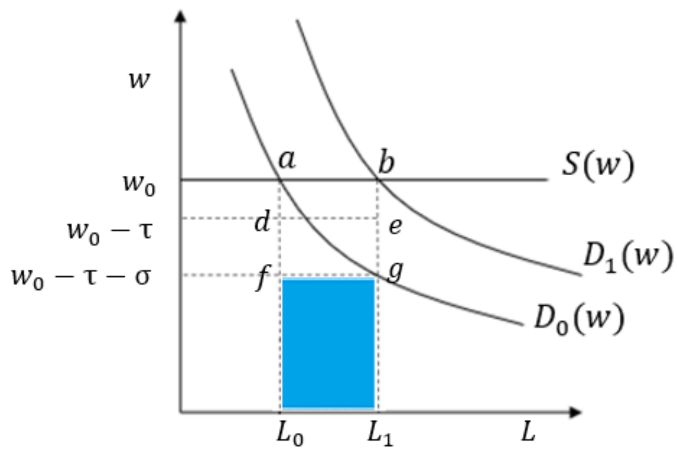
Figure 1. Labour markets and shadow price



Finally, the social opportunity cost may also differ when assuming involuntary unemployment (Figure 2). For instance, without income taxes (τ) or unemployment benefits (σ), the clearing salary (w_0) captures the social opportunity cost whose total change is denoted by the area abL_1L_0. However, by introducing taxes and/or unemployment benefits in this market, the salary w_0 no longer represents the social opportunity cost, but $w_0 - \tau$ and/or $w_0 - \tau - \sigma$, where τ denotes the income tax and σ unemployment benefits. In both cases, the social opportunity cost is represented by the areas deL_1L_0 and fgL_1L_0, respectively.

CGE models are capable of modelling any of these labour market situations. However, they do not calculate the welfare changes that are taking place under these different labour market situations as CBA does, but focus directly on the estimation of the representative household's welfare change. In sum, the question is whether the opportunity costs elicited by CBA, in any of these labour market situations, are implicitly incorporated into the welfare of the household in a CGE framework, or whether the former requires additional adjustments to address them correctly.

Figure 2. Involuntary unemployment and shadow price



7.3.2.1 <u>Open economy and involuntary unemployment with derived demand</u>

The existence of imports in the output markets or involuntary unemployment in the economy may also cause that $\Delta S \neq \Delta Y_Z$. The underlying idea is that the latter equality does not only rely on assuming that income level as constant, but also that the total sum of the variation in the demand of factors equals zero: $\sum_{i=1}^{n}(\Delta L_i + \Delta K_i) = 0$

Let's extend the technology of the output sectors (Y_Y and Y_X) to include imports (m_i) as follows:

$Y_i = F_i(K_i, L_i, Z_i, m_i)$

In consequence, total variation in production stands as:

$$\Delta Y = \sum_{i=1}^{n} \int_{w_0}^{w_f} D_L^i(I_i, w) + \sum_{i=1}^{n} \int_{r_0}^{r_f} D_K^i(I_i, r) + \sum_{i=1}^{n} \int_{r_0}^{r_f} D_m^i(I_i, Pm) + \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$$

where Pm denotes import prices. However, even assuming the income level as constant if, for instance, $\Delta m_i \neq 0$, then it implies that $\sum_{i=1}^{n}(\Delta L_i + \Delta K_i + \Delta m_i) \neq 0$, causing that:

$\Delta Y = \sum_{i=1}^{n} \int_{r_0}^{r_f} D_m^i(I_i, Pm) + \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z)$. Hence, $\Delta S \neq \Delta Y_Z$.

The existence of involuntary unemployment, or simply that $\sum_{i=1}^{n}(\Delta L_i + \Delta K_i) \neq 0$ [11], would also cause ($\Delta S^{output} \neq \Delta S^{input}$).

7.3.3 Derived demand with a negative externality

7.3.3.1 A negative externality

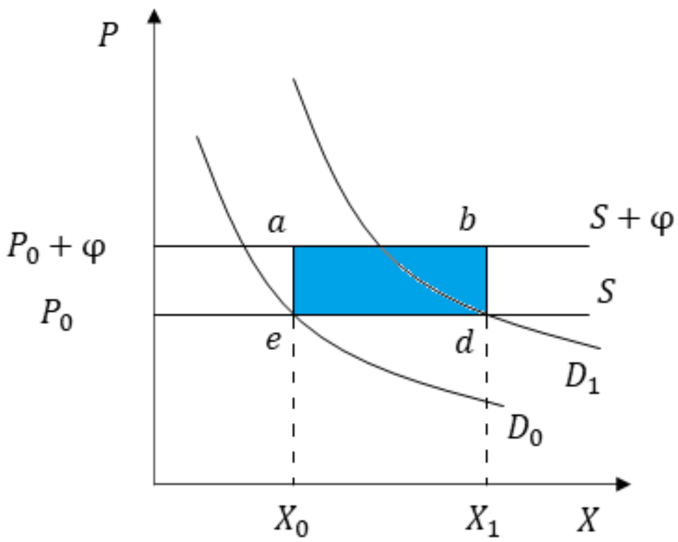
This example extends the previous by assuming the existence of a negative externality in the output market. As shown in Figure 3, the equilibrium in the market is e where the price paid is P_0 and the quantity exchanged is X_0. However, the "true" price (including the externality) is $(P_0 + \varphi)$, where φ denotes the externality. However, the market does not clear at this price, but at P_0; resulting in a greater provision of the good than is socially desirable. In other words, the externality operates as a subsidy in this good's production, i.e. the true marginal cost is $P_0 + \varphi$, but this good is produced assuming a marginal cost equal to P_0. When demand shifts upward from D_0 to D_1 because of the effect of the project in the input market, then the output market clears at

[11] This situation arises, for instance, when assuming an increase in capital productivity, instead of total factor productivity in the input market.

d, but the market is incurring a social cost represented by the area ($abde$) that has to be subtracted from the social welfare.

Once again, the question is whether the opportunity cost elicited by CBA in this case, is implicitly incorporated in the welfare of a household in a CGE framework, or whether the former requires additional adjustments, in order to address it correctly.

Figure 3. Negative externalities



As said, an important issue of concern when conducting project appraisal is the existence of externalities in the economy. In terms of welfare analysis, a difficulty arises when noting that its presence implies that one good is supplied above what is socially desirable because it does not internalize the social cost caused during its production, which means that the private cost is lower than the social cost. As a result, the presence of an externality not only causes an increase in production but, more importantly, it also affects the economy's welfare. Next, we more formally examine this consequence.

Let's assume that a closed economy produces according to the following production function $Y = Y^{\beta}F(K,L)$, where Y denotes total production, K and L represent capital and labour, respectively, $F(K,L)$ operates under constant returns to scale and β is a parameter that reflects the degree of the externality (Liu and Turnovsky, 2005; Romer, 1986; and Lucas, 1988). Hence, Y is homogenous of degree: $\frac{1}{1-\beta} > 1$.

According to the Euler theorem, a production function with constant returns to scale can be written in variations, as follows:

$$\Delta Y = \frac{\partial F(K,L)}{\partial K}\Delta K + \frac{\partial F(K,L)}{\partial K}\Delta L$$

Considering that $Y = Y^{\beta}F(K,L)$, then the previous equation can be rewritten as follows:

$$\Delta Y = \Delta Y^{\beta}\frac{\partial F(K,L)}{\partial K}\Delta K + \Delta Y^{\beta}\frac{\partial F(K,L)}{\partial L}\Delta L$$

Assuming that both factors of production are paid according to their marginal productivity, it implies that $\frac{\partial F(K,L)}{\partial K} = r$ and $\frac{\partial F(K,L)}{\partial L} = w$. Hence:

$$\Delta Y = \Delta Y^{\beta} r\Delta K + \Delta Y^{\beta} w\Delta L$$

Knowing that, by the circular flow of income, $\Delta M = r\Delta K + w\Delta L$:

$$\Delta Y = \Delta Y^{\beta}\Delta M$$

Operating this expression yields that:

$$\Delta Y = \Delta M^{\frac{1}{1-\beta}}.$$

Furthermore, recalling from the previous section that $EV = \Delta M$, we obtain that:

$$\Delta Y = EV^{\frac{1}{1-\beta}}.$$

This demonstrates that the existence of externalities in the production of a good causes a distortion with respect to welfare. It should be noted that when $\beta = 0$ (no externality), total variation in production equals the Equivalent Variation ($\Delta Y = \Delta M = EV$).

7.3.3.2 Externalities and intermediate demand

Now the analysis briefly returns to testing the consistency of the welfare measures previously demonstrated, but now assuming externalities. As already proven, in the case of derived demand, the total surplus variation equals the variation in production in the input market: $\Delta S = \Delta Y_Z$.

Let's extend the technology of the output sectors Y_Y to include the externality as follows:

$Y_i = Y_i^{\beta} F_i(K_i, L_i, Z_i)$ when $i = Y$

As a result, the factors' demand functions take the form:

$\frac{\partial Y_{i=Y}}{\partial K_{i=Y}} Y_{i=Y}^{\beta} = \frac{r}{P}\,; \frac{\partial Y_{i=Y}}{\partial L_{i=Y}} Y_{i=Y}^{\beta} = \frac{w}{P}\,; \frac{\partial Y_{i=Y}}{\partial Z_{i=Y}} Y_{i=Y}^{\beta} = \frac{P_Z}{P}$

Thus, total variation in production is:

$$\Delta Y = \Delta Y_{i=Y}^{\beta} \left(\sum_{i=1}^{n} \int_{w_0}^{w_f} D_L^i(I_i, w) + \sum_{i=1}^{n} \int_{r_0}^{r_f} D_K^i(I_i, r) + \sum_{i=1}^{n} \int_{P_0^f}^{P_Z^f} D_Z^i(I_i, P_Z) \right)$$

Remembering that $D_i^i(M, P_i) = Y_i$ yields, as previously, that $\Delta S = \Delta Y$. However now, even assuming a constant income level, $\Delta S > \Delta Y_Z$ ($\Delta S^{output} > \Delta S^{input}$), because ΔY is now affected by the externality of sector Y ($\Delta Y_{i=Y}^{\beta}$). This result means that approaching the welfare change using ΔS^{output} yields a biased result in the presence of externalities in the output markets, whereas ΔY_Z (ΔS^{input}) is not affected by the latter, and thus reports a reliable welfare value. This is solved in CBA by taking into account the presence of distortions in the good markets or ignoring them when the value of the distortions are common to the counterfactual.

Regarding the IWA and Pme, both are also affected by the externality by simply recalling that their calculus rely on the change of income level, and that, as previously shown, the externality causes the following effect on the latter: $\Delta Y = EV^{\frac{1}{1-\beta}} = M^{\frac{1}{1-\beta}}$. Thus, the externality must be subtracted from both measures to provide an unbiased welfare result.

7.3.4 Other theoretical issues of concern

There are two additional issues of concern when conducting welfare analysis: multiple households and *model closure,* also known as *macroclosure*. Both aspects have already been covered in Inchausti-Sintes and Njoya (2022) so this section briefly highlights their main consequences in terms of welfare. In any case, the EV continues to provide a correct welfare approach in any of these economic situations.

7.3.4.1 Multiple households

In general, CGE considers a single representative household. However, depending on the kind of project under analysis, more households may be required. As highlighted by Varian (1992), when the household functional form fulfils the Gorman norm, exact lineal aggregation is granted. This means that aggregate welfare remains constant, no matter the kind of income distribution.

However, when different types of households have got different income elasticities (different marginal social utility of income), the Gorman norm no longer holds, meaning that the aggregate welfare varies with changes in the income endowment (see, Varian, 1992 or Deaton and Muellbauer, 1980).

7.3.4.2 Model closure

This issue only affects CGE models because it refers to the *closure* of the foreign position, the governmental position and the investment-savings rule (Hosoe, et al, 2010; and Gilbert and Tower, 2013). The choice of the *closure* of any of these economic situations affects welfare. As stated by Inchausti-Sintes and Njoya (2022), a model is mathematically "closed" when we have sufficient independent equations to explain the endogenous variables (Gilbert and Tower, 2013). Further, the choice of exogenous and endogenous variables also determines the computability and complexity of the model (Hosoe, et al, 2010).

The first is generally imposed by the economy under analysis (i.e., practically all CGE models are built upon the small open economy assumption, meaning that the foreign position (zero deficit, deficit or surplus) is fixed). In other words, the capacity of the economy to attract foreign savings is limited. Thus, this is not an issue that can be freely determined by the modeller.

The second refers to how the government determines its deficit, surplus or zero deficit. Broadly speaking, the government collect taxes, make transfers to households, and spends on consumption, which, together, determine the budgetary position. Thus, depending on which of these items are exogenously or endogenously determined, the welfare will vary in consequence.

Finally, the investment-savings rule refers to the way of modelling the investment decision of the economy: assuming exogenous or endogenous investment. Paraphrasing Gilbert and Tower (2013), when the former holds (investment-driven decision), the welfare variation can be interpreted as the effect for a given level of investment in future consumption. However, according to the same authors, if the analysis seeks to determine how the project under analysis impacts the economy through its effect on savings, then the latter may be chosen (savings-driven decision).

In the following section, the theoretical welfare appraisal is applied and tested in a CGE framework for different markets situations introduced in the cases studies: a labour market with voluntary unemployment, a labour market with involuntary unemployment, derived demand and derived demand with a negative externality. Additionally, the case of derived demand is complemented assuming involuntary unemployment and non-competitive markets. Moreover, the case studies are extended to open economy situations to check the consistency of the results and conclusions. Finally, the empirical implication of *model closure* is covered in section 7.6, which also illustrates the capacity of CGE to conduct counterfactual scenarios.

7.4 CGE models

As shown in Inchausti-Sintes and Njoya (2022), any CGE model relies on fulfilling three conditions: zero benefit, market clearance conditions and income balance (Böhringer, Rutherford and Wiegard, 2003). Zero benefit means that the value per activity must be equal to or greater than the value of its output. Market clearance implies that the supply of any good/service must be equal to or exceed the demand for these goods/services. At the same time, the demand can be disentangled into intermediate and final demand. Finally, the income balance of each institution (government or households, mainly) must be equal to or exceed their final demands. The CGE models developed in this paper are built upon these three conditions, as explained below.

7.4.1 Voluntary unemployment

Let's assume a closed economy without government, with two sectors each producing one single output (Y_i, with $i = X\ and\ Y$), (Y_i). The two sectors employ capital and labour as factors of production. More specifically, the former is assumed sector-specific ($\widehat{K}_i$) and the latter is perfectly mobile among sectors (L_i). Thus, the economic decision adopted by each sector can be summarized according to the following maximising problem:

Sectoral behaviour

$$(1.M1) \quad max_{Y_i,\widehat{K}_i,L_i}\ (P_iY_i) - \left(r_i\widehat{K}_i + wL_i\right)$$

$$subject\ to: Y_i = f(\widehat{K}_i, L_i)$$

where P_i denotes the price of sector/good i, r_i denotes the cost of capital in sector/good i and w is the wage. The solution to this problem yields the demand of capital ($\widehat{K}_j$) and labour L_j by sectors. Assuming a Cobb-Douglas production function with constant returns to scale: $Y_i = f\left(X_{ij}, \widehat{K}_i, L_i\right) = \widehat{K}_i^{\alpha_i^{\widehat{K}}} L_i^{\alpha_i^L}$ the factors demand function takes the following functional forms: $\widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_iY_i$; and $L_i = \frac{\alpha_i^L}{w} P_iY_i$.

Finally, thanks to the production duality problem (Mas-Colell, Whinston and Green, 1995) (1.M1) is equivalent to the cost minimizing problem. Substituting the conditional demands for the factors of production obtained from this problem in the objective function yields the cost function ($C_i(r_i, w, Y_i) = r_i^{\alpha_i^{\widehat{K}}} w^{\alpha_i^L} Y_i$). This function allows us to obtain an expression of the cost of production associated with the level of output (Y_i). Finally, this function form, together with the income and the zero-profit condition provides that: $P_iY_i - r_i^{\alpha_i^{\widehat{K}}} w^{\alpha_i^L} Y_i$=0.

Voluntary unemployment

In a standard CGE model, labour is supplied perfectly inelastically to the market (vertical labour supply); ensuring that it is employed by the economic sectors (full employment). However, the existence of involuntary employment requires us to introduce an adjustment into the model. The labour endowment is owned by the households (representative household), but they have now to decide between leisure and labour, implying that the labour supply is upward sloping. As a result, the consumption of leisure must be introduced in the household's consumption basket. Mathematically, both economic behaviours are accommodated in a CGE model, as follows:

Labour supply

The labour supply adopts the following form and transforms leisure into labour supply, such that:

$$(2.M1)\ max_{L_s,L_H}\ (wL_s) - (P_L L_H)$$

$$subject\ to: L_s = f(L_H)$$

According to problem 2.M1, the labour endowment (L_H) is supplied to the market as L_s (labour supply), w denotes the wage, and P_L represents the opportunity cost of labour (the cost of leisure). When w rises, it causes an increase in the opportunity cost of leisure (P_L), meaning that more workers are willing to exchange leisure for working hours. If we assume a Cobb-Douglas production function with constant returns to scale, then the optimal demand of labour is: $L_H = \frac{1}{P_L} w L_s$. The cost function associated with this problem is $P_L L_s$ and the zero-profit condition is $wL_s - P_L L_s = 0$.

Household behaviour

All the production obtained from the maximization problem (1.M1) is devoted to satisfying each household's demand, which is constrained by their disposal income (M). The bundle of goods demanded from households are now composed by the two goods produced by the two sectors (C_X and C_Y) and the "consumption" of *leisure.* The household consumption decision is represented as follows:

$$(3.M1)\ max_{C_X,C_Y,leisure}\ U(C_X, C_Y, leisure)$$

$$subject\ to{:}\,M = \sum_{i=A}^{B} P_i C_i + P_L leisure$$

where U denotes total utility which comprises the consumption of both goods (C_X and C_Y) and the enjoyment of *leisure* (C_L). Finally, P_i and P_L denote the prices of each good and the opportunity cost of leisure (cost of labour), respectively. Assuming a Cobb-Douglas utility function with constant returns to scale ($U = C_X^{\beta_X} C_Y^{\beta_Y} C_L^{\beta_L}$), the demand functions of problem 3.M1 are:

$C_X = \frac{\beta_X}{P_X} M$; $C_Y = \frac{\beta_Y}{P_Y} M$; and ; $C_L = \frac{\beta_L}{L} M$

The expenditure function associated with this problem is: $P_U = P_X^{\beta_X} P_Y^{\beta_Y} P_L^{\beta_L}\, U$. This function represents the consumer price index of the economy, and it is usually employed as *numeraire* in CGE modelling to deflate all other prices (Wing, 2004). The zero-profit condition is: $P_U U - P_X^{\beta_X} P_Y^{\beta_Y} P_L^{\beta_L} U = 0$.

General equilibrium

The zero-profit conditions: $P_i Y_i - r_i^{\alpha_i^{\hat{K}}} w^{\alpha_i^L} Y_i$=0, $wL_s - P_L L_s = 0$ and $P_U U - P_X^{\beta_X} P_Y^{\beta_Y} P_L^{\beta_L} U = 0$. And the demand: $\hat{K}_i = \frac{\alpha_i^{\hat{K}}}{r_i} P_i Y_i$, $L_i = \frac{\alpha_i^L}{w} P_i Y_i$, $L_H = \frac{1}{P_L} w L_s$, $C_X = \frac{\beta_X}{P_X} M$, $C_Y = \frac{\beta_Y}{P_Y} M$ and $C_L = \frac{\beta_L}{L} M$ have to be complemented by additional equations (market clearance conditions for goods and factors, and income constraint) to obtain a full characterization of this economy.

(4.M1) $Y_i = C_i$

(5.M1) $\bar{L} = L_H + C_L$

(6.M1) $L_H = L_S$

(7.M1) $\bar{K}_\iota = \hat{K}_i$

(8.M1) $\bar{K}_\iota = \sum_{i=1}^{n} \hat{K}_i$

(9.M1) $M = \sum_{j=A}^{B} r_j \hat{K}_i + w\bar{L}$= $\sum_{i=A}^{B} P_i C_i + P_L C_L$

where Equation (4.M1) ensures that the production of each good i (Y_i) is demanded as final goods (C_i). Equations (5.M1), (6.M1) and (7.M1) ensure that the sectors entirely demand the labour and capital owned by the households. Equation (8.M1) assumes that all the sector-specific capital equals total capital endowment. Finally, equation (9.M1) represents the income balance constraint of the representative household. Table 1 summarizes the equations employed in this model.

Table 1. The CGE model equations, with voluntary unemployment.

Zero profit
$P_i Y_i - r_i^{\alpha_i^{\hat{K}}} w^{\alpha_i^L} Y_i = 0$
$(wL_s) - (P_L L_s) = 0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} P_L^{\beta_L} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\hat{K}}}{r_i} P_i Y_i$
$L_s = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$\overline{L} = \frac{1}{P_L} w L_s + \frac{\beta_L}{L} M$
$X = C_X \frac{\beta_X}{P_X} M$
$Y = C_Y = \frac{\beta_Y}{P_Y} M$
$Y_X + Y_Y = C_X + C_Y$
Income constraint
$M = \sum_{i=1}^{n} r_i \widehat{K}_i + w\overline{L} = \sum_{i=A}^{B} P_i C_i + P_L C_L$; being $\overline{K_\iota} = \sum_{i=1}^{n} \widehat{K}_i$

7.4.2 Open economy[12] with voluntary unemployment

Let's now distinguish between the tradable and non-tradable sectors to distinguish between exportable and non-exportable sectors/goods, respectively. In this sense, sector X will be regarded as tradable, meaning that its production is now disentangled into

[12] The open-economy assumption relies on considering a small open economy whose foreign position (zero deficit, deficit or surplus) is assumed to be fixed (standard *closure* in a small open economy).

domestic and exportable production. Whereas sector Y, the non-tradable sector, continues to operate domestically. Moreover, both sectors now demand imports as inputs (m_i). Finally, the economy represented in the model is considered small, implying that the international export (Pe^w) and import prices (Pm^w) are given exogenously and take the value 1. Thus, the domestic export and import prices are: $Pe = er\ Pe^w$ and $m = er\ Pm^w$; where er refers to the exchange rate. The export sector can be described by the following profit maximizing problem:

$$(10.M1)\quad max_{E_X, Y_X}\ (Pe_X E_X) - (P_X Y_X)$$

$$subject\ to: E_X = F(Y_X)$$

where E_X denotes exports of good Y_X. The solution to this problem yields the intermediate demand of the export sector to reach export production E_X. Once again, assuming a Cobb-Douglas production function with constant returns to scale for $E_X = f(Y_X)$, and solving problem (10.M1), yields the demand: $Y_X = \frac{1}{P_X} Pe_X E_X$. Using the cost function to form the zero-profit condition yields: $(Pe_X E_X) - (P_X E_X)$=0

Similarly, the sectoral behaviour must be rewritten to include the demand of imports as intermediate inputs:

$$(11.M1)\quad max_{Y_i}\ (P_i Y_i) - \left(r_i \widehat{K}_i + wL_i + P_m m_i\right)$$

$$subject\ to: Y_i = f(\widehat{K}_i, L_i, m_i)$$

Assuming again, a Cobb-Douglas production function: $Y_i = f\left(\widehat{K}_i, L_i, M_i\right) \widehat{K}_i^{\alpha_i^K} L_i^{\alpha_i^L} M_i^{\alpha_i^M}$, the demand functions of $\widehat{K}_i$, L_i and m_i from each sector i takes the following form: $\widehat{K}_i = \frac{\alpha_i^K}{r_i} P_i Y_i$; $L_i = \frac{\alpha_i^L}{w} P_i Y_i$; and $M_i = \frac{\alpha_i^M}{Pm} P_i Y_i$. The zero-profit condition associated with this problem is: $P_i Y_i$- $r_i^{\alpha_i^K} w^{\alpha_i^L} {P_m}^{\alpha_i^M} Y_i = 0$.

Finally, the bundle of goods demanded by the representative household are the same as in the closed economy. However, the income constraint (equation 9.M1) has to be rewritten to accommodate the current account position: $M = \sum_{j=A}^{B} r_j \widehat{K}_j + w\bar{L} + er\ ca$, where ca denotes the current account (exports minus imports) and the magnitude of which can be zero, positive or negative; implying zero deficit, deficit, or surplus with the rest of the world, respectively. Similarly, equation (4.M1) also has to accommodate the existence of exports and imports in the economy: $Y_Y = C_Y - m_Y$ and $Y_X = C_X + E_X - m_X$. Finally, equations (5.M1), (6.M1) (7.M1) and (8.M1) continue to hold in the small open economy framework. Table 2 shows the CGE model equations, assuming a small open economy with voluntary unemployment.

Table 2. The equations of the small open economy CGE model with voluntary unemployment.

Zero profit
$(Pe_Y E_Y) - (P_Y E_Y)=0$
$P_i Y_i\text{-}\, r_i^{\alpha_i^K} w^{\alpha_i^L} {P_m}^{\alpha_i^M} Y_i = 0$
$(wL_s) - (P_L L_s)=0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} P_L^{\beta_L} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$
$L_s = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$\overline{L} = \frac{1}{P_L} wL_s + \frac{\beta_L}{L} M$
$Y_Y = \frac{1}{P_Y} Pe_Y E_Y$
$m_i = \frac{\alpha_i^M}{P_m} P_i Y_i$
$C_X = \frac{\beta_X}{P_X} M = X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$Y_Y = C_Y - M_Y$
$Y_X = C_X + E_Y - M_X$
$Pe = er\ Pe^w$
$Pm = er\ {P_m}^w$
$E_Y - m_Y - m_X = ca$
Income constraint
$M = \sum_{j=A}^{B} r_j \widehat{K}_j + w\overline{L} + er\ fp = \sum_{i=A}^{B} P_i C_i + P_L C_L$; being $\overline{K_\iota} = \sum_{i=1}^{n} \widehat{K}_i$

7.4.3 Involuntary unemployment and unemployment benefits

The previous model must be slightly adjusted to cope with involuntary unemployment (classical unemployment). The latter is introduced in the model by assuming a lower bound on real wages (the legal minimum wage), where the minimum wage equals the consumer price index ($w^{min} \geq P_U$). Furthermore, in this new labour market situation, the representative household cannot decide between leisure and work. Hence, equation 2.M2 is not applicable. Similarly, $\bar{L} = L_w$, whereas the household decision is rewritten as follows:

Household behaviour

$$(1.M2)\ \ max_{C_X,C_Y}\ U(C_X, C_Y)$$

$$subject\ to: M = \sum_{i=A}^{B} P_i C_i$$

Household income constraint, denoted by equation (9.M1), is also accommodated as: $M = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) - P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) Un + sub\,\overline{Transfers}$ (9.M2), where P_{Ln} refers to the salary net of taxes ($P_{Ln} = w - \tau$), $\overline{Un}$ and $\overline{Transfers}$ are parameters denoting the initial unemployment rate and the initial level of unemployment benefits, respectively; whereas Un and sub are variables referring to the unemployment rate and unemployment benefit rates, respectively. The latter is positively related to the former ($sub = Un$). The representative household continues to operate with a Cobb-Douglas utility function ($U = C_X^{\beta_X} C_Y^{\beta_Y}$). Hence the demand functions of C_X and C_Y are: $C_X = \frac{\beta_X}{P_X} M$; $C_Y = \frac{\beta_Y}{P_Y} M$. Finally, the zero-profit condition is: $P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$.

The production-side of this economy continues to produce with the same technology and under the same market conditions. However, labour demand in both sectors is levied with an income tax (τ) collected by the government which, at the same time, demand final goods and transfer subsidies to the households. Hence, the zero-profit condition is: $P_i Y_i$- $r_i^{\alpha_i^K} (w + \tau)^{\alpha_i^L} P_m{}^{\alpha_i^M} Y_i$ and the demand of factors are: $\widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$ and $L_i = \frac{\alpha_i^L}{w+\tau} P_i Y_i$.

As a result, the wage observed by the representative household (P_L) is net of taxes, whereas equation (4.M1) also includes the demand for government goods (G_i), such that: $Y_i = C_i + G_i$.

Government behaviour

Government behaviour can be written as follows:

$$(2.M2) \quad max_{G_X,G_Y}\ U^G(G_X, G_Y)$$

$$subject\ to: M^G = \sum_{i=A}^{B} P_i G_i$$

Where $M^G = taxes - sub\ \overline{Transfers} = \sum_{i=A}^{B} P_i G_i$

where G_X and G_Y refer to the government consumption of goods Y_X and Y_Y, and $taxes$ refers to the income taxes collected ($\tau w(L_X + L_Y)$). The utility function of the public sector takes a Cobb-Douglas function form: $U^G = G_X^{\beta_X^G} G_Y^{\beta_Y^G}$. Hence, the zero-profit condition is: $P_{U^G} U^G - P_X^{\beta_X^G} P_Y^{\beta_Y^G} P_L^{\beta_L} U^G = 0$. Table 3 shows all the equations of the CGE model with involuntary unemployment.

Table 3. The equations of the CGE model with involuntary unemployment and unemployment benefits.

Zero profit
$P_i Y_i$- $r_i^{\alpha_i^K} (w+\tau)^{\alpha_i^L} P_m{}^{\alpha_i^M} Y_i$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$
$P_{U^G} U^G - P_X^{\beta_X^G} P_Y^{\beta_Y^G} P_L^{\beta_L} U^G = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$
$\frac{\overline{L}}{(1-\overline{Un})} - \left(\frac{\overline{L}}{(1-\overline{Un})}\right) Un = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$Y_i = C_i + G_i$
$C_X = \frac{\beta_X}{P_X} M + X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$G_X = \frac{\beta_X^G}{P_X} M^G$
$G_Y = \frac{\beta_T^G}{P_Y} M^G$
$Un(w^{min} - P_U) = 0$
$w = (P_{Ln} + \tau)$
Income constraint
$M = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\overline{L}}{(1-\overline{Un})}\right) - P_{Ln}\left(\frac{\overline{L}}{(1-\overline{Un})}\right) Un + sub\ \overline{Transfers} = \sum_{i=A}^{B} P_i C_i$; being $\overline{K}_\iota = \sum_{i=1}^{n} \widehat{K}_i$; and $P_{Ln} = w - \tau$
$M^G = taxes - sub\ \overline{Transfers} = \sum_{i=A}^{B} P_i G_i$

7.4.4 Open economy with involuntary unemployment and unemployment benefits

The model relies on the same assumptions as those in the open economy with voluntary unemployment. The model is shown in Table 4.

Table 4. The equations of the small open economy CGE model with involuntary unemployment and unemployment benefits.

Zero profit

$(Pe_X E_X) - (P_X E_X)$=0

$P_i Y_i$- $r_i^{\alpha_i^K} w^{\alpha_i^L} {P_m}^{\alpha_i^M} Y_i = 0$

$(wL_s) - (P_L L_s)$=0

$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$

$P_G U^G - P_X^{\beta_X^G} P_Y^{\beta_Y^G} U = 0$

Market clearance condition

$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$

$\left(\frac{\overline{L}}{(1-\overline{Un})}\right) - \left(\frac{\overline{L}}{(1-\overline{Un})}\right) Un = L_i = \frac{\alpha_i^L}{w} P_i Y_i$

$\overline{L} = \frac{1}{P_L} wL_s + \frac{\beta_L}{L} M$

$Y_X = \frac{1}{P_X} Pe_X E_X$

$m_i = \frac{\alpha_i^M}{Pm} P_i Y_i$

$C_X = \frac{\beta_X}{P_X} M = X$

$C_Y = \frac{\beta_Y}{P_Y} M = Y$

$G_X = \frac{\beta_X^G}{P_X} M^G$

$G_Y = \frac{\beta_T^G}{P_Y} M^G$

$Y_Y = C_Y - m_Y$

$Y_X = C_X + E_Y - m_X.$

$Pe = er\ Pe^w$

$Pm = er\ {P_m}^w$

$E_Y - m_Y - m_X = ca$

$Un(w^{min} - P_U) = 0$

$w = (P_{Ln} + \tau)$

Income constraint

$M = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\overline{L}}{(1-\overline{Un})}\right) - P_{Ln}\left(\frac{\overline{L}}{(1-\overline{Un})}\right) Un + sub\ \overline{Transfers} + ca = \sum_{i=A}^{B} P_i C_i$; being $\overline{K_\iota} = \sum_{i=1}^{n} \widehat{K}_i$

$M^G = taxes - sub\ \overline{Transfers}$=$\sum_{i=A}^{B} P_i G_i$

7.4.5 Derived demand

The model assumes a new good/sector, called Y_Z, the production of which is entirely demanded by the other two sectors (Y_X and Y_Y) as input. Both $\overline{K_\iota}$ and $\overline{L}$ are supplied perfectly inelastically to the factor markets.

Sectoral behaviour

$$(1.M3)\ \ max_{Y_i, Z_i, L_i, \widehat{K}_i}\ (P_i Y_i) - \left(P_Z Z_i + r_i \widehat{K}_i + w L_i\right)$$

$$subject\ to\colon Y_i = f(Z_i, \widehat{K}_i, L_i)$$

where Z_i denotes the new input demanded by the i sectors, and P_Z the input price. As noted, sector Z does not demand intermediate inputs, but labour and capital. Hence, when $j = Z$, the previous maximizing problem reduces to:

$$(2.M3)\ \ \ max_{Y_z, L_z, \widehat{K}_z}\ (P_z Y_z) - \left(r_z \widehat{K}_z + w L_z\right)$$

$$subject\ to\colon Y_Z = f(Z_Z, \widehat{K}_Z, L_Z)$$

The respective demand functions of the previous problems are: $\widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$; $L_i = \frac{\alpha_i^L}{w} P_i Y_i$; $Z_i = \frac{\alpha_i^Z}{P_z} P_i Y_i$; $\widehat{K}_Z = \frac{\alpha_Z^{\widehat{K}}}{r_Z} P_Z Y_Z$; $L_Z = \frac{\alpha_Z^L}{w} P_Z Y_Z$. The zero-profit conditions are: $P_i Y_i$-$r_i^{\alpha_i^K} w^{\alpha_i^L} P_Z^{\alpha_i^K} Y_i = 0$; and $P_z Y_Z$-$r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$. The other model assumptions and equations remain the same as stated in the example of voluntary unemployment. The model with derived demand is summarized in Table 5.

Household behaviour

$$(3.M3)\ \ max_{C_X, C_Y}\ U(C_X, C_Y)$$

$$subject\ to\colon M = \sum\nolimits_{i=A}^{B} P_i C_i$$

Household income constraint, denoted by equation (9.M1), is also accommodated as: $M = \sum_{j=A}^{B} r_j \widehat{K}_j + w\bar{L}$; (9.M3), where w refers to the wage and r_j the price of capital in each sector. The representative household continues to operate with a Cobb-Douglas utility function ($U = C_X^{\beta_X} C_Y^{\beta_Y}$). Hence the demand functions of C_X and C_Y are: $C_X = \frac{\beta_X}{P_X} M$; $C_Y = \frac{\beta_Y}{P_Y} M$. In sum, the zero-profit condition is: $P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$. Finally, the equations of the model are shown in Table 5.

Table 5. The equations of the CGE model with derived demand.

Zero profit
P_iY_i- $r_i^{\alpha_i^K} w^{\alpha_i^L} P_Z^{\alpha_i^Z} Y_i = 0$
P_zY_Z- $r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_iY_i$
$\overline{L} = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_iY_i$
$Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_iY_i$
$C_X = \frac{\beta_X}{P_X} M = X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$Y_X + Y_Y = C_X + C_Y$
Income constraint
$M = \sum_{i=1}^{n} r_i\widehat{K}_i + w\overline{L} = \sum_{i=A}^{B} P_iC_i$; being $\overline{K_\imath} = \sum_{i=1}^{n} \widehat{K}_i$

7.4.6 Open economy with derived demand

The model relies on the same assumptions as those in the open economy with voluntary unemployment, but assumes a perfectly elastic labour supply. The model is shown in Table 6.

Table 6. The equations of the small open economy CGE model with derived demand

Zero profit
$(Pe_X E_X) - (P_X E_X)=0$
$P_i Y_i - r_i^{\alpha_i^K} w^{\alpha_i^L} Pm^{\alpha_i^M} P_Z^{\alpha_i^Z} Y_i = 0$
$P_z Y_Z - r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$
$\overline{L} = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$Y_Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_i Y_i$
$Y_Y = \frac{1}{P_Y} Pe_Y E_Y$
$m_i = \frac{\alpha_i^M}{Pm} P_i Y_i$
$C_X = \frac{\beta_X}{P_X} M = X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$Y_Y = C_Y - m_Y$
$Y_X = C_X + E_X - m_X$.
$Pe = er\ Pe^w$
$Pm = er\ Pm^w$
$E_Y - m_Y - m_X = ca$
Income constraint
$M = \sum_{j=A}^{B} r_j \widehat{K}_j + w\overline{L} = \sum_{i=A}^{B} P_i C_i$; being $\overline{K}_i = \sum_{i=1}^{n} \widehat{K}_i$

7.4.7 Derived demand with involuntary unemployment without unemployment benefits

This model aims to test the role of idle resources (involuntary unemployment in this case) when addressing projects with derived demand. Intuitively, when assuming full use of resources, an improvement in the cost of this factor immediately affects the other sectors that benefit from demanding a cheaper input. However, when assuming involuntary unemployment, the same reduction in cost in this input may enhance a second effect by allowing the other sectors to increase their demand for labour, thereby achieving a higher social welfare variation, though for a net welfare effect of the project this variation may be irrelevant when it is approximately common to the next best alternative. The model maintains the same structure but without unemployment benefits. Hence, the income constraint stands now as: $M = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) - P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) Un = \sum_{i=A}^{B} P_i C_i$. The model's remaining equations are shown in Table 7.

Table 7. The CGE model's equations with derived demand and involuntary unemployment

Zero profit
$P_i Y_i$- $r_i^{\alpha_i^K} w^{\alpha_i^L} P_Z^{\alpha_i^Z} Y_i = 0$
$P_z Y_Z$- $r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$
$\left(\frac{\bar{L}}{(1-\overline{Un})}\right) - \left(\frac{\bar{L}}{(1-\overline{Un})}\right) Un = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_i Y_i$
$C_X = \frac{\beta_X}{P_X} M = X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$Y_X + Y_X = C_X + C_Y$
Income constraint
$M = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) - P_{Ln}\left(\frac{\bar{L}}{(1-\overline{Un})}\right) Un = \sum_{i=A}^{B} P_i C_i$.; being $\overline{K_l} = \sum_{i=1}^{n} \widehat{K}_i$

7.4.8 Derived demand with a negative externality

As stated, a sector that produces with an externality is producing with a marginal cost lower than the social cost, causing a provision of this good above what is socially desirable, which implies greater welfare variation with respect to a situation without the externality. Specifically, the externality is modelled assuming the following production function: $Y_Y = Y_Y^{1-\beta} F(K, L)$, where $F(K, L)$ shows constant returns to scale. Or, alternatively, $Y_Y = F(K, L)^{\frac{1}{1-\beta}}$, where Y is homogenous of degree $\frac{1}{1-\beta} > 1$. Hence, the factor Y^{β} operates as the externality, causing greater production of good Y. The optimal demands of K and L of this sector are now: $pY^{\beta} \frac{\partial Y_Y}{\partial L} = w$ and $pY^{\beta} \frac{\partial Y_Y}{\partial K} = r$.

This case is an extension of the model with derived demand, but omitting the involuntary unemployment, and assuming that one sector (sector Y_Y) produces with an externality. Table 8 summarizes the model's equations. Instead of analyzing the impact of an externality solely, the idea is to combine both economic situations, intermediate demand and externalities, in order to provide a more comprehensive approach.

Table 8. The CGE model's equations with derived demand and a negative externality.

Zero profit

$P_x Y_x$- $r_x^{\alpha_i^K} w^{\alpha_x^L} P_Z^{\alpha_x^Z} Y_x = 0$

$P_y Y_y$- $r_y^{\alpha_i^K} w^{\alpha_y^L} P_Z^{\alpha_x^Z} Y_y \frac{1}{Y^\beta} = 0$

$P_z Y_Z$- $r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$

$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$

Market clearance condition

$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i,$ where $i = Y_x \; and \; Y_z$

$$\overline{K}_Y = \widehat{K}_Y = \frac{\alpha_Y^{\widehat{K}}}{r_Y} P_Y Y_Y Y_y^{1-\beta}$$

$$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$$

$$\overline{L} = \frac{\alpha_x^L}{w} P_x Y_x + \frac{\alpha_z^L}{w} P_z Y_z + \frac{\alpha_y^L}{w} P_y Y_y Y_y^{1-\beta} = 0$$

$Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_i Y_i,$ where $i = Y_x \; and \; Y_y$

$C_X = \frac{\beta_X}{P_X} M = X$

$C_Y = \frac{\beta_Y}{P_Y} M = Y$

$Y_X + Y_Y = C_X + C_Y$

Income constraint

$M = \sum_{j=A}^{B} r_j \widehat{K}_j + w\overline{L} = \sum_{i=A}^{B} P_i C_i$.; being $\overline{K}_\iota = \sum_{i=1}^{n} \widehat{K}_i$; where $i = Y_x, Y_y \; and \; Y_z$

7.4.9 Derived demand and non-competitive markets

Finally, the analysis is extended to address the impact of assuming non-competitive behaviour in one market for the CGE model with derived demand. Specifically, the model assumes that one of the output markets (Y_Y) operates in a monopolistic market. The remaining assumptions and structure of the model resemble the CGE model with derived demand. The model is shown in Table 9. The variable $Markup$ is the benefit of the monopoly and causes the price to be higher than its marginal cost: $P_Y > MC_Y$. At the same time, the $Markup$ depends on the elasticity of substitution (σ) and on the share of the expenditure of the representative households on this good (Sh_Y). Finally, Table 10 summarizes each CGE model's main assumptions.

Table 9. The equations of the small open economy CGE model with derived demand and a non-competitive market.

Zero profit
$Markup P_Y Y_Y - r_i^{\alpha_Y^K} w^{\alpha_Y^L} P_Z^{\alpha_Y^Z} P_Y Y_Y = 0$
$P_X Y_X - r_i^{\alpha_X^K} w^{\alpha_X^L} P_Z^{\alpha_X^Z} P_X Y_X = 0$
$P_z Y_Z - r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$
$P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$
Market clearance condition
$\overline{K}_i = \widehat{K}_i = \frac{\alpha_i^{\widehat{K}}}{r_i} P_i Y_i$
$\overline{L} = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$
$Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_i Y_i$
$C_X = \frac{\beta_X}{P_X} M = X$
$C_Y = \frac{\beta_Y}{P_Y} M = Y$
$Y_X + Y_Y = C_X + C_Y$
Income constraint
$M = \sum_{i=1}^{n} r_i \widehat{K}_i + w\overline{L} + Markup = \sum_{i=A}^{B} P_i C_i$; being $\overline{K_\iota} = \sum_{i=1}^{n} \widehat{K}_i$
$Markup = 1/(\sigma - (\sigma - 1) Sh_Y)$
$Sh_Y = P_Y Y_Y / (P_Y Y_Y + P_X Y_X)$

Table 10. Overview of each CGE model.

	CGE models with voluntary unemployment	CGE models with involuntary unemployment and unemployment benefits	CGE models with derived demand	CGE models with derived demand with involuntary unemployment without unemployment benefits	CGE models with derived demand and a negative externality	CGE models with derived demand and a non-competitive market
Closed economy	Two sectors, two factors (capital and labour), one representative household.	Two sectors, two factors (capital and labour), one representative household, one government.	Three sectors, three factors (capital, labour and intermediate demand). The output of one of the sectors is demanded as input by the other two sectors. One representative household.	Three sectors, three factors (capital, labour and intermediate demand). The output of one of the sectors is demanded as input by the other two sectors. One representative household.	Three sectors, three factors (capital, labour and intermediate demand). The output of one of the sectors is demanded as input by the other two sectors. One representative household.	Three sectors, three factors (capital, labour and intermediate demand). The output of one of the sectors is demanded as input by the other two sectors. One representative household.
Open economy	Two sectors, three factors (capital, labour and imports), one representative household. Only one sector exports abroad (the tradable sector).	Two sectors, three factors (capital, labour and imports), one representative household. Only one sector exports abroad (the tradable sector).	Three sectors, three factors (capital, labour and imports), one representative household. Only one sector exports abroad (the tradable sector).	-	-	-

7.4.10 Parameter calibrations and shocks

The parameters employed in the calibration of the models are shown in Table 11. The shocks simulated in each model aim at triggering the economic effects conducted by CBA. Specifically, the shocks assumed in the models with voluntary unemployment and involuntary unemployment represent an increase in capital productivity in sector Y_Y; whereas the shock assumed in the model with derived demand represents an increase in total factor productivity (capital and labour) in sector Y_Z [13]. All models have been programmed in GAMS using MPSGE (Rutherford, 1999).

[13] See Annex I for a stylized formal demonstration of the economic impact of this shock.

Table 11. Calibrated parameters

	Voluntary unemployment		**Involuntary unemployment**		**Derived demand**	
	Closed economy	**Open economy**	**Closed economy**	**Open economy**	**Closed economy**	**Open economy**
α_X^K	0.6	0.5	0.6	0.50	0.41	0.25
α_X^L	0.4	0.33	0.4	0.28	0.26	0.22
α_X^M	-	0.17	-	0.14	-	0.16
α_X^Z	-	-	-	-	0.33	0.37
α_Y^K	0.4	0.33	0.4	0.24	0.26	0.25
α_Y^L	0.6	0.5	0.6	0.5	0.41	0.37
α_Y^M	-	0.17	-	0.26	-	0.12
α_Y^Z	-	-	-	-	0.33	0.25
α_Z^L	-	-	-	-	0.6	0.6
α_Z^K	-	-	-	-	0.4	0.4
β_X	0.5	0.31	0.47	0.47	0.5	0.5
β_Y	0.5	0.37	0.53	0.53	0.5	0.5
β_L	0.5	0.31	-	-	0.5	-
β_X^G	-	-	0.8	0.8	-	-
β_Y^G	-	-	0.2	0.2	-	-
M	300	320	210	230	300	320
M^G	-	-	10	10	-	-
Un	-	-	0.2	0.2	-	-
Sub	-	-	0.2	0.2	-	-
τ	-	-	0.2	0.2	-	-

7.5 Results from the CGE models

CGE models form a system of simultaneous equations with n equations and $n+1$ variables. Fortunately, all the equations are homogenous of degree 1 in prices. Thus, a model of this kind allows us to fix one variable to unity. This variable is known as the *numeraire,* and hence, all prices are interpreted in relative terms. In our case, the *numeraire* chosen is P_U (the consumer price index) because it allows for a more intuitive interpretation of the other prices in the economy (in real terms). Similarly, the variables that represent quantities equal one in the initial equilibrium. Hence, they also must be interpreted in relative terms (i.e., suppose the production of good Y_X grows from 1 to 1.01, this means that the initial production has been multiplied by 1.01, or that the new output is 1% higher than in the initial equilibrium)[14]. On the other hand, the income level and all welfare measures used throughout this Section are shown in absolute values. Specifically, the analysis distinguishes two welfare measures: the equivalent variation obtained through the CGE approach (SW^{CGE}), and the IWA.

7.5.1 Voluntary unemployment

As shown in Table 12, an increase in capital productivity (5%) when assuming voluntary unemployment causes an increase in production in the *primary* market (Y_Y) of 1.029. This additional production implies an increase in the demand for labour that pushes up wages, which triggers two additional effects. On the one hand, taking into account that the model assumes perfect labour mobility, the *secondary* market (Y_X) cannot afford to pay the higher wages, which causes a reduction in production (0.998) and labour displacement in favour of the primary market. Employment decreases from 40 to 39.757 in this market. On the other, the demand for labour in the *primary* market also creates new employment as captured by the $Labour\ supply$ that rises from 100 to 100.609. This new employment (0.609) is created at the cost of reducing $Leisure$ by the same magnitude (100-99.391) (i.e., the higher wages increase the opportunity cost of leisure (P_{Le}), which is now 1.013; fostering the labour supply). In sum, when assuming voluntary unemployment, the labour market behaves as conducted by CBA. Finally, the results show a social welfare gain (2.004) when analyzing the total equivalent variation (SW^{CGE}).

[14] For further information, see Hosoe, *et al*. (2010).

Table 12. Results of the model with voluntary unemployment (5% shock).

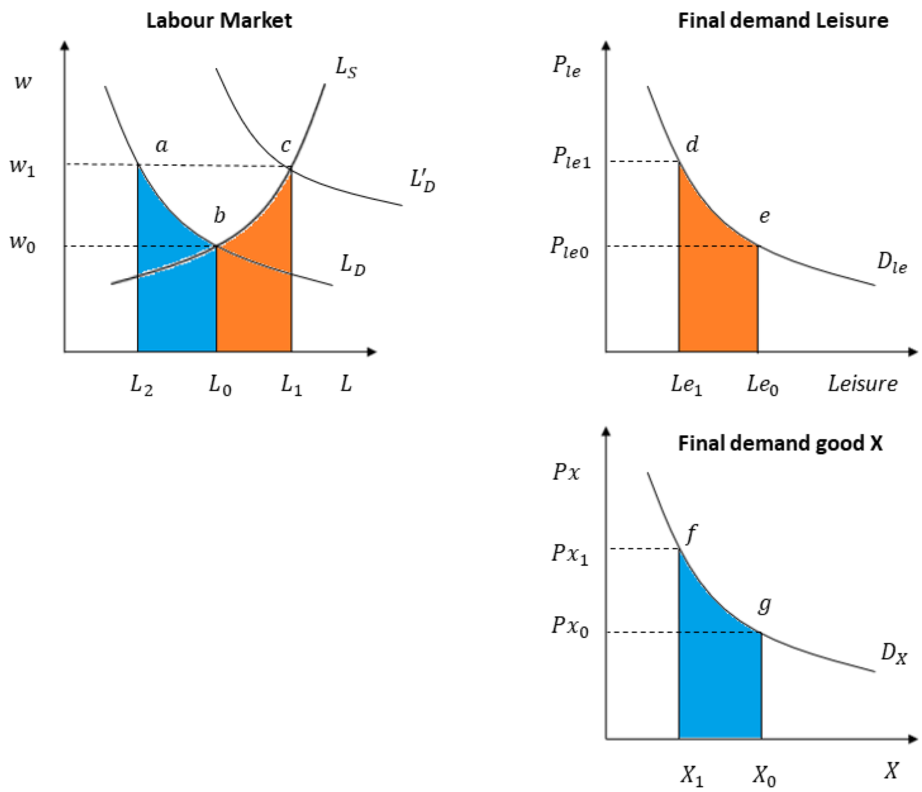
	Initial equilibrium	Final equilibrium
Y_X	1	0.998
Y_Y	1	1.029
T	1	1.006
P_X	1	1.007
P_Y	1	0.978
P_L	1	1.013
w	1	1.013
r_X	1	1.007
r_Y		0.976
$P_U(numeraire)$	1	1
$Income$	300	302.004
SW^{CGE}	-	2.004
$Employment\ X$	40	39.757
$Employment\ Y$	60	60.852
$Total\ Employment$	100	100609
$Leisure$	100	99.391
$Labour\ supply$	100	100.609
ALD	-	-0.244
ALC	-	0.607
ΔS_X	-	-0.244
$\Delta S_{Leisure}$	-	-0.607
IWA	-	2.004

Returning to Figure 1, the area abL_0L_2 represents the value of the production lost in the *secondary* market because of the displacement of labour from the former to the *primary* market. Similarly, the area bcL_1L_0 represents society's opportunity cost (the cost of leisure) of hiring these extra workers because of the project (voluntary unemployed, previous to the project). These areas are reported in Table 12 and Figure 4. They are, respectively: ALD (Area of Labour Displaced, blue-coloured area) and ALC

(Area of Labour Created, orange-coloured area), which, at the same time, coincide with the change observed in their respective final demands approached by the respective total surpluses: ΔS_X for good X (blue-coloured area) and $\Delta S_{Leisure}$ for leisure (orange-coloured area).

In sum, all changes (opportunity costs) triggered by the project in a labour market with voluntary unemployment are correctly included in the final demand of the representative household in a CGE framework (i.e., the welfare change of a project can be approached by merely concentrating on the representative agent, as is generally done by CGE). Alternatively, the welfare change can also be approached by focusing on the changes observed in the income (Income Welfare Approach, IWA) (IWA=SW^{CGE}).

Figure 4. Equivalence between the labour market's opportunity costs and final demands.



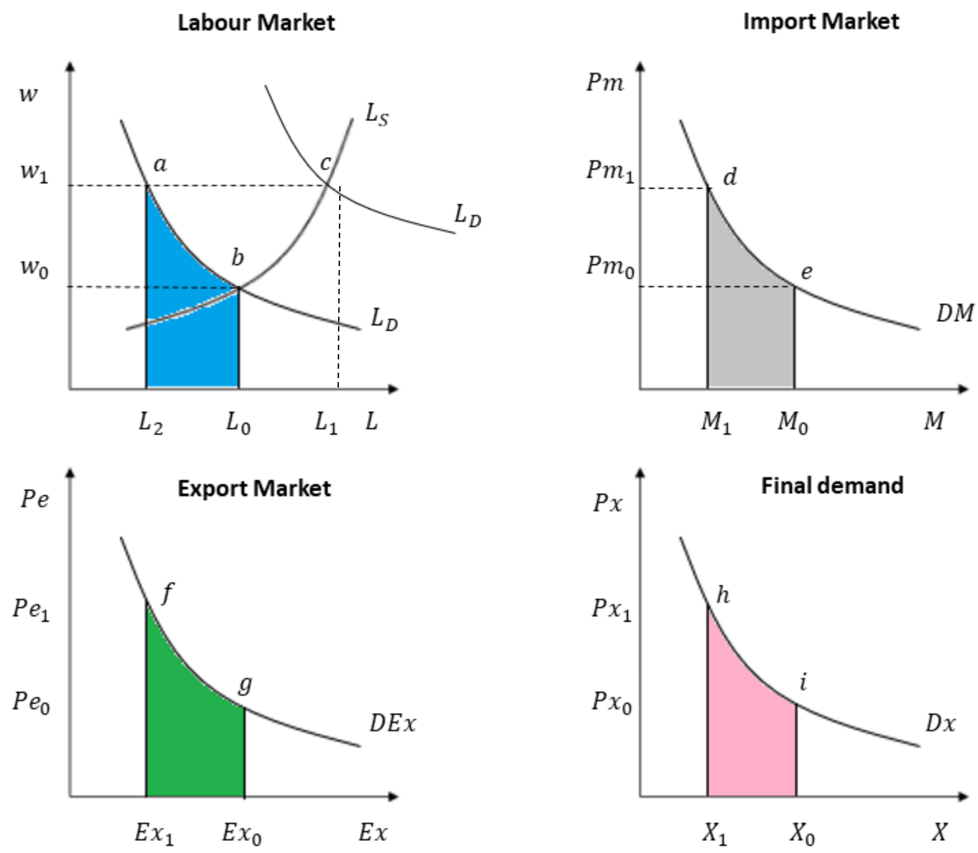
The identity between the opportunity cost of leisure and the area of labour created holds when assuming a small-open economy setting (see Table 13). However, the analysis of the labour force displaced from good Y_X (ALD) and its equivalence in the final demand of this good has to be extended to deal with other factors. On the one hand, the production of Y_X now requires demanding imports. On the other, good Y_X can also be exported. As a result, variation in the total surplus of this good (ΔS_X) equals the variation in labour demand (ALD), the variation in imports demand (AMD) and the variation in exports (AXD), such as $\Delta S_x = ALD + AMD - AXD$. Finally, ARD denotes the variation of factors displaced from sector Y_X that equates ΔS_x.

Table 13. A small open economy with voluntary unemployment (5% shock).

	Zero deficit		**Deficit**		**Surplus**	
	Initial equilibrium	**Final equilibrium**	**Initial equilibrium**	**Final equilibrium**	**Initial equilibrium**	**Final equilibrium**
E_X	1	0.983	1	1.012	1	1.004
Y_X	1	0.994	1	0.999	1	0.999
Y_Y	1	1.029	1	1.025	1	1.024
T	1	1.004	1	1.006	1	1.006
P_X	1	1.011	1	1.010	1	1.012
P_Y	1	0.978	1	0.982	1	0.983
P_L	1	1.011	1	1.012	1	1.013
w	1	1.011	1	1.012	1	1.013
r_X	1	1.011	1	1.009	1	1.012
r_Y	1	0.978	1	0.972	1	0.973
rer *(real exchange rate)*	1	1.011	1	1.010	1	1.012
$P_U(numeraire)$	1	1	1	1	1	1
$Income$	300	302.007	320	321.996	280	281.997
SW^{CGE}	-	2.007	-	1.996	-	1.997
$Employment\ X$	40	39.352	40	39.881	40	39.938
$Employment\ Y$	60	61.088	60	60.677	60	60.655
$Total\ Employment$	100	100.440	100	100.558	100	100.593
$Leisure$	100	99.560	100	99.442	100	99.913
$Labour\ supply$	100	100.440	100	100.558	100	100.086
ALC	-	0.44	-	0.55	-	0.59
$\Delta S_{Leisure}$	-	-0.44	-	-0.55	-	-0.59
ALD	-	-0.654	-	-0.11	-	-0.062
ΔY_{M_X}		-0.130		-0.024		-0.012
ΔY_{E_X}	-	-0.351	-	0.236	-	0.224
ARD		-0.43	-	-0.38		-0.30
ΔS_X	-	-0.43	-	-0.38	-	-0.30
IWA	-	2.007	-	1.996	-	1.997

Figure 5 shows this new equivalence when assuming a zero deficit in the current account position. ΔS_x (Pink-coloured area) = ALD (blue-coloured area) + AMD (grey-coloured area) – AXD (green-coloured area).

Figure 5. Equivalence between the opportunity costs in the input market and final demands of *X* in an open economy setting, with zero deficit.



In sum, CGE models are capable of modelling voluntary unemployment and capturing all the opportunity costs that take place in this market, as noted by CBA. Further, changes observed in the labour market are implicitly included in the total equivalent variation

SW^{CGE}). Thus, from a CGE perspective, the welfare changes that take place in the labour market are directly observed in the final demand (representative household). The results hold when assuming a small open economy setting.

7.5.2 Involuntary unemployment and unemployment benefits

In economic terms, the existence of involuntary unemployment (idle workforce) implies a different *model closure* compared with those previous. The underlying idea is that the model is in equilibrium with all markets clearing, except for the labour market that operates with an excess of supply. In terms of the model's adjustment, it implies that the economy may eventually grow without diverting labour from other activities or uses; causing a different economic adjustment, as explained below.

Table 14. Results of the model with involuntary unemployment and unemployment benefits (5% shock).

	Initial equilibrium	Final equilibrium
Y_X	1	1.018
Y_Y	1	1.048
U	1	1.023
U^G	1	1.244
P_X	1	1.023
P_Y	1	0.980
w	1	1
r_X	1	1.041
r_Y	1	0.993
$P_U(numeraire)$	1	1
$Income$	210	241.817
SW^{CGE}	-	1.475
IWA	-	1.475
ΔS_X	-	0.013
ΔS_Y	-	4.715
$Unemployment$	0.2	0.165
$Subsidies$	0.2	0.165
$Employment\ X$	40	41.657
$Employment\ Y$	60	62.706

Table 14 shows the results of a 5% shock in capital productivity. The first difference, when compared with previous models, is that, both sectors (Y_X and Y_Y) increase their production (by 1.018 and 1.048, respectively). Specifically, this is caused by the involuntary unemployment that allows all sectors to increase their output by demanding more workers. As a result, the unemployment rate falls from 0.2 to 0.165. This *model closure* also affects the adjustment in other factors of production (capital). This resource keeps clearing at the market price, is still a sector-specific factor, and is also supplied perfectly inelastically to the market (fixed supply).

Nonetheless, the increase in production in both sectors forces an increase in the price of this input. In other words, involuntary unemployment triggers a double induced effect. On the one hand, there are more workers employed, which at the same time means lower unemployment benefits (lower public expenses). On the other, capital is also more demanded, but its supply is fixed; and hence, its price increases. Thus, the $Income$ increases from 210 to 241.817. The SW^{CGE} continues to equate with the change in income (IWA), measured by the 'change in the income constraint' (1.475). In this sense, income constraint has been enriched to fulfil two additional roles to reconcile CBA and CGE. Firstly, wages enter net of taxes in income constraint. Secondly, it takes into account the reduction in unemployment benefits that is now retained by the government. Hence, in the context of involuntary unemployment, the income constraint is also capable of measuring the labour opportunity cost by subtracting income labour taxes and unemployment benefits, as postulated by CBA (Johansson and Kriström, 2022), and shown in Figure 2.

Under an open economy framework (see Table 15), the economic impacts of the project result in a real exchange depreciation (rer) that increase exports (E_X). The remaining results are similar to those of the closed economy. In terms of welfare, the conclusions are the same. The SW^{CGE} continues to equate to the IWA.

Table 15. A small open economy with involuntary unemployment and unemployment benefits (5% shock).

	Zero deficit	Deficit	Surplus
E_X	1.013	1.024	1.010
Y_X	1.013	1.011	1.015
Y_Y	1.034	1.032	1.036
U	1.007	1.015	1.020
U^G	1.177	1.161	1.2
P_X	1.019	1.016	1.022
P_Y	0.986	0.985	0.987
w	1	1	1
r_X	1.032	1.028	1.037
r_Y	0.980	0.978	0.984
rer	1.019	1.016	1.022
$P_U(numeraire)$	1	1	1
$Income$	213.561	233.341	193.856
SW^{CGE}	3.561	3.341	2.497
IWA	3.561	3.341	2.497
$Unemployment$	0.174	0.177	0.171
$Subsidies$	0.174	0.177	0.171
$Employment\ X$	41.275	41.116	41.485
$Employment\ Y$	61.920	61.758	62.144

7.5.3 Derived demand

As shown in Table 16, an increase in total factor productivity in the input market (Y_Z) reduces its cost of production (0.966), causing an increase in output (1.053) (direct effect). Similarly, taking into account that this good is demanded as an intermediate good by the output markets (Y_X and Y_Y), both are capable of increasing its production as well (1.017 and 1.017, respectively). Finally, the shock also increases wages (w) and the remuneration of capital (r_X and r_Y) triggering an induced effect as captured by the rise in $Income$. In terms of welfare change, Table 16 now reports the variation in total surplus (ΔS), both in the input market (ΔS^{input}) and the output markets (ΔS^{output}). The results show that $\Delta S^{input} = \Delta S^{output}$, meaning that, as higlighted by CBA in the case of derived demand, the welfare analysis in CGE can also focus on the input market/s or on the output markets. It should be remembered that ΔS^{output} differs from SW^{CGE} because the latter is approached by the equivalent variation. Finally, the input market multiplicative effect (Pme) is introduced into the analysis. As shown, its value coincides with the welfare change of the representative household (U), meaning that the 5% increase in total factor productivity boosts a multiplicative effect in sector Y_Z, which coincides with the multiplicative change in total welfare (SW^{CGE}). More precisely, the conclusion holds regardless of the magnitude of the project, as shown in Table 17.

Table 16. Results of the model with derived demand (5% shock).

	Initial equilibrium	Final equilibrium
Y_X	1	1.017
Y_Y	1	1.017
Y_Z	1	1.053
P_X	1	1.000
P_Y	1	1.000
P_Z	1	0.966
U	1	1.017
w	1	1.01 7
r_X	1	1.017
r_Y	1	1.017
r_Z	1	1.017
$P_U(numeraire)$	1	1
$Income$	300	305.173
SW^{CGE}	1	5.173
ΔS^{input}	1	5.129
ΔS^{output}	1	5.129
IWA	1	5.173
Pme	1	1.017

Table 17. Results of the model with derived demand by varying the magnitude of the shock

	Final equilibrium (1% shock)	Final equilibrium (5% shock)	Final equilibrium (10% shock)
Y_X	1.003	1.017	1.036
Y_Y	1.003	1.017	1.036
Y_Z	1.010	1.053	1.111
P_X	1.000	1.000	1.000
P_Y	1.000	1.000	1.000
P_Z	0.993	0.966	0.932
U	1.003	1.017	1.036
w	1.003	1.017	1.036
r_X	1.003	1.017	1.036
r_Y	1.003	1.017	1.036
r_Z	1.003	1.017	1.036
$P_U (numeraire)$	1	1	1
$Income$	301.007	305.173	310.723
SW^{CGE}	1.007	5.173	10.723
ΔS^{input}	1.005	5.129	10.536
ΔS^{output}	1.005	5.129	10.536
IWA	1.007	5.173	10.723
Pme	1.003	1.017	1.036

Table 18. Results of the model with derived demand in an open economy

	Zero deficit		Deficit		Surplus	
	1% shock	**10% shock**	**1% shock**	**10% shock**	**1% shock**	**10% shock**
SW^{CGE}	1.007	10.723	1.007	10.719	1.007	10.700
ΔS^{input}	1.005	10.536	1.005	10.543	1.005	10.525
ΔS^{output}	1.005	10.536	1.007	10.553	1.006	10.550
IWA	1.007	4.010	1.007	10.719	1.007	10.700
U	1.003	1.036	1.003	1.033	1.003	1.033
Pme	1.003	1.036	1.003	1.035	1.003	1.031

Table 18 shows that approaching the welfare variation by focusing on the input market coincides with the total surplus when assuming zero deficit ($\Delta S^{input} = \Delta S^{output} = \Delta Y_Z$). Nevertheless, it slightly differs with respect to the other *closures* since the value of the discrepancy increases with the magnitude of the project. In terms of the economic impact, the adjustment is very similar in all three cases (zero deficit, deficit and surplus). It should be noted that the current account position causes the main difference. When assuming zero deficit, the change in the current account does not affect income constraint. But in the other two cases, these kinds of variations affect the position; by increasing/decreasing the deficit/surplus.

7.5.4 Derived demand with involuntary unemployment without unemployment benefits

As expected, the existence of involuntary unemployment without unemployment benefits, in the context of derived demand, enhances a second effect by facilitating an increase in labour demand that boosts the economy's income level (see Table 19). As a result, the welfare impact is larger than that without involuntary unemployment. Assuming a shock of 10% in total factor productivity allows us to appreciate the previously described effects more starkly.

Table 19. Results of the model with derived demand and with involuntary unemployment.

	Derived demand (10% shock)	Derived demand with involuntary unemployment (10% shock)
Y_X	1.036	1.073
Y_Y	1.036	1.084
Y_Z	1.111	1.162
P_X	1.000	1.005
P_Y	1.000	0.995
P_Z	0.932	0.928
U	1.036	1.078
w	1.036	1.078
r_X	1.036	1.078
r_Y	1.036	1.078
r_Z	1.036	1.078
$P_U(numeraire)$	1	1
$Income$	310.723	323.449
SW^{CGE}	10.723	23.449
ΔS^{input}	10.536	22.577
ΔS^{output}	10.536	15.052
IWA	10.723	23.449
Pme	1.036	1.078

7.5.5 Derived demand with a negative externality

The model assumes a 5% shock to appreciate more clearly the welfare variation triggered by the externality. As shown in Table 20, the existence of an externality fosters a higher economic and welfare change when comparing the SW^{CGE}, the Pme or the IWA. In all cases, the three values are higher when assuming externalities. Alternatively, the cost of the externality can be *endogenized* by levying a tax on the production of sector Y_Y. In this case, the SW^{CGE} and the IWA would report an unbiased result.

It should be stressed that, as shown in section 7.4.8, in the case of externalities, ΔS and ΔY_Z diverges such as: $\Delta S > \Delta Y_Z$ ($\Delta S^{output} > \Delta S^{input}$). Furthermore, as can also be appreciated, the variation in the production of Y_Z is the same in both cases (with and without externality), showing that the variation of the total surplus in the input market (ΔS^{input}) provides an unbiased welfare evaluation when externalities are present in output markets.

Table 20. Results of the model with derived demand and a negative externality.

	Without externality (5% shock)	With externality (5% shock)
Y_X	1.017	1.017
Y_Y	1.017	1.017
Y_Z	1.053	1.053
P_X	1.000	1.002
P_Y	1.000	0.998
P_Z	0.966	0.968
U	1.017	1.019
w	1.017	1.019
r_X	1.017	1.019
r_Y	1.017	1.019
r_Z	1.017	1.019
$P_U(numeraire)$	1	1
$Income$	305.173	305.829
SW^{CGE}	5.0173	5.826
ΔS^{output}	5.129	5.770
ΔS^{input}	5.129	5.129
IWA	5.173	5.826
Pme	1.017	1.019

7.5.6 Derived demand with non-competitive markets

As shown in Table 21, the welfare measures continue to work adequately according to the theory. SW^{CGE} equals IWA, and U equals Pme. In CBA, the variation in production in the input market ($\Delta Y_Z = \Delta S^{input}$) would show a biased result unless the imperfect market situation in sector $Y_Y$is accounted for. Hence, $\Delta S^{output} > \Delta S^{input}$. In these cases, the welfare change that takes place in the non-competitive market must be included to that obtained in the input market, as done in CBA. Fortunately, the latter is suitably captured in CGE by the SW^{CGE} and IWA when focusing on the output markets. The intuition behind this result is like that of the open economy situation, or when assuming involuntary unemployment.

Table 21. Results of the model with derived demand and a non-competitive market.

	Initial equilibrium	Final equilibrium (5% shock)
Y_X	1	1.020
Y_Y	1	1.017
Y_Z	1	1.019
P_X	1	1.260
P_Y	1.261	1.001
P_Z	1	0.967
U	1	1.019
w	1	1.018
r_X	1	1.018
r_Y	1	1.019
r_Z	1	1.018
$Markup$	0.522	0.522
Sh_Y	0.207	0.207
$P_U(numeraire)$	1	1
$Income$	313.891	319.777
SW^{CGE}	1	5.843
ΔS^{output}	1	5.541
ΔS^{input}	1	5.136
IWA	1	5.843
Pme	1	1.019

7.6 The relevance of the counterfactual and model closure in CGE welfare appraisal

A proper economic evaluation requires us to consider counterfactual scenarios in order to compare the project's social benefit that are triggered with a reasonable alternative use of the resources. In this sense, three kinds of counterfactual are usually employed in CBA (European Investment Bank, 2013): "Do nothing", "Do the minimum", "Do something (else)".

Furthermore, the development of an investment project distinguishes two stages, with each generating its own economic and welfare impact: Stage 1, also known as CAPEX (capital expenditure), comprises the investment phase (construction). In terms of CBA, this stage represents a social cost, but it may also trigger economic and welfare effects. Stage 2, also known as OPEX (operational expenditure), takes place once the infrastructure is implemented, and implies social changes in the welfare of the economy.

A CGE model will take into account all the multiplier effects of the investment phase. These are relevant if the economy is working with involuntary unemployment. In this scenario, the investment phase implies production, lower unemployment, and higher income that leads to higher consumption and firms earning higher profits. These are known as multiplier effects, which are a second-round income effect that happen in the economy after any income shock. This effect occurs in the whole economy and not necessarily in the project's markets of interest. However, the multiplier effect is not required to be measured in CBA when the counterfactual project is expected to impulse the multiplier effects in a similar way. In CGE, the multiplier effects are computationally always part of the results, so that, for an adequate comparison between CGE and CBA they need to be calculated within CGE, and deducted.

In order to deal with this issue, we have considered a counterfactual scenario consisting of returning the investment funds (lump sum transfer) to the taxpayers (representative household). Alternative scenarios may be considered, such as alternative investment projects. The idea is to compare both policies and to decide if the investment project, in its CAPEX phase, results in a welfare gain above the counterfactual scenario.

The model employed in this section is similar to that with derived demand and involuntary unemployment (without unemployment benefits) (see Table 7), but adding the investment (INV) and slightly reformulating the government's role. The former is now demanded by the representative household and government, and it is generated according to the following zero profit condition: $P_{INV}INV - P_X^{\vartheta_X}P_Y^{\vartheta_Y}INV = 0$ where P_{INV} denotes the investment price and, ϑ_X and ϑ_Y denotes the share of goods X and Y in the generation of the investment. Thus, the final goods X and Y are now demanded as consumption and as investment. Regarding the government, it now collects indirect taxes on goods, transfers incomes to the representative household, obtains income from the rent of capital, consumes final goods and invests in capital goods, as previously mentioned. Finally, the analysis will also show the consequences, in terms of welfare, of choosing different *closures*. Specifically, the analysis focuses on assuming three different closures concerning the government's decision to finance the investment, as explained below.

Turning to the model, the government's maximizing problem is similar to problem 2.M2 in the CGE model with derived demand and involuntary unemployment, but adding the investment by goods ((Inv_i^G) multiplied by their prices ($Pinv_i$), the rents of capital ($rK_X^G + rK_Y^G$) and where $deficit$ denotes the government's budgetary position that, in this case, is running a deficit. The new maximizing problem is:

$$max_{G,Inv^G}\ U^G(G, Inv^G)$$

$$subject\ to: M^G = \sum_{i=A}^{B} P_i(1 + tax_i)G_i + Pinv_iInv_i^G$$

where $M^G = taxes + rK_X^G + rK_Y^G + \ P_{UG}deficit$, $G = G_X + G_Y$ and $Inv^G = Inv_X^G + Inv_Y^G$, which represent the total level of consumption and investment of the government, respectively, and $taxes = \sum_{i=X}^{Y} tax_i$.

Similarly, the maximizing problem of the households must be adapted to include the investment decision. The latter is similar to problem 1.M2.

$$max_{C,Inv^H}\ U(C, Inv^H)$$

$$subject\ to: M^H = \sum_{i=A}^{B} P_i(1 + tax_i)C_i + Pinv_iInv_i^H$$

where $C = C_X + C_Y$ and $Inv^{GH} = Inv_X^H + Inv_Y^H$, which represent the total level of household consumption and investment, respectively.

The household income constraint, denoted by equation (9.M1), is also accommodated as follows: $M^H = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\bar{L}}{(1-Un)}\right) - P_{Ln}\left(\frac{\bar{L}}{(1-Un)}\right) Un + P_{UG} transfers$,; where now P_{Ln}, wages net of taxes, equal the gross wage w because there are no unemployment benefits, Un and $Transfers$ are parameters denoting the initial unemployment rate and the social transfers that equate to the government's budgetary position ($deficit = transfers$). Specifically, the way the government decides to finance these transfers defines an important *closure* of the model with a direct impact on the simulation, as noted. If the government decides to assume a fixed deficit, ($\Delta deficit = 0$) then this implies that the social transfer remains fixed as well. Hence, the government will be conditioned by keeping the budgetary position fixed. Alternatively, it could opt to allow the budgetary position to vary ($\Delta deficit \neq 0$). In all cases, the *closure* will affect the governmental decision of consumption and investment and thus, will also affect the economic impact and welfare change. The closure of the governmental position is even more important in this case, because both the investment project and the assumed counterfactual scenario imply public investment. The different closures are accommodated by establishing a constraint, such that: $\Delta deficit = deficit_0 - public_{investment} = 0, > 0\ or < 0$; where $deficit_0$ denotes the initial governmental position and $public_{investment}$ the public funds required to carry out the investment. For the sake of exposition, we will run the simulations under the three different closures ($\Delta deficit = 0$, $\Delta deficit > 0, \Delta deficit < 0$) to highlight the different welfare results. However, in project appraisals, the choice of the closure will depend on the characteristics of the economy and the case study. It should be stressed that, in its current formulation, we are following an investment-driven *closure* for both agents, because the level of investment is determined endogenously[15]. Finally, the investment project to be simulated implies a public investment in good Y_Z. The magnitude of the investment represents around 1.25% of this economy's GDP. Alternatively, the counterfactual scenario implies transferring this amount of public funds to households. Table 22 summarizes the main equations of the model, while Table 23 shows the model's calibrated parameters and values.

[15] In order to follow a savings-driven *closure*, the investment level should be assumed exogenously by establishing an endowment in the income constraint of both agents.

Table 22. The CGE's equations for the counterfactual analysis and different government *closures*

Zero profit
$P_i(1+tax_i)Y_i$- $r_i^{\alpha_i^K} w^{\alpha_i^L} P_Z^{\alpha_i^Z} Y_i = 0$, where $\sum_{i=A}^{B} tax_i = taxes$ $P_z Y_Z$- $r_z^{\alpha_z^K} w^{\alpha_z^L} Y_z = 0$ $P_U U - P_X^{\beta_X} P_Y^{\beta_Y} U = 0$ $P_{UG} U^G - P_X^{\beta_X^G} P_Y^{\beta_X^G} U^G = 0$ $P_{INV} INV - P_X^{\vartheta_X} P_Y^{\vartheta_Y} INV = 0$
Market clearance condition
$\overline{K} = \sum_{j=A}^{B} \widehat{K}_j + K_X^G + K_Y^G$ $\left(\frac{\overline{L}}{(1-Un)}\right) - \left(\frac{\overline{L}}{(1-Un)}\right) Un = \sum_{i=1}^{3} \frac{\alpha_i^L}{w} P_i Y_i$ $Z = \sum_{i=1}^{2} \frac{\alpha_i^Z}{P_Z} P_i Y_i$ $C = C_X + C_Y$ $Inv^H = Inv_X^H + Inv_Y^H$ $G = G_X + G_Y$ $Inv^G = Inv_X^G + Inv_Y^G$ $Y + X = C + G + Inv^H + Inv^G$
Income constraint
$M^H = \sum_{j=A}^{B} r_j \widehat{K}_j + P_{Ln}\left(\frac{\overline{L}}{(1-Un)}\right) - P_{Ln}\left(\frac{\overline{L}}{(1-Un)}\right) Un + P_{UG} transfers =$ $\sum_{i=A}^{B} P_i C_i + Pinv_i Inv_i^H .;$ $M^G = taxes + rK_X^G + rK_Y^G + P_{UG} deficit = \sum_{i=A}^{B} P_i G_i + Pinv_i Inv_i^G$
additional constraint
$\Delta deficit = deficit_0 - public\_investment \ = 0, > 0 \ or < 0$

Table 23. Calibrated parameters for the counterfactual analysis and different governmental closures

α_X^K	0.60
α_X^L	0.18
α_X^Z	0.22
α_Y^K	0.25
α_Y^K	0.40
α_Y^Z	0.22
α_Z^L	0.38
α_Z^K	0.4
ϑ_X	0.5
ϑ_Y	0.5
β_X	0.5
β_Y	0.5
β_X^G	0.5
β_Y^G	0.5
M	370
M^G	74.444
Un	0.10
$deficit$	70
$taxes$	0.1

Table 24 shows the results of the analysis. As can be appreciated, the economic impact and welfare vary slightly with the governmental *closure*. The main source of change is caused by governmental behaviour, measured by its equivalent variation, $SW_{government}^{CGE}$, that varies from -4.169 to -5.776 when assuming that the investment is financed with more deficit ($\Delta deficit > 0$) or less deficit ($\Delta deficit < 0$), respectively. In any event, in all cases the investment project triggers larger economic and welfare impacts than the counterfactual scenario. Likewise, the former also reduces the unemployment rate, which decreases from 0.1 in the equilibrium, to 0.082 in all cases.

Table 24. Results of the model with different governmental *closures*

	$\Delta deficit = 0$		$\Delta deficit > 0$		$\Delta deficit < 0$	
	Investment project	Counterfactual	Investment project	Counterfactual	Investment project	Counterfactual
Y_X	1.019	1.000	1.019	1.000	1.019	1.000
Y_Y	1.021	1.000	1.021	1.000	1.021	1.000
Y_Z	1.061	1.000	1.061	1.000	1.061	1.000
P_X	1.001	1.000	1.001	1.000	1.001	1.000
P_Y	0.999	1.000	0.999	1.000	0.999	1.000
P_Z	0.961	1.000	0.961	1.000	0.961	1.000
U	1.016	1.014	1.016	1.014	1.016	1.014
U^G	1.038	0.922	1.049	0.944	1.029	0.922
INV	1.019	1.012	1.010	0.994	1.027	1.012
w	1.000	1.000	1.000	1.000	1.000	1.000
r_X	1.020	1.000	1.020	1.000	1.020	1.000
r_Y	1.020	1.000	1.020	1.000	1.020	1.000
r_Z	0.907	1.000	0.907	1.000	0.907	1.000
$P_U(numeraire)$	1	1	1	1	1	1
$Unemployment$	0.082	0.10	0.082	0.10	0.082	0.10
$SW_{households}^{CGE}$	5.947	5	5.947	5	5.947	5
$SW_{government}^{CGE}$	2.864	-5.776	-2.136	-4.169	7.530	-5.776
SW^{CGE}	8.811	-0.776	3.811	0.831	12.477	-0.776

7.7 Conclusions

This paper has shown that a project's net welfare change can be approached in CGE by differences in the economy's income constraint - with and without the project - by employing the *Income Welfare Approach*. This result coincides with Johansson (2022) when deriving general equilibrium cost-benefit rules, and shows that when considering the same economic situations, both CBA and CGE should provide identical welfare measures.

Overall, the paper shows that CGE models are already capturing most of the opportunity costs (shadow prices) emphasized by CBA. Specifically, all welfare variations that take place in the different markets are captured in the CGE's final demand goods. The analysis demonstrates that all the economic changes that occur in the primary markets of an economy are included in the final demand of the representative/s household/s in a CGE model. Thus, the welfare analysis can focus on final demands. In this case, both the Equivalent Variation (EV) and the Income Welfare Approach (IWA) provide identical and suitable approaches for measuring any welfare variation.

The paper has shown that there is a special case that takes place when omitting the impact on output markets, so that the welfare in CGE and CBA equates when dealing with derived demand ($\Delta S^{output} = \Delta S^{input}$). However, as also noted by CBA, this result does not hold in certain open economy situations; or when assuming idle resources (involuntary unemployment), imperfect markets or externalities. For instance, the existence of involuntary unemployment with derived demand enhances a second effect by facilitating an increase in labour demand. As a result, the welfare impact is greater than without the assumption of involuntary unemployment. In any case, CBA does incorporate the value of distortions in any market when calculating a project's net welfare effect. Nevertheless, when the value of the distortions is related to the multiplier effect of the project, and the multiplier effect of the next best alternative is expected to be similar to the counterfactual, they can be ignored.

Similarly, in the case of derived demand with a negative externality, the welfare valuation when focusing on final demand, either measured by the equivalent variation or the variation in surplus, is larger than the welfare obtained when focusing on the input market ($\Delta S^{output} > \Delta S^{input}$). This bias is caused by the negative externality that pushes the price in this market down (below the true social cost), generating a provision of this good above what is socially desirable. However, when detracting this social cost from the final demand for this good, both the EV and surplus approach converge to the value reported by ΔY_Z. Alternatively, the social cost can also be internalized by levying a tax on the consumption of this good in the model; causing that ΔY_Z equates to the surplus without *ex-post* adjustments.

A CGE model can also shed light on the welfare impact in cases of derived demand. As theoretically proven and tested in the models, the economic impact in the input market, in multiplicative terms ($\widetilde{P_Z}\widetilde{Y_Z}$), (input market multiplicative effect, Pme) coincides with the total welfare effect ($\widetilde{EV}$ and $\widetilde{M}$, which denote the equivalent variation and income variation in multiplicative terms) in all economic situations, except in open economy situations with a surplus or deficit, such as: $PME = \widetilde{M} = \widetilde{EV} = \widetilde{P_Z}\widetilde{Y_Z}$.

Moreover, it should be noted that CGE provides a comprehensive methodology to conduct counterfactual scenarios. Thus, once the model is built, it is relatively straightforward to conduct any policy analysis. Likewise, the *model closure* represents an issue of concern when conducting welfare analyses in CGE. Specifically, as demonstrated for the government's budgetary position in the final section, the way the government decides to finance a public investment does affect the welfare measurement. Fortunately, a CGE framework can address different *model closures*. Table 25 summarizes the main welfare measures and their divergences under different market situations in CGE.

Hence, we conclude that a project's net welfare effect conducted with CGE should equate to that of CBA when both methods are consistently applied. The presence of distortions or appraisal in an open economy, should not be a cause of divergence in the measurement of a project's net welfare effect, as CBA incorporates any relevant distortion in other related markets. In the case of the multiplier effect, when the value of the distortions is expected to be similar to the counterfactual, they can be ignored.

Table 25. Welfare measure divergences under different market situations in CGE

		SW^{CGE}	IWA	ΔCS	PME
Voluntary unemployment	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	-*	-
	Open economy	Unbiased	$SW^{CGE} = IWA$	-	-
Involuntary unemployment	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	-	-
	Open economy	Unbiased	$SW^{CGE} = IWA$	-	-
Derived demand	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	$\Delta S^{output} = \Delta S^{input}$	$PME = \widehat{EV}$
	Open economy	Unbiased	$SW^{CGE} = IWA$	$\Delta S^{output} \neq \Delta S^{input}$	$PME \neq \widehat{EV}$
Derived demand and involuntary unemployment	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	$\Delta S^{output} \neq \Delta S^{input}$	$PME = \widehat{EV}$
Derived demand and externalities	**Closed economy**	Biased**	$SW^{CGE} = IWA$	Unbiased*** $\Delta S^{output} \neq \Delta S^{input}$	$PME \neq \widehat{EV}$
Derived demand and imperfect competition	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	$\Delta S^{output} \neq \Delta S^{input}$	$PME = \widehat{EV}$
Derived demand and different *model closure*	**Closed economy**	Unbiased	$SW^{CGE} = IWA$	$\Delta S^{output} \neq \Delta S^{input}$	$PME = \widehat{EV}$

*Not applicable

**Unbiased when endogenizing the externality's cost by levying a tax on the consumption of the good that is causing it.

***Biased when the externality is caused by a sector whose production is demanded from Y_Z.

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ANNEX I

Proposition: *A rise in productivity enhances a welfare improvement*

Proof:

Let's assume the introduction of a productivity improvement technology in a closed economy with two factors of production K and L and one single good Y. And where superindex 0 and f denote the initial and final situation following introduction of the technology.

The first derivatives of the production are all positives:

$$\frac{\partial F^0}{\partial L} > 0, \frac{\partial F^0}{\partial K} > 0, \frac{\partial F^f}{\partial L} > 0, \frac{\partial F^f}{\partial K} > 0$$

But decreasing:

$\frac{\partial F^{0\prime}}{\partial L \partial L} < 0, \frac{\partial F^{0\prime}}{\partial K \partial K} < 0, \frac{\partial F^{f\prime}}{\partial L \partial L} < 0, \frac{\partial F^{f\prime}}{\partial K \partial K} < 0$

Finally, $\frac{\partial F^0}{\partial L} < \frac{\partial F^f}{\partial L}$ and $\frac{\partial F^0}{\partial K} < \frac{\partial F^f}{\partial K}$ capture the productivity improvement of the new technology.

By the circular flow of income, $Y = F(K, L) = M = wL + rK$.

Imposing that, the real price of L (w) and K (r) equals its marginal productivity:

$MP_L = \frac{\partial F}{\partial L} = \frac{w}{P}; MP_K = \frac{\partial F}{\partial K} = \frac{r}{P}$

By the Euler theorem and distinguishing between both situations:

$$Y^0 = F^0(K, L) = \frac{\partial F^0}{\partial L} L_0 + \frac{\partial F^0}{\partial K} K_0$$

$$Y^f = F^f(K, L) = \frac{\partial F^f}{\partial L} L_0 + \frac{\partial F^f}{\partial K} K_0$$

Remembering that $\frac{\partial F^0}{\partial L} < \frac{\partial F^f}{\partial L}$ and $\frac{\partial F^0}{\partial K} < \frac{\partial F^f}{\partial K}$, implies that:

$\frac{w_0}{P_0} < \frac{w_f}{P_f}$ and $\frac{r_0}{P_0} < \frac{r_f}{P_f}$

which also causes that: $Y^f > Y^0$ and that $M^f > M^0$. Hence, $EV = M^f - M^0 > 0$.

8 Economic appraisal with CBA and CGE: Transport case study

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8.1 Introduction

Cost-Benefit Analysis (CBA) and Computable General Equilibrium (CGE) models are tools for the measurement of the effects of public intervention on the economy. They have traditionally been used to measure different effects. CBA, on the one hand, is in essence a general equilibrium set of shortcuts that aims to address the impossible challenge of measuring every effect on the economy but, focusing on a set of strongly interrelated market (e.g., the set of transport modes), seeks to approximate the social *net welfare effect* of public intervention. There is no reason to initially ignore other markets or any estimation of relevant additional effects, such as the wider economic impacts derived from changes in location (when they are expected to be significant). CGE models, on the other hand, have traditionally been used to estimate the *impact* of investments on production and employment, by accounting for indirect and induced effects (income and employment multipliers), which can have a significantly greater impact on the economy when compared to a typical CBA.

In this paper, we compare the measurement of the benefits of an investment in the construction and operation of a new High-Speed Railway (HSR) to replace an existing conventional rail service that connects two cities with no intermediate stations. For illustrative purposes the case is a simplification of actual HSR evaluations, and aims to compare the net social welfare obtained from the project's implementation using CBA and CGE methods.

An investment in transport infrastructure absorbs scarce resources, like any alternative project, but in exchange aims to deliver direct benefits such as time savings, lower operating costs, less accidents or positive environmental impacts. Moreover, the impact on the economy exceeds the limits of the primary market through multiple channels in so-called secondary markets linked by relationships of complementarity and substitutability; and through additional rounds of effects, known as induced effects (the multiplier effect), in practically the whole economy. In this process, consumers and firms adjust their decisions, with long-term effects that sometimes go beyond the economic life of the project.

CBA can provide an estimation of the net social benefit of many typical projects, bearing in mind the multi-market effects of such public interventions. The point is to distinguish between the impact on the economy and net welfare effects. Indirect effects in the absence of distortions (price is not equal to social marginal cost) can be ignored. The same is true with induced effects (in the presence of distortions) when they are expected to be shared with the next best alternative. CBA is incremental, and this simplifies the task.

An alternative way to estimate the welfare effect of a project is through a CGE model where the production technology, resource constraints and preferences are explicitly modelled, and the project's welfare effects are calculated with this global perspective. The problem is, as we show in this paper, that there is not a single CGE model that can be used for any project, nor even a specific transport CGE model for any transport project. These general models "…may be appropriate for some large projects but is not a general solution. Such models are expensive, and it would be disproportionate to use them for most projects. A consequence of their expense is that typically one model is built and then applied to different situations in a somewhat mechanical manner, paying insufficient attention to the characteristics of the scheme and its likely effects. They then fail to capture the quite different impacts of e.g. an urban commuting scheme, an urban by-pass, or an inter-city rail line. These projects have different stated objectives and will trigger different private sector responses. It follows that the appraisals must be designed to be context specific. Some should focus on the consequences of getting more people into a city centre, others on relieving traffic congestion or on better linking remote locations, and so on" (Laird and Venables, 2017).

It is worth emphasizing that CBA rules are obtained from the same general equilibrium theory as CGE. CBA is not a partial equilibrium approach where everything remains constant in the rest of the economy. On the contrary, there is a well-developed theoretical justification for the use of market demand functions for general equilibrium welfare effects assessment (Johansson, 1993; Johansson and Kriström, 2016). The

Projects' welfare consequences can be estimated using a set of reduced-form elasticities that incorporate general equilibrium effects in all the affected markets (Just et al, 2004; Chetty, 2009; Kleven 2018, Kriström, 2023). The measurement of direct effects in the primary market or in the key group of strongly inter-related markets and the estimation of any relevant wider economic impact can be a good approximation of the project's social value (see de Rus, 2023).

Methodological examples and actual cases of the CBA of HSR, can be found in Nash (1991), de Rus and Inglada (1993), Vickerman (1997), Martin (1997), Levinson *et al.* (1997), de Rus and Inglada (1997), Steer Davies Gleave (2004), Atkins (2004), de Rus and Román (2005), de Rus and Nombela (2007), de Rus (2011), de Rus (2012), de Rus *et al*. (2020), AIReF (2020), and Johansson (2023).

CGE models consider the whole economy and assume that both market prices and quantities are determined endogenously. As a result, CGE models provide a complete overview of the economic impacts of an investment project in all sectors and for all agents. This is precisely the approach adopted by Berg (2007), Ando and Meng (2009), Kim and Hewings (2009), Verikios and Zhang (2015), Shahrokhi and Bachmann (2018), Robson *et al*. (2018) and Shahirari *et al*. (2021) to conduct transport evaluations.

In the literature, CGE modelling has been widely applied to international trade, taxation, and any kind of macroeconomic shock, rather than to the economic evaluation of projects. Consequently, the focus has been more on calculating economic impacts instead of net welfare effects. This paper considers the appropriate adjustments required in the CGE model to estimate net welfare effects.

As said, this paper analyzes CBA and CGE models that measure benefits in a simplified case of a transport investment project. Following this introduction, Section 8.2 provides a social appraisal of transport investments under both methods. Section 8.3 describes the simplified case and the main assumptions and parameters; while Section 8.4 gives the results and compares them. Finally, Section 8.5 provides the conclusions.

8.2 The social appraisal of transport investments

8.2.1 CBA of transport projects[1]

We assume an economy consisting of a representative individual, who has a continuous and increasing utility function that depends on the amounts chosen within a set of n consumption activities that includes all goods and services produced in the economy, $U(x_1,\ldots, x_n)$, where x_j represents the quantity of good or service j, with $j = 1,\ldots, n$. This individual chooses his optimal set of consumption activities by maximizing his utility given his budget constraint. This constraint delimits all combinations of goods and services, including leisure, that may be obtained at any given time, according to their (exogenous) market prices and individual income, which has two components (wage and profits).

This individual obtains income by working, given his time endowment, $\bar{l}$ (for example, 24 hours per day or 365 days per year). Let us denote by t_j the time required to consume each unit of good or service j, w the wage received per unit of working time, so the individual´s labour income is given by wl, where l represents the working time chosen ($l = \bar{l} - \sum_{j=1}^{n} t_j x_j$).

Moreover, we will assume that all firms are ultimately owned by this representative individual and they distribute all their profits; thus, the individual´s total income obtained from profits is given by $\Pi = \sum_{j=1}^{n} \pi_j$, where π_j is the maximum profit obtained by firm j from producing and selling good or service j. From each firm´s point of view, this profit is obtained by solving the standard maximization program, which allows us to obtain a solution $\pi_j = p_j f_j(l_j^*) - w l_j^*$ (see Appendix), where p_j is the market price of good or service j, and l_j^* represents the amount of labour (the only input in this model) used by firm j to produce x_j^s through the production function $f_j(l_j)$ in equilibrium. Note that, in equilibrium, the sum of all labour inputs used by firms must be equal to the working time offered by the representative individual ($\sum_{j=1}^{n} l_j^* = l$).

The results from the maximization program can be used to define the individual´s budget constraint:

$$\sum_{j=1}^{n} p_j x_j \leq \Pi + wl, \tag{1}$$

[1] The subsection heavily draws on Johansson and de Rus (2018), de Rus and Johansson (2019) and de Rus *et al*. (2022).

which can be also rewritten as:

$$\sum_{j=1}^{n} p_j x_j \leq \Pi + w\left(\bar{l} - \sum_{j=1}^{n} t_j x_j\right),$$

that is:

$$\sum_{j=1}^{n} g_j x_j \leq \Pi + w\bar{l}, \tag{2}$$

where $g_j = p_j + wt_j$ represents the generalized price of good or service j. For example, in the case of air transport, it includes the monetary price paid (the airline fare, airport charges, etc.) and the users' time cost (access and egress time, waiting time and flying time).[2]

It can be noted that expressions (1) and (2) are equivalent and, thus, we can write the individual's budget constraint in terms of market prices, $p = (p_1, \dots, p_n)$, and the individual's income (y), $\Pi + wl$; or in terms of the generalized prices, $g = (g_1, \dots, g_n)$, and the potential maximum income (profit income plus the value of time endowment), $\Pi + w\bar{l}$, here called generalized income (y^g).

Thus, we can solve the individual´s maximization problem that can be expressed in terms of market or generalized prices (see Appendix), with the latter being preferred when we are evaluating transport projects, since most can be interpreted as changes in generalized prices (either due to changes in market prices and/or in travel time).[3] A simplifying assumption that does not affect the main results of the paper is that the opportunity cost of travel time is the wage rate (see Hensher, 2011 for an overview of the major theoretical and empirical issues concerning the value of travel time savings).[4]

The solution of the individual´s maximization problem yields the Marshallian demand function for each good or service j, given by $x_j^* = x_j(g, y^g)$, with $g =$

[2] Price and value of travel time may not be the only relevant parameters affecting consumers' travel behaviour. When the overall conditions of transport services matter (in terms of comfort, reliability, safety, etc.), some additional elements of utility should be added to the generalized price. For the sake of simplicity, we omit these elements here, as the main results are unaffected.

[3] Note that if a transport project reduces travel time, the individual will have more time to work (or for leisure), which in turn will lead to the production of additional goods. Moreover, the project costs are measured in terms of the goods' net monetary value that the individual has to give up in order to implement such a project.

[4] In practice, determining the value of time often becomes an empirical question since for some individuals (those who are willing to work, but unable to find a job) the wage rate might overestimate the true opportunity cost of leisure, whereas for others the wage rate underestimates their non-working time (when other non-monetary benefits are associated with the job). In practice, the value of travel time is usually denoted by vt_j (and not just wt_j, as assumed for simplicity in our model).

$(g_1, \dots, g_n)$ representing the vector of all generalized prices, and the generalized income $y^g = \Pi + w\bar{l}$, which is given by the sum of profit income and the value of the individual's time endowment.

When the individual is maximizing his utility, the opportunity cost of one hour is the wage rate w, identified with the value of time in our model because, in the optimum, the individual is indifferent between consuming additional goods, including leisure, or working more (and giving up the corresponding units of time). Hence, the hourly wage w, is the opportunity cost of time, disregarding its final use (either leisure or consumption). This is the key idea for the measurement of direct benefits of transport improvements: reducing the required time for transport, increases the time available for consumption of other goods or for working. These benefits imply an opportunity cost, measured in terms of the monetary value of the other goods that the individual gives up when implementing the project.[5]

By substituting all these demands in the (direct) utility function, we obtain the individual's indirect utility function, defined as:

$$U(x_1^*, \dots, x_n^*) = V(g, y^g), \tag{3}$$

which gives the individual's maximal attainable utility when faced with a vector g of generalized prices and y^g, the individual's generalized income. This utility function is called indirect because individuals usually think about their preferences in terms of what they consume rather than in terms of prices and income.

In addition, note that by replacing the Marshallian demands into the Lagrange function and considering first order conditions (see Appendix), we find that, in equilibrium $L^* = V(g, y^g) - \lambda\left(\sum_{j=1}^{n} g_j x_j^* - \Pi - w\bar{l}\right) = V(g, y^g)$. Therefore, $\frac{\partial L^*}{\partial y^g} = \lambda = V_y = \frac{\partial V(g, y^g)}{\partial y^g}$, i.e. the Lagrange multiplier can be interpreted as the individual's marginal utility of generalized income (V_y).

We are now ready to analyze the effects of a transport project, i.e. an exogenous intervention that reduces the generalized price and/or increases the number of trips,

[5] Once the spatial nature of transport activities is included in the model, the explicit treatment of changes in proximity and location might yield potential increases of productivity and the so-called 'wider economic benefits'. Thus, time savings (as measured in our model) would underestimate the social benefits of transport projects (see de Rus, 2023).

either via investments (e.g., an increase in capacity) or other policies (such as more efficient pricing, better management practices, etc.). In our single representative individual world, the change in social welfare, dW, is simply given by the change in individual utility ($dW = dU$) and, thus, considering the direct utility function evaluated in the initial equilibrium, we can write:[6]

$$dW = dU = \sum_{j=1}^{n} \frac{\partial U(x^*)}{\partial x_j} dx_j. \tag{4}$$

Then, substituting the first order condition of the individual's maximization program (see Appendix):

$$\frac{dW}{V_y} = \sum_{j=1}^{n} (g_j - wt_j) dx_j = \sum_{j=1}^{n} p_j dx_j. \tag{5}$$

According to this expression, the change in social welfare resulting from a transport project that implies a marginal change in the number of trips is equal to the difference between the individual's generalized willingness to pay (WTP) for those additional trips minus the value of its travel time, that is, the market price. Note that, if the transport project has a cost, some dx_j are negative, representing the monetary value of production and consumption of other goods, including time, that the individual must give up for the project to be implemented.

Equivalently, if we use the indirect utility function, we get:

$$dW = dV = \sum_{j=1}^{n} \frac{\partial V}{\partial g_j} dg_j + V_y dy^g. \tag{6}$$

Applying the envelope theorem, we obtain:

$$\frac{\partial V}{\partial g_j} = -\lambda x_j = -V_y x_j, \tag{7}$$

[6] Leaving aside the assumption of a representative individual, the change in social welfare is given by the sum of the change in each individual's utility, weighted by the social marginal utility of each individual. The value of the social marginal utility of income can be assumed to be equal to one, only if income distribution is optimal, or society has at its disposal a means for unlimited and costless redistribution and, therefore, monetary gains and losses can be aggregated across individuals in order to determine whether the project is socially worthy. However, redistribution is not costless since, for example, it might affect incentives in a negative way. In this case, the actual income distribution may not be far from the constrained optimal one. This means that the actual situation represents a kind of constrained optimum, and possibly we can just sum gains and losses across individuals. This is also sufficient if relative prices are left more or less unchanged (see Johansson and Kriström, 2016, for further details on aggregation problems).

which can be replaced into expression **(6)** to finally obtain a usable expression that allows us to evaluate the effects of transport projects:

$$\frac{dW}{V_y} = -\sum_{j=1}^{n} x_j dg_j + dy^g. \quad (8)$$

The reduction of the generalized price in expression (8) can be a change in the market price, a change in travel time, or both.

A price reduction

Let us consider that the change in the generalized price of good or service j is only due to a change in the market price p_j, while the required (travel) time t_j remains constant, that is, $dg_j = dp_j$. In this case we have:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^{n} \frac{\partial \pi_j}{\partial p_j} dp_j = \sum_{j=1}^{n} x_j^s \, dp_j. \quad (9)$$

By substituting this result into expression (8), and assuming all product markets clear, $x_j = x_j^s$:

$$\frac{dW}{V_y} = -\sum_{j=1}^{n} x_j dp_j + \sum_{j=1}^{n} x_j^s dp_j = 0, \quad (10)$$

that is, a marginal variation in the generalized price of good or service j due to a change in the market price p_j (with t_j constant) does not produce any effect on welfare. The reason is that, if all product and labour markets clear, a change in the market price without any time saving is simply a transfer between consumers and producers. Moreover, we assume that there are no other additional welfare effects to be considered in the rest of the economy.

A time-saving

Let's consider now that the change in the generalized price of good or service j is due to a change in time t_j while the market price p_j remains constant, that is, $dg_j = wdt_j$. In this case:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^{n} w \frac{\partial \pi_j}{\partial t_j} dt_j = \sum_{j=1}^{n} w \left(p_j \frac{\partial f_j(l_j^*)}{\partial l_j} - w \right) \frac{\partial l_j}{\partial t_j} dt_j, \quad (11)$$

which, according to the first order condition of the profit maximization program of firm j is zero (see Appendix), i.e., $dy^g = 0$. Then, by substituting this into expression (8), we finally obtain that:

$$\frac{dW}{V_y} = -\sum_{j=1}^{n} x_j w dt_j. \tag{12}$$

In other words, the increase in social welfare due to a marginal reduction in travel time is equal to the value of time savings ($dt_j < 0$) multiplied by the number of trips benefiting from that improvement.

If the effect of the investment project is not marginal, we can approach the change in welfare through the change in the consumer's utility compared with the counterfactual, i.e., the comparison between the situation "with the project" (superscript 1) and "without the project" (superscript 0):

$$\Delta W = \Delta V = V(g^1, y^{g^1}) - V(g^0, y^{g^0}), \tag{13}$$

Although this utility is not directly measurable, expression (13) is very useful. If the individual is asked how much money he is willing to pay to enjoy the benefits derived from the reduction in the generalized price of transport, we obtain a monetary measure of the change in utility. This is the so-called 'compensating variation' (CV), which can also be interpreted as how much money the individual would be willing to pay to have the project approved by the government. When CV is taken from the individual's income, he is indifferent between the situation with and without the project, as expressed by:

$$V(g^1, y^{g^1} - CV) = V(g^0, y^{g^0}). \tag{14}$$

If the project implies costs, the compensating variation does not only account for the benefits of the project but also for the negative effects on utility derived from the diversion of goods and labour from other uses (i.e., the cost of the project). Therefore, the compensating variation represents the change in the generalized WTP due to the project benefits, minus the willingness to accept for the goods and labour required by the project. The net social value of the government intervention is then:

$$\Delta W = CV = \Delta WTP - \Delta Resources. \tag{15}$$

Time savings, the main benefit in many transport projects, can be considered either as an increase in the WTP or a positive change in resources. We follow here the latter option. The decrease in the generalized price of transport with the project increases the number of trips, and thus a change in the WTP of this additional demand. For the existing traffic, the WTP (including time) has not changed and thus we can consider the value of time saved as a (positive) change in resources.

Suppose the representative individual is asked for his WTP for the transport project, disregarding any effects on profit income. Then, the maximum WTP, CV, as defined in expression (14), and the new partial one, denoted by CV^P are given by:

$$CV = CV^P + \Delta PS, \tag{16}$$

where ΔPS represents the change in firms' profits due to the transport project. If income effects are not significant, CV^P can be approximated through the change in consumer surplus (CS),[7] and then:

$$\Delta W = CV \approx \Delta CS + \Delta PS, \tag{17}$$

that is, social welfare changes can be approximated through the sum of changes in the surpluses of consumers and producers affected by the project.

Expressions (13) to (17) can be generalized to include other roles of the individual in society. As explained in de Rus (2023), a useful disaggregation includes six roles. In addition to consumer and taxpayers, we differentiate:

- Owners of capital: generally called producers, who have a variety of equipment, infrastructure and facilities where goods and services are produced.
- Owners of labour: including, for simplicity, employees with different skills and productivity levels
- Landowners: Notice that the fixed factor 'land' is restricted here to soil for agriculture or land for residential or productive uses.
- Rest of society: Including the common property of natural and environmental resources (also called 'natural capital').

To illustrate these ideas, consider a market with n modes of transport or activities, and consider a transport project consisting in constructing and operating a new HSR line to replace an existing conventional rail service. The initial equilibrium ('without-the-project') is given by $(x_r^0, g_r^0,)$, where g_r^0 represents the generalized price for conventional train users, $g_r^0 = p_r^0 + v_r t_r^0$, with p_r^0 and t_r^0 denoting the conventional train monetary price and total travel time (that includes access, waiting, in-vehicle and

[7] The relative error of using the change in consumer surplus instead of CV^P is low if the elasticity of demand with respect to income, or the proportion of change in consumer surplus with respect to income, is small enough (Willig, 1976).

egress time), respectively, and v_r is the value of time for users initially travelling by conventional train;[8] and x_r^0 is the existing conventional train services demanded at generalized price g_r^0. The project implies a reduction in the generalized price ($g_r^1 < g_r^0$) because of a reduction in travel time ($t_r^1 < t_r^0$). Note that, although there is a reduction in generalized price, it is possible to charge a higher price $p_r^1 > p_r^0$, though it must be lower than the reduction in the value of the time component.

We assume that the value of time for users initially choosing an alternative mode or activity j (v_j) is different than the value of time for users initially travelling by conventional train; with $j = 1, \dots, n$ and $j \neq r$. We also assume that income effects are not significant.

The change in social welfare is the sum of the changes in surpluses of all the agents affected by all transport modes and in other economic activities, affected by the project, which can easily be calculated using the standard assumption of a linear approximation between the initial and the final generalized prices (the so called 'Rule of a Half').[9] We may distinguish between existing demand (users already travelling by conventional train), deviated demand (users changing from an alternative mode with the project) and generated demand (coming from other consumption activities). We follow the same procedure for deviated and generated demand since the former comes from other modes while the latter comes from other activities, so we call them both deviated demand. Using the superscripts *e* and *d* to denote changes due to existing demand, and deviated demand from mode or activity *j*, respectively, the transport project implies a change in social welfare given by $\Delta W = \Delta W^e + \sum_{\substack{j=1 \\ j\neq r}}^{n} \Delta W_j^d$.

The change in the surplus of existing users associated with the reduction in the generalized price from g_r^0 to g_r^1 is given by $(g_r^0 - g_r^1)x_r^0$. The change in the firm's revenues for existing users is equal to $(p_r^1 x_r^0) - (p_r^0 x_r^0)$. To simplify the analysis, we do not consider investment nor operating costs in the rail market. Moreover, taxes (and other distortions) are not considered in this example, and we assume no change in workers' surplus nor landowners' surplus.[10] Finally, we assume that there is

[8] The value of time may be different to the wage rate, depending on the sort of travel they undertake (see Mackie *et al*., 2001, for further details).
[9] See Harberger (1965), Neuberger (1971) and Small (1999).
[10] Nevertheless, taxpayer' surplus would include the taxes paid by users, as the difference between seller and buyer prices, plus the taxes paid by producers over their production factors. Revenues must be

competition in all other modes or activities, so the change in their producers' surplus is zero.

Therefore, the change in social welfare due to the existing demand is given by:

$$\Delta W^e = (g_r^0 - g_r^1)x_r^0 + (p_r^1 x_r^0 - p_r^0 x_r^0) = (v_r t_r^0 - v_r t_r^1)x_r^0. \quad (18)$$

In the case of deviated demand from mode or activity j, $g_j^0 = p_j + v_j t_j^0$ denotes the generalized price for the user indifferent between conventional train and alternative j without the project, with p_j and t_j^0 denoting the alternative transport mode or activity monetary price and total travel time of such an indifferent user, respectively. Notice that in the initial equilibrium g_j^0 must be equal to $g_r^{0d} = p_r^0 + v_j t_r^0$. All those users with generalized price in mode or activity j higher than the generalized price of the indifferent user had decided to travel on conventional train instead of consuming alternative j. On the contrary, users with generalized price in mode or activity j lower than the generalized price of the indifferent user $g_j^0 = g_r^{0d}$ had chosen this alternative instead of the conventional train. Once the project is implemented, the generalized price is reduced to $g_r^{1d} = p_r^1 + v_j t_r^1$ and, due to this reduction, some users that preferred mode or activity j before the project now prefer HSR. Thus, x_j^d represents the deviated demand from mode or activity j to HSR, and total demand with the project (x_r^1) is equal to $x_r^0 + \sum_{\substack{j=1 \\ j \neq r}}^{n} x_j^d$.

Now, there is a new indifferent consumer, and his generalized price in the alternative is $g_j^1 = p_j + v_j t_j^1$, where t_j^1 denotes the travel time of this new indifferent consumer once the project has been implemented. Notice that t_j^1 is different to t_j^0 since, for example, consumers have different access or egress time. Finally, similarly to the former indifferent user, in the final equilibrium, g_j^1 has to be equal to g_r^{1d} for the new one.

Adding the change in surpluses for deviated demand, the project benefits come from the change in consumer surplus of the deviated users from mode or alternative j

therefore computed net of taxes, and transfers between different agents are now made explicit. The externalities should be estimated and quantified through the changes in surplus of the rest of society. Moreover, the change in workers' surplus and the landowners' surplus, are equal to the wage and land income, respectively, minus the minimum payment they are willing to accept for the use of the factor, that is, its private opportunity cost.

(linear approximation), $\frac{1}{2}(g_j^0 - g_r^{1d})x_j^d$, and change in the firm´s revenues, $p_r^1 x_j^d$. Hence, the change in social welfare due to the deviated demand from mode or activity *j* is:

$$\Delta W_j^d = \frac{1}{2}(g_j^0 - g_r^{1d})x_j^d + p_r^1 x_j^d. \quad (19)$$

This approach is useful to analyze how the project's social benefits and costs of are distributed across different stakeholders, making transfers explicit (including taxes and without shadow price adjustments), and providing a first glance at who wins and who loses as a result of the project.[11] Since all changes in surpluses are finally added together, the transfers net out and the overall result in terms of social welfare will be equal to that obtained through the changes in resources and WTP approach.

The welfare effects of this project can also be measured through changes in the use of resources and changes in the WTP following the unimodal or single graph analysis. The WTP of existing demand has not changed, and the value of their time savings is considered as a positive change in resources, $(v_r t_r^0 - v_r t_r^1)x_r^0$. Therefore, for the existing demand in the rail market, we have that the increase in social welfare is given by:

$$\Delta W^e = (v_r t_r^0 - v_r t_r^1)x_r^0, \quad (20)$$

which equal to expression (18).

The change in WTP and resources due to deviated demand from model or alternative *j* is equal to the difference between the increase in users´ WTP for the new trips deviated from mode or activity *j*, and the resources requires to obtain those benefits.[12] Therefore, for the deviated demand of the alternative *j* we have that the increase in social welfare is given by:

$$\Delta W_j^d = \frac{1}{2}(g_j^0 + g_r^{1d})x_j^d - v_j t_r^1 x_j^d. \quad (21)$$

It is easy to check that expression (19) is equal to expression (21).

[11] The distinction between different agents does not mean that they are the final beneficiaries of the transport improvement. The existence of fixed factors, such as land, though it does not change the value of the final result of the project, may completely modify the distribution of the social surplus.

[12] Note that, in this case, it is incorrect to include the change in resources used or saved in the alternative markets, but if there are market distortions in the other modes or economic activities, like taxes or externalities, we must add their effects to previous benefits and cost.

As expected, both approaches lead to the same result in term of the change in social welfare: the sum of $\Delta W^e + \sum_{\substack{j=1 \\ j\neq r}}^{n} \Delta W_j^d$ through (18) + (19) is equal to $\Delta W^e + \sum_{\substack{j=1 \\ j\neq r}}^{n} \Delta W_j^d$ through (20) + (21).

Alternatively, we may add the changes in WTP and resources following the multimodal or corridor analysis. Since we are not considered operating cost for the rail market, the change in social welfare is equal to time savings. No change in WTP occurs within the corridor as, by assumption, the modal change does not affect the quality of travel. For existing demand, the change in social welfare following the multimodal or corridor analysis is given by:

$$\Delta W^e = v_r(t_r^0 - t_r^1)x_r^0 \, , \tag{22}$$

For deviated demand, to calculate the change in social welfare we must compute the cost and time saved by this demand from alternative mode or activity *j*. Regarding the time saved by each consumer shifting from alternative j to HSR, it should be highlighted that time savings are not the same for everyone who deviated from the alternative. Time savings for the indifferent consumer without the project are the highest and equal to $v_j(t_j^0 - t_r^1)$, while time savings for the new indifferent consumer with the project are the lowest and equal to $v_j(t_j^1 - t_r^1)$. Time savings are given by $\frac{1}{2}v_j\left[(t_j^0 - t_r^1) + (t_j^1 - t_r^1)\right]x_j^d$, and could also be computed as:

$$\frac{1}{2}\left[\left((g_j^0 - p_j) - (g_r^{1d} - p_r^1)\right) + \left((g_j^1 - p_j) - (g_r^{1d} - p_r^1)\right)\right]x_j^d =$$

$$= \frac{1}{2}\left[(v_j t_j^0 - v_j t_r^1) + (v_j t_j^1 - v_j t_r^1)\right]x_j^d. \tag{23}$$

Recall that for the new indifferent user the generalized price is g_j^1 and equal to g_r^{1d}. Therefore, we can rewrite expression (23) as:

$$\frac{1}{2}\left[\left((g_j^0 - p_j) - (g_r^{1d} - p_r^1)\right) + \left((g_r^{1d} - p_j) - (g_r^{1d} - p_r^1)\right)\right]x_j^d =$$

$$= \frac{1}{2}(v_j t_j^0 - v_j t_r^1)x_j^d + \frac{1}{2}(p_r^1 - p_j)x_j^d. \tag{24}$$

With the corridor analysis, we should include any change in resources used or saved in the conventional train (not considered) and any other mode or activity included in the corridor. Thus, adding cost saving in alternative j and recalling that there is competition in all other modes or activities, i.e., $p_j = c_j$, the change in social welfare because of deviated demand from alternative j could be rewritten as:[13]

$$\Delta W_j^d = \frac{1}{2} v_j (t_j^0 - t_r^1) x_j^d + \frac{1}{2} (p_r^1 - p_j) x_j^d + c_j x_j^d =$$

$$= \frac{1}{2} v_j (t_j^0 - t_r^1) x_j^d + \frac{1}{2} (p_r^1 - p_j) x_j^d + p_j^0 x_j^d =$$

$$= \frac{1}{2} (v_j t_j^0 - v_j t_r^1) x_j^d + \frac{1}{2} (p_r^1 + p_j) x_j^d = \frac{1}{2} \left(g_j^0 + g_r^{1d} \right) x_j^d - v_j t_r^1 x_j^d, \qquad (25)$$

equal to expression (21). Thus, the three ways lead to the same result. The sum of $\Delta W^e + \sum_{\substack{j=1 \\ j \neq r}}^{n} \Delta W_j^d$ is the same through (18) + (19), or through (20) + (21) or through (22) + (25).

It is worth noticing that, when changes in social welfare are measured using the methodological approach based on changes in the use of resources and the WTP, internal payments that represent transfers between different agents should not be included (e.g. access charges paid by operators to infrastructure managers) and costs must then be valued at their social opportunity costs. This implies, for example, that costs must be computed net of taxes (when the input supply is perfectly elastic) and that labour (and other input) costs must be corrected according to their shadow price, when applicable.[14] Moreover, changes in external costs are also included as an increase in the use of resources.

Alternatively, when the increase in social welfare is measured using changes in the surpluses of different agents, prices for the owner of capital must be valued net of taxes, costs must be computed with taxes and, in general, no correction with shadow prices applies. Moreover, changes in external costs are excluded from the producer's costs and are included in the rest of society surplus.

The change in the operating and investment costs completes the total change in social welfare, i.e., the costs of the HSR for existing and deviated demand, and the avoided costs of conventional train. Finally, both approaches can be used to calculate

[13] It is common to consider that time savings of deviated traffic are given by $\frac{1}{2} w_j (t_j^0 - t_r^1)$ but this is only the case if $p_j = p_r^1$.

[14] See de Rus (2023) for further details on this issue.

the social net present value (NPV) of the project by adding the discounted changes in social welfare over the evaluation period using the corresponding social discount rate.

8.2.2 The CGE-Transport model

The case study that seeks a further understanding of the differences between CBA and CGE methodologies in terms of project appraisal deals with the following key issues:

i) The substitution pattern and redistribution of travellers following project implementation.
ii) Higher productivity of labour due to travel time savings during working hours within the CGE model.
iii) The implications of travel time savings for additional leisure within the CGE model.
iv) The relevance of the induced effects in an economy with involuntary unemployment.

The project is expected to increase the travellers' demand of HSR, such that, part of the increase corresponds to new traffic generated and the other part is due to a redistribution of travellers from other modes of transport. In order to handle these effects, the generalized price needs to be considered. Moreover, the elasticity of demand and cross price elasticities of demand among alternative modes of transport are required. They are modelled within the CGE by disentangling the transport sector into four modes of transport, i.e. by train, bus, car and air transport.

Moreover, CGE distinguishes between three kinds of travellers, i.e. leisure travellers, commuters and travellers during working hours. Such distinction is necessary to understand the implications of time savings for the productivity of the labour factor. It is relevant for the equivalent variation measurement within CGE. Provided productivity and income increases, then it is expected to produce induced effects. Such effects are triggered by a rise in consumption, which also implies a second-round production effect that is only relevant for the measurement of the change in welfare of the project under the presence of unemployment when those effects are significantly different to the counterfactual.

The contribution of this exercise is that: the transport sector is disentangled in CGE and linked to productivity changes. Travel time savings are modelled within CGE and linked to leisure as an additional good of the economy. Finally, a transport project appraisal (not an economic impact) is assessed with CGE, and then compared with CBA.

Briefly, although the economy under analysis is hypothetical, given the model's complexity many of the calibrated parameters have been taken from the Input-Output tables (IOT) of the Spanish economy for 2015. This economy has been modelled as a small-open economy[15] composed of 16 activities (a) and goods/commodities (i): "agriculture and fishing", "energy, water and minery", "industry", "construction", "trade", "accommodation and catering services", "transport by train", "transport by bus", "other road transports", "maritime transport", "other transport services", "air transport", "travel agencies", "real estates", "entertainment" and "other services". Both domestic and imports goods are assumed to be imperfect substitutes. Hence, the intermediate and final demands of this economy are satisfied with Armington goods (Armington, 1969). Moreover, it is assumed that there is one representative household and one central government. Both labour (L) and capital (K) are assumed to be perfectly mobile among sectors. Regarding *model closure,* it is assumed that the government deficit and the current account deficit are fixed, the labour market operates with involuntary unemployment (14% of unemployment) and the model follows a savings-driven investment decision. Finally, all markets operate under perfect competition, except the labour market that, as already noted, operates with involuntary unemployment.

While this economic structure and its main assumptions can be considered standard in CGE models (see, Hosoe *et al.*, 2010 or Gilbert and Tower, 2013), the inclusion of the use of time implies a series of changes in the way that the representative household employs this limited resource within the whole economy. Firstly, it is assumed that time has three main alternative uses: labour (the classical economic decision between leisure and work -including commuting-), leisure-consumption (those goods that require the use of time to be consumed) and leisure (spare time in a broad sense)[16]. In this sense, the model assumes that the representative household devotes one-third of her time to work and another one-third to consuming goods. The other one-third is taken as spare time. Regarding the use of transport modes considered by the representative household,

[15] International prices are assumed as given.
[16] Given the lack of information in this regard, these values have been calibrated freely.

it is assumed that the demand for trains, buses, the remaining road transport (that includes car) and air transport represent about 10%, 10%, 70% and 10% of the total demand for transport, respectively.

The modelization of the use of time works as a satellite account, complementing the productive mix captured by the IOT. Specifically, this new information must fulfil the circular flow of income. As previously mentioned, there are three main alternative uses of time (labour, consumption and spare time), and these three must equal the total endowment of time. Similarly, all the economy's sectors and goods/services now require the use of time. More precisely, the sectors use time by demanding the labour force (effective labour demand in our notation). i.e., the effective labour demand equals the effective labour supply that is formed by the time to labour and the time to commute. The coefficient shares of this decision are calibrated by dividing the labour time and the time to commute by the effective labour supply.

Another adjustment in the IOT requires disaggregating the transport sector to introduce the use of transport modes considered in the analysis. In this sense, there are three transport sectors initially in the IOT: air, maritime and ground. However, for our case, ground transportation requires further disentangling into car, train and bus. The relationship between these ground modes is assumed to be independent of maritime transport. However, it is not independent of the air transport market because airlines compete with HSR operators. The shares of these transportation modes in the corridor are 70%, 10%, 10%, and 10% for car, train, bus and air, respectively. Moreover, these shares are applied to the remaining IOT to obtain the productive-mix disentangled for the three modes of transport, while ensuring the circular flow of income, i.e. the latter allows us to know the intermediate demand (inputs) by each mode of transport.

For simplicity, the production functions of ground transport are assumed to be the same in relative terms (same technical coefficients), although they differ in absolute terms. Further research may be required to polish such distinction. Finally, it should be noted that the IOT does not distinguish between the transport of passengers and goods, which is also a serious limitation as the technical coefficients in the IOT do not distinguish freight from passenger transport. Finally, there is an additional sector in the IOT ("other transport services") which include other activities such as "pipeline transport", among others.

The final step in this process requires combining the use of time and the new disaggregated IOT. This step is addressed by assuming two kinds of travellers: "commuters" and "rest of travellers". In this sense, it is assumed that the commuters represent around 60% of transport demand and the rest 40%. The former uses transport modes to work, whereas the latter demands them to consume goods/services. Both decisions are modelled similarly.

Thanks to this information, we can obtain both the generalized demand of transport and their generalized cost by mode of transportation and kind of traveller. Moreover, this disaggregation also allows us to obtain the effective labour supply and to capture productivity gains by sectors.

The main equations of the model are:[17]

- Supply-side (firms)

Production by sector a and good i ($X_{a,i}$) is composed of intermediate demands (Armington goods, Ar_i), capital (K_i) and labour (LST_i), whereas production is disentangled into domestic (D_i) and exports goods/services (E_i). As explained by Gilbert and Tower (2013), this production process can be disentangled into two. Firstly, the sectors that establish total production level by goods ($X_{a,i}$) and the associated demand of factors ($Ar_{a,i}$, K_a and LST_a). Secondly, the sectors that decide on the share of production devoted to satisfying both the international and domestic demand. At each step, prices are assumed as given:

Sectoral behaviour

First step:

$$max_{X_i,A_i,K_i,LST_i}\left(P_i X_{a,i}\right) - \left(P_{A_i} Ar_{a,i} + P_{VA_i} VAr_{a,i}\right)$$

$$subject\ to: X_{a,i} = f\left(A_{a,i}, VA_{a,i}\right) = {A_{a,i}}^{\alpha_i^{ar}} {VA_{a,i}}^{\alpha_i^{va}}$$

where $VA_{a,i} = \left(\theta_{a_i} {K_a}^{\rho_a} + \left(1-\theta_{a_i}\right) {LST_a}^{\rho_a}\right)^{1/\rho_a}$. VA_i reflect the degree of substitution between capital (K_{actv_i}) and labour (LST_{actv_i}), and where ρ_a denotes this

[17] Taxes and time subscripts have been omitted from the equations for the sake of clarity.

elasticity by activities[18]. Finally, P_i, P_{A_i} α_i^{ae} and α_i^{va} denote prices of goods, Armington prices, the coefficient share of Armington goods and $VA_{a,i}$, respectively.

Domestic production and exports

Second step:

$$max_{D_i,E_i}\left(\sum_i \alpha_{DE,i}D_i^{\sigma_{T_{DE,i}}} + \left(1-\alpha_{DE,i}\right)E_i^{\sigma_{T_{DE,i}}}\right)^{1/\sigma_{T_{DE,i}}}$$

$$subject\ to: \sum_i P_{D_i}D_i + erE_i = P_i\bar{Y}_i \ \text{ with } \bar{Y}_i = \sum_a Y_{a,i}$$

where $\alpha_{DX,i}$ and $\left(1-\alpha_{DX,i}\right)$ denotes the coefficient shares of domestic production and exports by goods, respectively. $\sigma_{T_{DX,i}}$ reflects the elasticity of transformation between both kinds of goods and is assumed to be equal to 0.[19] P_{D_i} and er denote domestic prices and the real exchange rate, respectively. The first-order conditions of the first step yield the demands of intermediate goods, labour and capital, and production level by activities; while the first-order conditions of this second step yield the supply of domestic and exports goods.

Armington goods

Likewise, the Armington goods (A_i) are produced according to the following maximizing problem. The CES (Constant Elasticity of Substitution) production function reflects the imperfect substitution between domestic (D_i) and imports (M_i) goods, where θ_{ar_i} and $(1-\theta_{ar_i})$ denote their coefficient shares and ρ_{ar_i} is the elasticity of substitution between both kinds of goods, and whose values were sourced from Hertel (1997):

$$max_{Ar_i,D_i,M_i}\left(P_{Ar_i}Ar_i\right) - \left(P_{D_i}D_i + erM_i\right)$$

$$subject\ to: Ar_i = f(D_i,M_i) = \left(\theta_{ar_i}D_i^{\rho_{ar_i}} + \left(1-\theta_{ar_i}\right)M_i^{\rho_{ar_i}}\right)^{1/\rho_{ar_i}}$$

The first-order conditions of this problem yield the optimal demand for domestic and imported goods.

[18] Hertel (1997).

[19] Considering that CBA assumes a closed economy in this paper, this elasticity allows us to enhance the comparability between both methodologies by reducing the economic effects of imports and exports.

- Demand-side (households and government)

Briefly, this side of the economy considers the demand decisions of the households and the government regarding investment, consumption and the use of time. Let firstly explain the economic decision about the latter in the model. As mentioned earlier, the household has a fixed endowment of time that, broadly speaking, can be devoted to labour, leisure, and consumption. Thus, the representative household needs to decide which part of her fixed time available is devoted to carrying out any of the previous alternatives. At the same time, transport time is disentangled into time for commuting and time for travelling to consume (rest of travellers). Algebraically, such time decisions are modelled as follows:

Labour-transport choice

First, according to her endowment of time $\overline{L_{LS}}$, the representative household decides between the time devoted to work and transport (commuting) according to the following maximizing problem:

$$max_{L_{TR_{LS}},L_{LS}} \left(\sum \alpha_{LS} {L_{TR_{LS}}}^{\sigma_{T_{LS}}} + (1-\alpha_{LS}) {L_{LS}}^{\sigma_{T_{LS}}}\right)^{1/\sigma_{T_{LS}}}$$

$$subject\ to{:}\, P_{L_{TR_{LS}}} L_{TR_{LS}} + P_{L_{LS}} L_{LS} = P_L \overline{L_{LS}}$$

where $L_{TR_{LS}}$ denotes the time devoted to transport, L_{LS} the labour supply, $\sigma_{T_{LS}}$ the elasticity of transformation that it is assumed equal to zero (i.e., both the transport and the labour supply are combined linearly as broadly done in CBA),[20] $P_{L_{TR_{LS}}}$ represents the cost of transport as commuters, $P_{L_{LS}}$ the shadow price of labour, P_L the composite cost of the previous variables and finally, α_{LS} and $(1-\alpha_{LS})$ represents the coefficient shares. Overall, this maximizing problem[21] fulfils two model issues. Firstly, it allows us to enhance the model by endogenizing both decisions instead of assuming a fixed endowment of both. Secondly, it is a necessary step to introducing the value of time in the transport mode decision (commuter time) in order to obtain the generalized transport cost of each mean of transport, as explained below.[22]

[20] See Mackie *et al*. (2001), Koopsmans *et al*. (2013) or De Jong and Kouwenhoven (2020).
[21] It should be noted that the result would be equivalent using the dual problem (minimizing cost problem).
[22] For instance, this assumption is mathematically similar to Agbahey *et al.* (2020) when modelling the labour-leisure trade-off under different labour supply specifications in CGE.

Consumption-leisure choice

Like the labour-transport decision, the household also decides, according to her endowment of time ($\overline{L_L}$), the time devoted to leisure in a broad sense, and the time spent travelling to consume goods ("remote" goods/services). This decision is modelled according to the following maximizing problem:

$$max_{L_{TR_{LSE}},L_{LSE}}\left(\sum_{i}\alpha_L L_{TR_{LSE}}{}^{\sigma_{T_L}}+(1-\alpha_L)L_{LSE}{}^{\sigma_{T_L}}\right)^{1/\sigma_{T_L}}$$

$$subject\ to\colon P_{L_{TR_{LSE}}}L_{TR_{LSE}}+P_{L_{LSE}}L_{LSE}=P_L\overline{L_L}$$

where $L_{TR_{LSE}}$ denotes the demand of transport time for consumption, L_{LSE} denotes the demand for leisure in a broad sense, α_L and $(1-\alpha_L)$ represents the coefficient shares, and σ_{T_L} denotes the elasticity of transformation that is assumed to be 0. Finally, it should be noted that both the labour-transport decision and the consumption-leisure decision could have been modelled jointly, departing from the time endowment. However, this disentanglement allows us to capture and appreciate more vividly such simultaneous decisions.

Means of transport

Likewise, each mode of transport operates according to the following maximizing problem:

$$max_{Zgen_{tm},L_{TR_{LS}},L_{TR_{LSE}},Ar_i}(G_{tm}Zgen_{tm})-P_{L\_TR,tm}L_{TR_{LS}}-P_{L\_TR\_LSE,tm}L_{TR_{LSE}}-P_{Ar_i}Ar_i$$

$$subject\ to\colon Zgen_{tm}=f\left(L_{TR_{LS,tm}},L_{TR_{LSE,tm}},Ar_{i,tm}\right)=min_{i,tm}\left(\frac{L_{TR_{LS,tm}}}{\alpha_{Z\_gen_{L\_TR_{tm}}}},\frac{L_{TR_{LSE},tm}}{\alpha_{Z\_gen_{L\_TR\_LS_{tm}}}},\frac{Ar_{i,tm}}{\alpha_{i,tm}}\right)$$

where each transport mode (tm) is composed of its own transport demand ("train", "bus", "other road transports" and "airplane") (Ar_i) and the transport time by mode of transport when commuting ($L_{TR_{LS}}$) (labour-transport choice problem); or because of leisure ($L_{TR_{LSE}}$) (consumption-leisure choice problem). $Zgen_{,tm}$ is the generalized transport demand of transport by modes of transport. Hence, the generalized cost of transport is: $G_{tm} = \alpha_{Z\_gen_{L\_TR_{tm}}} P_{L\_TR,tm} + \alpha_{Z\_gen_{L\_TR\_LS_{tm}}} P_{L\_TR\_LSE,tm}$, where P_{L_TR} denotes the transport cost and $P_{L\_TR\_LSE}$ the value of the transport time; which implicitly includes: access/egress time, waiting and in-vehicle time. Finally, $\alpha_{Z\_gen_{L\_TR}}$, $\alpha_{Z\_gen_{L\_TR\_LS}}$ and α_{i_t} represent the coefficient share of each of these demands. The modes of transport are demanded by two kinds of travellers (transport choice): commuters and rest of travellers. This distinction allows us to capture the different values for transport time of both kinds of travellers.

Transport choice (commuters)

The transport variable is a composite transport good composed by the demand of the different means of transport used by individuals: “train”, “bus”, “other road transport” and “airplane” that are assumed to be imperfect substitutes and are separated by sectors (Tr_a) to capture the difference in use, which also affects the productivity gains in the effective labour supply decision, as explained below (labour supply). $G_{tr,a}$ represents the generalized cost of transport modes by activities (a). The idea is like the imperfect substitution between domestic and imports goods. Algebraically, this transport decision is:

$$max_{Tr_a, Zgen_a}\left(P_{tr,a}Tr_a\right) - \left(G_a Zgen_a\right)$$

$$subject\ to:$$

$$Tr = f(Zgen_a) = \left(\alpha_{tr_{public,a}} Zgen_{public,a}{}^{\epsilon} + \alpha_{tr_{private,a}} Zgen_{private,a}{}^{\epsilon}\right)^{1/\epsilon}$$

$$Zgen_{public,a} = \left(\sum_{ptm} \alpha_{tr_{ptm,a}} Zgen_{ptm,a}^{\epsilon_{public}}\right)^{1/\epsilon_{public}}$$

$$Zgen_{private,a} = \left(\alpha_{tr_a} Zgen_{private,a}^{\epsilon_{private}}\right)^{1/\epsilon_{private}}$$

G_a and $Zgen_a$ denote the generalized transport price of transport and the generalized transport demand of transport of the modes of transport by sectors (a), respectively. $\alpha_{tr_{public,a}}$ and $\alpha_{tr_{private,a}}$ denote the transport share by transport modes and sectors, distinguishing between public (train, bus, and airplane) and private transport modes (road transport), while ε is reflecting the elasticity of substitution among them. In this sense, two additional nests are assumed in order to ensure an equal elasticity of demand in the modes of transport (elasticity of substitution equals 2). One nest is composed by the three public transport modes (train, bus and airplane), which obtains a generalized demand of modes by activities ($Zgen_{public,a}$). The second nest consists of road transport yielding a generalized demand of this mean of transport by activities ($Zgen_{private,a}$), accompanied by the respective coefficient share (α_{tr_a}). Both nests are modelled following a constant elasticity of substitution (ϵ_{public} and $\epsilon_{private}$, respectively) and are also formed by their respective coefficient shares ($\alpha_{tr_{ptm,a}}$ and $\alpha_{tr_{private,a}}$), respectively. Where subindex ptm refers to public transport modes). In the top nest, both kinds of transport modes are finally combined to obtain a generalized demand of transport by sectors ($Zgen_a$). Besides, assuming imperfect substitution also allows us to avoid 'corner solutions' when demanding different modes of transport.

Effective labour supply

The representative households decide her total effective labour supply by sectors (LST_a) based on transport time by sectors (Tr_a) (transport choice decision (commuters)), and the labour supply (L_{LS}). Thus, the former will be finally demanded by firms while paying the wage $P_{LST,a}$ by sector. More formally, this decision can be stated:

$$max_{LST,LS,Tr}\left(\sum_{a=1} P_{LST,a}LST_a\right) - \left(P_{LS}L_{LS} + P_{Tr,a}Tr_a\right)$$

$$subject\ to: LST = f(LS, Tr_a) = \sum_{a=1} L_{LS}{}^{\alpha_{LST}} Tr_a{}^{\alpha_{LST,a}}$$

This step assumes a Cobb-Douglas function $f(LS, Tr) = L_{LS}{}^{\alpha_{LST}} Tr^{(1-\alpha_{LST,a})}$), where α_{LST} and $\alpha_{LST,a}$ denote their respective coefficient shares. The idea is that the decision of working (total effective labour supply) depends on transport time and the labour supply. It should be noted that, while transport time varies by activities, there is a total labour supply that, combined with the transport time, will be transferred to the different activities. This distinction allows us to capture differences in productivity by sector, but, at the same time, keeping the labour supply perfectly mobile among sectors.

As expected, each variable is accompanied by its respective price: $P_{Tr,a}$, P_{LS} and $P_{LST,a}$. Finally, this step also allows us to capture potential labour productivity gains by sectors that are boosted by the transport project when it reduces transport time in the economy.

Transport choice (consumers/rest of travellers)

Similar to the transport choice for commuters, the individuals decide the mode of transport according to the following problem:

$$max_{Tr_{cons},Zgen_{LSE}}\left(P_{Tr_{cons}}Tr_{cons}\right) - \sum_{tm} G_{LSE}Zgen_{LSE}$$

$$subject\ to:$$

$$TTr_{LSE} = f(Zgen_{tm})$$
$$= \left(\alpha_{LSE_{public}}Zgen_{LSE,public}{}^{\epsilon} + \alpha_{LSE\ private}Zgen_{LSE,private}{}^{\epsilon}\right)^{1/\epsilon}$$

$$Zgen_{LSE,public} = \left(\sum_{ptm} \alpha_{LSE_{ptm}}\, Zgen_{LSE,ptm}^{\epsilon_{public}}\right)^{1/\epsilon_{public}}$$

$$Zgen_{LSE,private,a} = \left(Zgen_{LSE,private}^{\epsilon_{private}}\right)^{1/\epsilon_{private}}$$

This problem keeps the same meaning and explanation as the transport choice for commuting, but without distinguishing among sectors. Now Tr_{cons} and $P_{Tr_{cons}}$ refers to the demand for transport time for consumption and its price, respectively, whereas G_{LSE} and $Zgen_{LSE}$ denote the generalized transport cost and the generalized demand of transport for this kind of passengers, respectively. It should be noted that the transport cost and elasticity of substitution among modes (ε) are similar to both kinds of passengers (commuters and general travellers) in the different nest, but they may differ in the valuation of time, eventually yielding different generalized transport prices. The latter is captured by the respective coefficient shares ($\alpha_{LSE_{public}}$, $\alpha_{LSE\ private}$, $\alpha_{LSE_{ptm}}$) in the different nests.

In the next step (leisure consumption decision), the household demands Armington goods that require the transport demand to be consumed (Ar_{trans_i}). These goods/services are “accommodation and catering services”, “train”, “bus”, “other road transport”, “maritime transport”, “air transport” “other transport services”, “entertainment” and “other services”.

- Consumption

Leisure consumption

Like the labour supply decision, the household also demands transport to consume (Tr_{cons}) certain kinds of goods (Ar_{trans_i}), so that:

$$max_{Y_{LSE_i},Ar_i,Tr_{LSE}}\left(P_{Ar_{trans}}Ar_{trans}\right)-\left(\sum_i P_{Ar_i}Ar_{trans_i}-P_{Tr_{cons}}Tr_{cons}\right)$$

$$subject\ to: Ar_{trans}=f(Ar_i,Tr_{LSE})$$

$$=\left(\sum_i \theta_{AR_{trans_{cons_i}}}{Ar_{trans,i}}^{\rho_{Y_{cons}}}+\left(1-\sum_i \theta_{AR_{trans_{cons_i}}}\right){Tr_{cons}}^{\rho_{Y_{cons}}}\right)^{1/\rho_{Y_{cons}}}$$

where $\theta_{AR_{trans\_cons_i}}$, $(1-\sum_i \theta_{AR_{trans\_cons_i}})$ and $\rho_{Y_{cons}}$ refer to the respective coefficient shares and the elasticity of substitution that takes a value of 0, respectively. Finally, the representative household (H) demands these goods (Ar_{trans_i}) plus the remaining Armington goods (Ar_i) and the enjoyment of the rest of leisure (LSE), according to the following maximizing problem:

Household consumption

$$max_{C_H,A_{H,i},CL}(P_C C_H)-\left(\sum_i P_{A_i}A_{H,i}+P_{CL}CL\right)$$

$$subject\ to: U=f\left(A_{H,i},CL\right)=\prod_i {A_{H,i}}^{\alpha_{cons}}CL^{(1-\alpha_{cons})}$$

$$CL=\left(\theta_{p\_cons}LSE^{\rho_{p\_cons}}+\left(1-\theta_{p\_cons}\right){Ar_{trans}}^{\rho_{p\_cons}}\right)^{1/\rho_{p\_cons}}$$

where C denotes the total consumption, α_{cons}, $(1-\alpha_{cons})$, θ_{p_cons} and $(1-\theta_{p\_cons})$ refer to the coefficient shares and ρ_{p_cons} denotes the elasticity of substitution that is assumed to be 0.5. It should be noted that both decisions, the leisure consumption and household decision, could be modelled simultaneously by including the former as nesting in the latter. As expected, the total demand of goods of the representative household rests on fulfilling the income level (income constraint) (Y_H), such that:

$$C_H = Y_H = P_L(L - Un) + P_K K_H + er\ ca - savings_H$$

where L refers to the total endowment of time, Un denotes the unemployment rate that is initially assumed to be 14%, P_L denotes the shadow price of time, P_K the cost of capital, K the capital endowment that is inelastically supplied, er the exchange rate, ca the Spanish economy's current account deficit and $savings_H$ the endowment of this economy's private savings, which is assumed to be fixed (reflecting the savings-driven rule). Similarly, government behaviour rests on consuming goods according to the following maximizing problem while fulfilling its income constraint.

Government consumption

$$max_{Gov,A_{Gov,i}}(P_{Gov}Gov) - \sum_i P_{A_i}A_{Gov,i}$$

$$subject\ to: Gov = f\left(A_{Gov,i}\right) = \prod_i A_{Gov,i}^{\alpha_{Gov_i}}$$

where Gov denotes total government consumption, and $A_{Gov,i}$ the demand of Armington goods that are demanded according to a Cobb-Douglas function where α_{Gov_i} denotes the coefficient shares of these goods. Government income constraint (Y_{Gov}) comprises income obtained from its capital endowment (K_{Gov}), ca_{Gov} reflects the public foreign deficit, $savings_{Gov}$ is the public savings level that, similar to the household, is assumed to be fixed (savings-driven rule) and $taxes$ denotes the taxes collected in the economic system, net of subsidies.

$$G = Y_{Gov} = P_K K_{Gov} + er\ ca_{Gov} - savings_{Gov} + taxes$$

Tourists

The last consumer in this economy, tourists, follow consumer behaviour as descripted below:

$$max_{Tou,A_{tou,i}}(P_{tou}Tou) - \sum_i P_{A_{tou}}A_{tou,i}$$

$$subject\ to: Y_{tou} = f(A_{tou,i}) = min_i \left(\frac{Ar_{tou,i}}{\alpha_{tou_i}}\right)$$

where P_{tou} and Tou denote the total tourism price and tourism consumption, respectively. $A_{tou,i}$ denotes the demand of Armington goods by the tourists which are demanded according to a Leontief function[23] (elasticity of substitution equals to zero), where α_{tou_i} denotes the coefficient shares of these goods. Tourism income constraint (Y_{tou}) comprises total tourism expenditure (Tex), which represents the total demand of tourists' goods multiplied by the real exchange rate (er).

$$Tou = Y_{tou} = Tex$$

Investment

The total investment level (Inv) equals the private and public savings endowment ($savings_H$ and $savings_G$, respectively); reflecting more clearly the savings-driven rule. Thus, the investment decision in this economy depends on a fixed level of savings. The investment decision (Inv) adopts the following form:

$$max_{Inv,Ar_i}(P_{Inv}Inv) - \sum_i P_{Ar_i}Ar_{inv,i}$$

$$subject\ to: Inv = f(Ar_i) = min_i \left(\frac{Ar_{inv,i}}{\alpha_{Inv_i}}\right)$$

where its first-order conditions yield the investment demand for goods ($Ar_{inv,i}$) and α_{Inv_i} denotes the coefficient shares.

Jointly with the zero-profit conditions and income constraints, the model is closed when including the market clearance conditions by which the supply equals the demand for all goods and factors of production in this economy. Overall, these three conditions fulfil the circular flow of income.

[23] Like the elasticity of transformation, this elasticity allows us to enhance comparability between both methodologies.

8.3 Case study and general considerations

As said, we compare the measurement of the benefits of an investment consisting of constructing and operating a new HSR to replace an existing conventional rail service that connects two cities with no intermediate stations. Following construction of the HSR line, conventional train services will be discontinued. This project reduces total travel time for conventional train users by 40%. We are not considering maintenance and operating costs of the rolling stock, nor the infrastructure. Three alternative modes are considered: air transport, car and bus. Additionally, two scenarios (given by CGE) with high (12,513,799) and low transport demand (5,653,801) are assumed, by changing the percentage of the population affected by the project (10% and 5%, respectively).

It should be noted that the purpose of this study is to compare CBA and CGE results and analyze the possible causes of existing divergences, which may make the CBA case study look grossly simplified.[24] In order to maximize comparability, several key variables and parameters used in the CBA come directly from the IOT or CGE model (demand and modal split), and other values from CBA feed CGE analysis (prices and value of time). Moreover, we only calculate and compare CBA and CGE benefits of the first year of operation.

CGE provides the modal split by assuming an elasticity of substitution among the different transport modes equal to 2, as shown in Table 1.

Table 1. Sources of HSR demand

	High demand	Low demand
HSR demand diverted from air transport	5.63%	3.83%
HSR demand diverted from bus	8.48%	5.62%
HSR demand diverted from car	7.63%	4.91%
HSR demand diverted from conventional train	58.71%	64.97%
Generated demand	19.55%	20.67%

Note: high demand = 12,513,799; low demand = 5,653,801.

Travel times are shown in Table 2. Time has been calculated assuming an average waiting time of 40 minutes for air transport and 20 minutes for other modes. Access

[24] For the evaluation of actual cases, see for example, de Rus (2012) or de Rus *et al*. (2021).

and egress time have been assumed to be 40 minutes for all transport modes except air, which was assumed to be 80 minutes.

Table 2. Travel time in the corridor (hours)

	Access/Egress time	Waiting time	In-vehicle time
HSR	0.66	0.33	1.50
Air transport	1.33	0.66	1.00
Bus	0.66	0.33	4.25
Car	0	0	3.50
Conventional train	0.66	0.33	3.17

Table 3 shows the average value of travel time for each transport mode. Note that these values are roughly based on Bickel *et al*. (2006), but updated through the Consumer Price Index and income growth, and remain constant over the project life.

Table 3. Value of time (euros/hour)

Air transport	35
Bus	10
Car	20
Conventional train	20

Finally, we assume the following prices and avoidable costs. The avoidable costs are obtained by applying the corresponding shadow price, assuming the existence of an indirect tax (VAT) equal to 10% for each transport mode, except for car (30%). These prices and costs are shown in Table 4.[25]

[25] We assume that the values for generated demand are obtained according to the distribution of deviated traffic.

Table 4. Prices and avoidable costs of each transport mode (euros)

Prices	
HSR	50
Air transport	80
Bus	30
Car	60
Conventional train	40
Avoidable costs	
Air transport	72.73
Bus	27.27
Car	46.15

8.4 Results

8.4.1 CGE results

The travel time savings with the project change the modal split, as shown in Table 5. All transport modes lose passengers in favour of HSR (diverted passengers), and demand for the railways option goes up 51% for the high demand scenario, and 59.62% for the low demand scenario. As a result, the generalized prices of the bus (G_{bus}), airplane (G_{air}), other road transport (G_{ort}) and train (G_{train}), go down in both scenarios. These simultaneous changes in the demand and prices occur because in a CGE model, prices and quantities are determined endogenously.

The economic impact continues by analyzing sectoral changes (Table 6). Time savings that take place in the train sector are transferred to the rest of activities that demand its services, causing positive changes in production in the rest of the economy. As a result, practically, all sectors increase their production, except the substitutes modes of transport (other road transport, bus and air transport).

Focusing on the demand side, as shown in Table 7, the representative household increases the demand for goods as well as demand for goods that require the use of time for its consumption (demand for goods with leisure). However, this rise in consumption is at the expense of reducing the enjoyment of free time (leisure time).

Table 5. Changes in transport demand and generalized price by transport mode (%)

	High demand	Low demand
Other Road transport	-1.83	-1.14
Train	51	59.62
Bus	-8.66	-5.56
Air transport	-13.10	-8.63
G_{bus}	-0.5	-0.25
G_{train}	2.95	1.5
G_{air}	-0.2	-0.1
G_{ort}	-0.25	-0.1

Note: high demand = 12,513,799; low demand = 5,653,801.

Table 6. Sectoral economic impacts (%)

	High demand	Low demand
Agriculture and fishing	0.044	0.019
Energy, water and minery	0.093	0.041
Industry	0.051	0.022
Construction	0.013	0.006
Trade	0.098	0.046
Accommodation	0.123	0.056
Other road transport	-1.545	-0.709
Train	34.397	15.997
Bus	-5.629	-2.663
Maritime transport	0.099	0.045
Air transport	-8.953	-0.264
Other transport services	0.069	0.029
Travel agencies	0.114	0.052
Real state	0.085	0.039
Entertainment	0.089	0.039
Other services	0.151	0.040

Note: high demand = 12,513,799; low demand = 5,653,801.

Table 7. Household demand by kinds of good/service (%)

	High demand	Low demand
Demand for goods	0.097	0.045
Leisure time	-0.133	-0.053
Demand for goods with leisure	0.282	0.126

Note: high demand = 12,513,799; low demand = 5,653,801.

Table 8. Change in sectoral productivity (%)

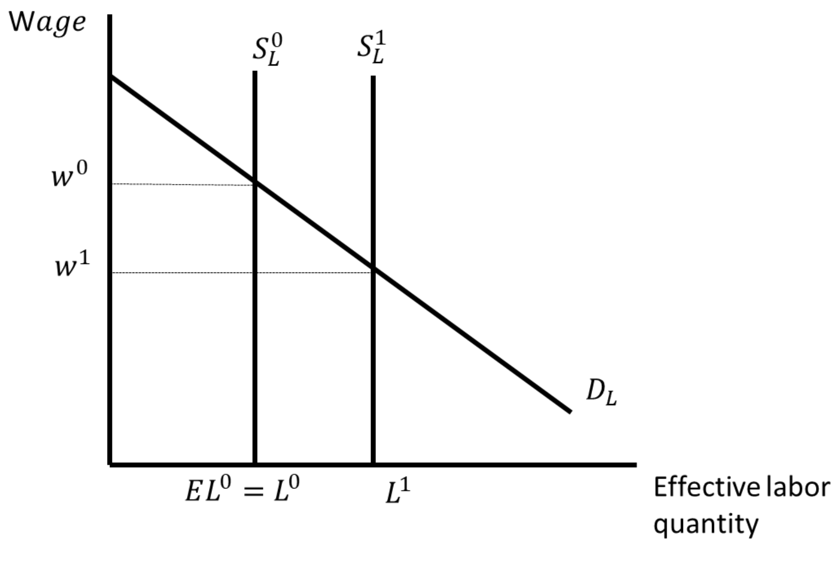
	High demand	Low demand
Agriculture and fishing	0.044	0.019
Energy, water and minery	0.093	0.041
Industry	0.051	0.022
Construction	0.013	0.006
Trade	0.098	0.046
Accommodation	0.123	0.056
Other road transport	-1.545	-0.709
Train	34.397	15.997
Bus	-5.629	-2.663
Maritime transport	0.099	0.045
Air transport	-8.953	-4.346
Other transport services	0.069	0.029
Travel agencies	0.114	0.052
Real state	0.085	0.039
Entertainment	0.085	0.039
Other services	0.089	0.040

Note: high demand = 12,513,799; low demand = 5,653,801.

The time savings triggers a change in sectoral productivity, allowing more goods and services to be produced with less employees (an increase in effective labour). This is precisely the result shown in Table 8, where all sectors increase productivity after travel time savings in both scenarios, except the substitute modes of transport (other road transport, bus and air transport). However, it should be noted that reduction in productivity in the substitute modes of transport is partially compensated for by the demand of transport as intermediate demand (inputs) by other the sectors of the economy, which reduces the fall in production. This result is conditioned by the existence of a unique IOT technical coefficient for ground transport, aggregating freight and passengers. The induced effect in the economy of time savings in freight transport is expected to be quite different to those affecting HSR passengers.

Finally, the increase in productivity does not reduce unemployment because current workers benefit from the time savings and can produce more, causing an increase in the effective labour quantity, as noted by Burfisher (2011). This is shown in Figure 1: a productivity gain causes an increase in the labour supply from S_L^0 to S_L^1 lowering the wage per effective worker from w^0 to w^1, where D_L is labour demand. However, we still have the initial labour endowment (L_0) in charge of the tasks of L_1 workers. Hence, L_1 represent effective labour endowment, and the actual wage should be different than the wage per effective worker shown in Figure 1. Following Burfisher (2021), the salary per effective worker was adjusted to reflect the change in actual wages by activities (see Table 9). Overall, the change in actual wages varies among sectors depending on labour intensity and use of the transport modes in their productive-mix.

Figure 1. Effect of an increase in labour productivity



Source: Burfisher (2011)

Table 9. Change in actual wage (%)

	High demand	Low demand
Agriculture and fishing	-0.28	-0.13
Energy, water and minery	-0.17	-0.08
Industry	0.06	0.02
Construction	0.06	0.02
Trade	0.15	0.07
Accommodation	0.18	0.08
Other road transport	-0.17	-0.031
Train	36.27	16.78
Bus	-4.31	-1.98
Maritime transport	0.17	0.080
Air transport	-1.04	-0.51
Other transport services	0.14	0.06
Travel agencies	-0.09	-0.03
Real state	0.17	0.08
Entertainment	0.10	0.04
Other services	0.05	0.02

Note: high demand = 12,513,799; low demand = 5,653,801.

8.4.2 CBA results

The CBA results are shown in Table 10, following the WTP net of resource aggregation (corridor analysis). In this project we differentiate between deviated demand (passengers shifting from other transport modes) and generated demand. There are two sources of benefits: time and operation cost savings, i.e., freed resources in the rest of the transport mode due to reduction in demand after the project.

In Table 10, the time savings and operating cost savings of each transport mode are shown. Most benefits derive from time savings (58.97% and 65.15% of the social benefit in year 1 for the high demand and low demand scenarios, respectively). Moreover, time savings of the existing demand (conventional train) accounts for

45.80% and 52,22% of the social benefit in year 1 for the high demand and low demand scenarios, respectively, while cost savings from generated demand account for 17.79% and 18.98% for each scenario.

Table 10. The project's CBA in the first year (million €)

	High demand	**Low demand**
Time savings from:	315.36	152.74
conventional train	244.89	122.44
air transport	-4.40	-1.35
bus	25.20	7.55
car	4.78	1.39
generated demand	44.90	22.72
Costs savings from:	219.37	81.72
conventional train	0	0
air transport	51.23	15.74
bus	28.94	8.66
car	44.08	12.81
generated demand	95.12	44.51
Benefits year 1	534.73	234.46

Note: high demand = 12,513,799; low demand = 5,653,801.

8.4.3 Welfare measure: comparing CGE and CBA

Table 11 shows the difference in social benefits with both methods. The CGE welfare analysis has been calculated focusing on the welfare change in two economic agents: the representative household and the government.[26] Further, this value was adjusted by the induced effect generated by the CGE model in order to calculate the net welfare effect because they are expected to be similar with the next best alternative. Hence, we deduce 20% of the first-year benefits, considering the induce effect estimated by

[26] The welfare measure is calculated on the basis of the final demand of the representative household and the government, using the equivalent variation.

Schallenberg-Rodriguez and Inchausti-Sintes (2021) for the Spanish economy (around 20%-22%).

Table 11. First year gross social benefits with CBA and CGE (million €)

	High demand	Low demand
ΔW^{CBA}	535	234
ΔW^{CGE}	559	258

Note: high demand = 12,513,799; low demand = 5,653,801.

Regarding the differences in magnitude, and considering the intrinsic differences between both methodologies, some of the possible reasons for the divergences between the appraisal of this transport project with CBA and CGE can be summarized as follows:

- CBA assumes linear demand functions, whereas CGE models are mainly non-linear. However, some functions have been assumed linear for the sake of comparability.
- The welfare effect is approached through equivalent variation in CGE and with consumer surplus in CBA, in which case the income effect could affect the result.
- The treatment of taxes is also different in both methodologies. While CGE works with actual indirect net taxes in the economy (all of them net of subsidies), CBA assumes an exogenous positive percentage for each transport mode.

Finally, if we wish to calculate the project's net present value, in the case of CGE we have to use a dynamic model, assuming exogenous values for the economic growth, interest rate, and capital depreciation rate compatible with the stock of capital and the productive-mix observed in the IOT, in order to ensure the economy's stationary state. All these additional model implications reduce the comparability with CBA.

8.5 Conclusions

This paper has sought to compare the net welfare divergence/convergence between CBA and CGE when conducting the social evaluation of an investment project in rail transport. To meet this aim, a highly simplified railway project has been evaluated with both methods. The CBA follows the conventional criterion of measuring the time saving of existing demand and accounting for the additional value of diverted traffic with the change in modal split, following a reduction in the generalized cost of rail caused by the investment.

According to the results, the CGE model yields a higher welfare impact in both scenarios. Regarding this welfare divergence, it should be noted that though both methodologies are based on general equilibrium theory, they differ in the application affecting comparability and convergence between both.

Firstly, CGE model are calibrated at national or regional level at most, while CBA can work at local level. Similarly, the sectoral aggregation of the IOT may be incompatible with the sectoral disaggregation level required by projects that take place at lower levels. In this sense, according to the Spanish Inputs-Outputs used to calibrate the CGE model, “ground transport” includes rail and road, and passengers and freight. Therefore, though we have disaggregated road and rail in a satellite account, the technical coefficient for ground transport does not distinguish between the effect of a unit of time savings between rail and road, or between passenger and freight.

There is no CGE model that fits all. This case study shows that additional and more disaggregated information is required to carry out a realistic differentiation between modes of transports and the output (passengers-goods), not only to distinguish the modal demand and their use of time, but also the productive structure.

CGE models work in total values where prices and quantities must be separated for calibration and analysis. This issue is addressed in CGE by assuming that all prices are initially equal to one and working on relative changes in prices and quantities. However, in order to obtain quantities to feed the CBA and enhance methodological comparability, different prices and time values by transport modes were assumed in order to obtain their respective demands from the CGE’s total values.

Finally, additional assumptions were made in the CGE model to improve comparability and convergence with CBA. For instance, the elasticity of transformation between domestic and exports, and the demand elasticity of tourists were assumed equals to zero, in order to control foreign sectoral adjustment. Further, transport choice was modelled assuming Leontief functions in order to obtain linear demand functions.

However, the CGE model continues to rely on highly non-linear functions, which limits full comparability with CBA. Similarly, the welfare measure is approached by equivalent variation in CGE and with consumer surplus in CBA

The clear conclusion is that unless a spatial CGE model is specifically built for the evaluation of a type of transport project we cannot expect too much from the additional complexity introduced by the CGE approach. An intercity rail investment affecting passengers, and an urban commuter line increasing proximity and generating economies of density or a road investment affecting freight, are very different. For many standard projects, a CBA, properly conducted, including the set of strongly interrelated markets, should deliver similar results to a CGE model specifically designed for the project under evaluation.

In the moment in which the analyst realizes that the induced effects are generally common to the next best alternative, their inclusion is unnecessary because net impact on welfare nets out.

What we have learned in conducting this exercise is that it is perfectly possible to use an existing CGE model based on the available IOT, but unless a serious additional modelling is added, the results are not expected to add value to the project's CBA.

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Appendix

From each firm's point of view, this profit is obtained by solving the standard maximization program:

$$\max_{l_j} \pi_j = p_j x_j^s - w l_j = p_j f_j(l_j) - w l_j, \tag{A1}$$

where π_j is the maximum profit obtained by firm j from producing and selling good or service j, $j = 1,\ldots, n$; p_j is the market price of good or service j; l_j represents the amount of labour (the only input in this model) used by firm j to produce x_j^s through the production function $f_j(l_j)$; and w the wage received per unit of working time. If all the required equilibrium properties hold, the first order condition of this problem is given by:

$$\frac{\partial \pi_j}{\partial l_j} = p_j \frac{d f_j(l_j^*)}{d l_j} - w = 0, \tag{A2}$$

which allows us to obtain as a solution $\pi_j = p_j f_j(l_j^*) - w l_j^*$.

For the individual's decision problem, if the utility function $U(x_1, \dots, x_n)$ satisfies the local non-satiation property, where x_j represents the quantity of good or service j, the budget constraint is binding. Then, the individual's maximization problem reduces to:

$$\max_{x_1,\dots,x_n} U(x_1, \dots, x_n)$$

$$\text{s.t.} \quad \sum_{j=1}^{n} p_j x_j = \Pi + wl, \tag{A3}$$

where l represents the working time chosen by the individual, and the individual´s total income obtained from profits is given by $\Pi = \sum_{j=1}^{n} \pi_j$.

Equivalently, in terms of generalized prices $g_j = p_j + wt_j$ (that includes monetary price paid (and users' time cost):

$$\max_{x_1,\dots,x_n} U(x_1, \dots, x_n)$$

$$s.t. \quad \sum_{j=1}^{n} g_j x_j = \Pi + w\bar{l}, \tag{A4}$$

where $\bar{l}$ represents individual time endowment.

The corresponding Lagrange function used to solve problem (A4) is then given by:

$$L = U(x_1, \dots, x_n) - \lambda\left(\sum_{j=1}^{n} g_j x_j - \Pi - w\bar{l}\right), \tag{A5}$$

which can be also rewritten as:

$$L = U(x_1, \dots, x_n) - \lambda\left(\sum_{j=1}^{n} g_j x_j - \sum_{j=1}^{n} p_j f_j(l_j^*) - w \sum_{j=1}^{n} t_j x_j\right). \tag{A6}$$

First order conditions are given by:

$$\frac{\partial L}{\partial x_j} = \frac{\partial U(x^*)}{\partial x_j} - \lambda(g_j - wt_j) = 0,$$

$$\frac{\partial L}{\partial \lambda} = \sum_{j=1}^{n} g_j x_j^* - \Pi - w\bar{l} = 0, \tag{A7}$$

with $j = 1,\dots,n$ and $x^* = (x_1^*, \dots, x_n^*)$.

The solution of the above maximization program yields the Marshallian demand function for each good or service j, given by $x_j^* = x_j(g, y^g)$, with $g = (g_1, \dots, g_n)$ representing the vector of all generalized prices, and the generalized income $y^g = \Pi + w\bar{l}$, which is given by the sum of profits' income and the value of the individual's time endowment.

9 Combining multimarket and general equilibrium welfare measurement in applied CBA. A case study of the Swedish forest sector

Bengt Kriström

9.1 Introduction

This paper uses a multimarket model to measure the benefits and costs of a large, albeit hypothetical, forest conservation project in Sweden. My main aim is to suggest the use of a particular approach, rather than to provide a detailed analysis of the benefits and costs. The scale of the program[1] is chosen such that it is likely that prices within the sector will be affected. A similar analysis to the one undertaken here is in Geijer et al (2011), who considers an identical, if larger reform, focusing on the market consequences. A main difference, which also is the aim of this paper is to show how non-market benefits can be added to the welfare analysis.

In general terms, the analysis is partly motivated by the fact that large-scale reforms that may affect non-market values in a material way, raises questions about how willingness-to-pay (WTP) should be estimated. It is particularly difficult to estimate WTP when income changes with the project. Therefore, a methodology that allows consistent estimates of WTP along an equilibrium path might be useful in cases when a project affects a particular sector of the economy. While computable general equilibrium (CGE) models can also be used to address the issues, the multi-market approach has some advantages when a policy affects a particular sector of the economy. First of all, data limitations may make a CGE-analysis infeasible or at least more difficult, when data on the necessary level of aggregation is not available. Second, the multi-market approach makes the welfare analysis transparent and intuitive. Third, it is possible to explore in detail key parameters (such as substitution elasticities and price elasticities) that drive the differences between a partial and multi-market equilibrium approach. One can employ a basic result in welfare economics, showing that the all welfare impacts can be summarised in one market. It is as if the analysis can be

[1] The scale is similar to a (later rejected) proposal put forward by a Government Commission in 2020 on Swedish forest policy, SOU 2020:73 ”Stärkt äganderätt, flexibla skyddsformer och ökade incitament för naturvården i skogen med frivillighet som grund”, Swedish Government official remit, 30 November 2020

summarised in one demand-supply diagram, even though the policy affects many markets. This involves using demand and supply curves that are slightly different from the usual partial equilibrium curves, whence they include changing conditions on other markets. The multi-market approach also has its downsides, since one must make assumptions about which prices that are to be exogenous to the model. Altogether it is simply one empirical approach that is useful in certain contexts.

I apply the suggested approach to Swedish forest policy discussions for two main reasons. First of all, it is well established in the literature on non-market valuation that forest conservation in Sweden is associated with significant non-use values[2]. Secondly, the forest sector remains a key industrial sector of the Swedish economy, providing significant export revenues and employment opportunities. Consequently, the trade-offs that need to be made are consequential at the scale considered here.

The paper is structured as follows: section 9.2 presents the theoretical models, in which I delineate benefits and costs for projects affecting the forest sector. To set the stage I begin with a simple model of the forest sector and derive general equilibrium welfare measures, including the case of unemployment. I then present a more detailed multi-market model of the forest sector, and obtain welfare measures in this more complex setting. The multi-market model integrates secondary market effects that all can be measured at the primary market. As noted, this is a standard result that carries over to the setting. The main theoretical contribution is to suggest how costs and benefits can be estimated consistently in a multimarket model. I then turn to the empirical application, detailing the data on the cost and benefits in section 9.3, summarizing market and non-market studies. The empirical results are presented in section 9.4. The beginnings of a more complete cost-benefit analysis are presented in section 9.5. The paper ends with some remarks on how the analysis can be developed further.

9.2 Cost-benefit analysis of forest sector projects

9.2.1 A simple model

I begin with a simple case[3] and then turn to a more detailed multi-market model. The first model can be seen as a approximate CBA of "small" forest projects, in which I

[2] Therefore a direct method (i.e. a survey) is the only way to estimate the total benefits.
[3] Based on Johansson & Kriström (2018)

also include a discussion about how to handle unemployment. In the second model, I develop welfare measurement in multimarket models in more detail.

Consider a representative household that owns all the firms in the economy. A forestry firm (f) produces sawlogs and pulpwood. I will later expand on this model to include additional activities, but this workhorse model will ultimately be the one I use for the empirical part. The sawmill and the pulp & paper industry each produce a final product that is consumed by the household. To simplify the presentation, I let the household consume the forest products instead of using them as input products in the household's production of utilities. The indirect utility function is written:

$$V = V(p^c, p^{pw}, p^{st}, w, \Pi), \tag{1}$$

where p^c is a composite good, p^{pw} denotes the price of the pulp product, p^{st} the price of the sawlog product, w the wage level, Π denotes total profit income, and the price of the numeraire is normalized to one and suppressed henceforth.

The output of the forestry firm is assumed to be exogenously determined and is used to generate a cost-benefit rule. Let us define profits as

$$\pi = p^{st} \cdot y^{st} + p^{pw} \cdot y^{pw} - w \cdot l^f, \tag{2}$$

where p^{st} (p^{pw}) denotes the price of sawlogs (pulpwood), y^{st} (y^{pw}) the quantity of sawlogs (pulpwood) and l^f its demand for labour, which for simplicity is the only factor of production.

The two sectors of the forest industry, pulp & paper (sawmills), uses pulpwood (sawlogs) and labor (for now, I ignore other inputs). Their profit functions are functions of respective input and output prices. We will detail them in the next section. The representative firm producing the composite good is assumed to use labour as the only factor of production.

Let us now marginally change the supply of sawlogs and pulpwood. A simple cost-benefit rule of profitability of such a project is given by the following expression:

$$\frac{dV}{\lambda} = dCV = p^{st} \cdot dy^{st} + p^{pw} \cdot dy^{pw} - w \cdot dl^f, \tag{3}$$

where λ denotes the marginal utility of income and dCV denotes the marginal compensating variation, i.e., the willingness to pay for the project (CV denotes the compensating variation). Notice that all quantity and price effects on other markets vanish, since price is assumed to be equal to marginal cost and all markets are in equilibrium. This is a useful rule of thumb, which consequently is true also in general equilibrium. CBA appears to be partial equilibrium, but it is based on general equilibrium foundations.

This is clear when the price changes are small. However, a change in timber supply may be so large that it affects prices more than marginally. Using equation (1) define the compensating variation that makes the household indifferent to the change:

$$V\left(p^{c^1}, p^{pw^1}, p^{st^1}, w^1, \Pi^1 - CV\right) = V\left(p^{c^0}, p^{pw^0}, p^{st^0}, w^0, \Pi^0\right), \qquad (4)$$

where a index 1 (0) denotes the final (initial) level.

As long as the forest industry sets $p^i = MC^i$, i.e., applies marginal cost pricing, we can ignore value added changes outside the primary sector. It should be noted, however, that the equilibrium paths for the two wood variants are difficult to estimate. The equilibrium conditions of the different markets must be used to simultaneously solve the equilibrium prices as functions of the exogenous variables. More on this below, where this problem is solved using an estimated equation system.

Alternatively, we can integrate equation (3) along the equilibrium path to obtain CV. The integrals reflects areas under ”Bailey”, or observed supply curves from which we deduct the cost of labor. This version assumes that all markets are competitive. The key point of writing CV in this way is that we can summarise all effects in the primary market.

Finally, I illustrate how unemployment is usually handled in CBA by generalizing equation (3) as follows:

$$\frac{dV}{\lambda} = dCV = p^{st} \cdot dy^{st} + p^{pw} \cdot dy^{pw} - w \cdot (dL^f - dL^u) - w^R \cdot dL^u, \qquad (5)$$

where $w^R \leq w$ is the reservation wage or the minimum compensation the unemployed person is willing to accept and $dL^u \geq 0$ is the number of unemployed people who are employed in the project. The cost of recruiting the otherwise unemployed is *positive* as long as the reservation wage is strictly positive but normally lower than the cost of recruiting a person who also has a job in the alternative case.[4]

To conclude: it is easier to conduct a CBA if one can focus on a single market, rather than analyzing either highly aggregated forest industry markets or a myriad of markets for consumer products. In addition, in most cases the project under analysis can be expected to be so small that prices are left more or less unaffected. An analysis based on equation (3) is then sufficient to approximate the socio-economic value of the project. But there are cases when such assumptions may be useful to relax, at least to some extent. We thus turn to a case when prices are thought to change significantly in a given sector using a slightly different approach.

9.2.2 Multimarket welfare measurement

The theory behind multimarket welfare measurement is presented in e.g. Just et al (2005), which in turn is inspired by Bailey (1954). The methodology has wide applicability, see e.g., Alston & James (2002) (agriculture), Ankarhem (2005) (forest sector) and Geijer et al (2011) (climate policy). The model presented in this section is a generalization of Brännlund & Kriström (1996). The main extension is the embedding of the multimarket welfare measure into a general equilibrium structure in an approximate manner, where I include non-market goods in the welfare measure. In this way, it is possible to obtain measures of benefits and costs that take into account sector repercussions. At the outset, it should be stressed that some prices are held exogenous and therefore the measures are not general equilibrium in the conventional sense.

Forest owners use labor l^{f}, energy e^{f} and one fixed input K^{f} to supply (s) three different outputs, $\mathbf{y}^{\mathrm{f}} = \{y^{fw}, y^{pw}, y^{st}\}$, where y^{fw} is fuelwood. I assume a constant returns to scale short-run technology, with the standing stock of timber being fixed in the short-run. The forest technology is implicitly given by $H^{\mathrm{f}}\left(y^{fw}, y^{pw}, y^{st}, -l^{f}, -K^{\mathrm{f}}\right) = 0$, where H^{f} is a transformation function.

Maximizing profits subject to the technology gives the profit function in forestry

$$\Pi^{\mathrm{f}}\left(p^{fw}, p^{pw}, p^{st}, w^{l}, ; K^{\mathrm{f}}\right). \tag{6}$$

[4] Theoretically, a project can also affect unemployment elsewhere in the economy, although it is difficult to see how such effects can be ”tracked” in an evaluation of a small project.

With the assumptions laid out by Diewert (1973), there is a duality between the transformation functions and the profit function, and I henceforth use the latter. Supply functions for forest owners are obtained via Hotelling's lemma;

$$y^{fw} \quad = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{fw}} \tag{7}$$

$$y^{pw} \quad = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{pw}} \tag{8}$$

$$y^{st} \quad = \frac{\partial \pi^{\mathrm{f}}}{\partial p^{st}} \tag{9}$$

I next introduce three activities that buys inputs from the forestry-sector; $\mathtt{nf} = \{dh, pp, sm\}$. District heating (dh) uses inputs $\{x^{fw}, l^{dh}, e^{dh}, K^{dh}\}$, where l^{dh}, e^{dh} is the demand for labor and other energy inputs than firewood in district heating, respectively; K^{dh} is a quasi-fixed input. This sector produces heating services y^{dh}. The pulp industry (pp) employs energy, labor with prices $\{l^{pp}, e^{pp}\}$ and a quasi-fixed capital stock input (K^{pp}) to produce an output denoted y^{pp}. Finally sawmills combine variable inputs sawlogs, labor, energy together with a quasi-fixed input, to supply an output y^{sm}.

let Π^{nf} denote the profit functions in the non-forestry sector that buys forestry output. These functions are obtained by maximizing profits subject to the respective technologies. The forestry products are demanded by the nf firms, and their demand functions are given by Hotelling's lemma

$$x^{fw} = -\frac{\partial \pi^{dh}}{\partial p^{fw}} \tag{10}$$

$$x^{pw} = -\frac{\partial \pi^{pw}}{\partial p^{pw}} \tag{11}$$

$$x^{st} = -\frac{\partial \pi^{dh}}{\partial p^{st}} \tag{12}$$

9.2.2.1 Sector equilibrium

I assume supply equal to demand in the market for forestry products. The remaining markets outside of the forest sector are all assumed to be in competitive equilibrium with exogenous (relative to this model) output prices. Thus, labor markets and energy markets are all in equilibrium throughout the change considered here. The prices on these and other suppressed markets change are assumed to change only marginally due to the project. I normalize the number of firms to one and focus on the equilibria in the system, which I write as, suppressing all but the own-prices in the demand and supply functions,

$$x^{fw} = y^{fw} \quad (13)$$
$$x^{pw} = y^{pw} \quad (14)$$
$$x^{st} = y^{st} \quad (15)$$

other markets are suppressed and assumed to be in equilibrium throughout. In principle, the system can be solved for the equilibrium prices $\{p^{fw}, p^{pw}, p^{st}\}$, as functions of the exogenous variables in the model. I will use this fact when computing welfare measures in the next section.

9.2.2.2 Profit changes due to conservation

I consider a conservation project, which I model as a reduction of the forest capital stock using a project parameter α. I interpret a reduction of forest capital as a way of withdrawing a certain fraction of available forest capital from the market. Thus, a small project is modelled as $K^{\mathrm{f}} \cdot d\alpha$ and a non-marginal project $K^{\mathrm{f}} \cdot \Delta\alpha$. Observe that while the stock of forest is not a part of the profit function in the nf-firms, it will affect the equilibrium prices in an indirect way.

I assume that all markets are in equilibrium throughout the change induced by the project. Let • denote the exogenous prices of the model and $p^* = \{p^{fw}(\bullet, \alpha \cdot K^{\mathrm{f}}), p^{pw}(\bullet, \alpha \cdot K^{\mathrm{f}}), p^{st}(\bullet, \alpha \cdot K^{\mathrm{f}})\}$.

Let $\alpha^0 = 1 \rightarrow \alpha^1 \in (0,1)$ represent the project and let ”0” denote profits in the status quo. Then,

$$\Delta\pi^{\mathrm{f}} = \pi^{\mathrm{f}}\left(p^*(\alpha^1), \bullet; \alpha^1 \cdot K^{\mathrm{f}}\right) - \pi^{\mathrm{f}^0} \quad (16)$$
$$\Delta\pi^{l^{dh}} = \pi^{dh}(p^*(\alpha^1), \bullet; K^{dh}) - \pi^{dh^0} \quad (17)$$
$$\Delta\pi^{pp} = \pi^{pp}(p^*(\alpha^1), \bullet; K^{pp}) - \pi^{pp^0} \quad (18)$$
$$\Delta\pi^{st} = \pi^{st}(p^*(\alpha^1), \bullet; K^{sm}) - \pi^{sm^0} \quad (19)$$

Thus, $\Delta\pi^j = \int_1^{\alpha^1} K^{\mathrm{f}} \frac{\partial \pi^j}{\partial \alpha} d\alpha, j \in \{\mathrm{f}, dh, pp, sm\}$. Using the equilibrium conditions, we obtain:

Proposition 1. *Let* $\alpha > 0$ *be a project parameter used to exogenously change the stock of forest, such that* $dK^{\mathrm{f}} = K^{\mathrm{f}} \cdot d\alpha$. *The sum of the profit changes (*$\equiv \Delta\Pi$*)* ***in the forest sector*** *under the project* $\alpha^0 = 1 \rightarrow \alpha^1 \in (0,1)$ *is*

$$\Delta\Pi \quad = \Delta\pi^f(\alpha) + \Delta\pi(\alpha) + \Delta\pi(\alpha) + \Delta\pi^{l^{dh}}(\alpha) \tag{20}$$

$$= \int_1^{\alpha^1} K^{\mathrm{f}} \frac{\partial\pi^{\mathrm{f}}(p^*(\alpha),\bullet;\alpha\cdot K^{\mathrm{f}})}{\partial\alpha} d\alpha \tag{21}$$

Proof.

$$\Delta\Pi \quad = \sum_{s\in f\cup nf} \Delta\,\pi^s \tag{22}$$

$$= \sum \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^f}{\partial p^i}\frac{\partial p^i}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} + \sum \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^{nf}}{\partial p^i}\frac{\partial p^i}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} + \int_{K^{\mathrm{f}^0}}^{K^{\mathrm{f}^1}} \frac{\partial\pi^f}{\partial K^{\mathrm{f}}} dK^{\mathrm{f}} \tag{23}$$

$$= \int_1^{\alpha} \frac{\partial\pi^f}{\partial\alpha} K^{\mathrm{f}} \cdot d\alpha \tag{24}$$

The key idea is that the induced price changes net out, assuming that the markets are in equilibrium throughout the change. Thus, the sum of the profit changes in the sector is obtained by integrating along the equilibrium path. The basic idea has been well articulated by Carbone & Smith (2013):

> The comparisons [...] parallel the distinctions between consumer surplus for a price change measured along a partial versus a general equilibrium demand function (see Just, Hueth and Schmitz (2004), pp. 327-330). The general equilibrium demand function for a particular good measures the consumer surplus due to an intervention - say a new commodity tax on that good - by evaluating that good's demand at the general equilibrium prices for all goods

The project studied here is different from the one studied in the original paper by Brännlund & Kriström (1997), because the project affects three markets simultaneously. In their study, the initial perturbation was limited to one market. Their key result was that the sum of profits in the forest sector could be measured in one market, provided that one integrates along the equilibrium path. This is a standard result, that is useful for empirical application.

9.2.3 Non-market goods

We now proceed with an extension of multimarket welfare measurement by introducing households, so that I can disentangle benefits and costs in the natural way. I abstract away from foreign ownership. Thus, any change of profits in any firm in the forestry sector will accrue to the domestic consumer I simply assume that the price changes in other sectors than forestry are marginal; importantly, the output prices for firms using inputs bought from forest owners are assumed fixed. In effect, actors in the forestry sectors acts as if the prices exogenous to this model are given. For general equilibrium applications using CGE-modelling involving non-market goods, see e.g., Carbone & Smith (2013) and Smith & Qiang (2018).

One advantage with the approach taken here is that there is no need for calibration of the model in the status quo. Indeed, for a CGE-model to replicate the benchmark, parameters need to be set such that supply is equal to demand (assuming that the benchmark is interpreted as a general equilibrium, which is typically the case). One way to accomplish this is to use expenditure data combined with assumptions on key elasticities. If a non-market activity is active in the benchmark, then parameters of the utility function need to be set such that the model can replicate the initial equilibrium, including the non-market good. For example, in the benchmark equilibrium of the Carbone & Smith (2013) model (an extension of Goulder & Williams (2003)), there are acidific deposition from nitrogen- and sulphur oxides. These affect fish, scenic vistas and tree cover. Calibration involves an augmented income-concept, such that income includes the value of an environmental quality endowment. Thus, in the benchmark, spending is equal to income, using a virtual price on environmental quality. These calibration concepts are not needed in this framework.

It should be stressed that the main focus is the benefits and costs of forest policy, not, as in Carbone & Smith (2013), substitution patterns in general equilibrium when public goods are non-separable in the utility function. In this paper there is only one public good and I do not explicitly study interactions with private goods. Also, environmental quality does not enter per se in the production functions in my case.

Assume that the individual appreciates the preservation of forests, represented by an index z, so that an increase in z increases utility. Other goods are for simplicity assumed to be a composite good with price one and it is suppressed. Let Π, the sum of all profits in the economy. I assume that there is no labor-leisure choice, so that income from labor is the value of time sold in the labor market. If the change in the market wage due to the project is "small enough", I take change in income from labor to be approximately zero. Furthermore, I assume that marginal profit induced by the project is zero elsewhere in the economy.

I therefore write the indirect utility function as;

$$V(p^{dh}, p^{st}, p^{pp}, \Pi, z) \tag{25}$$

V is assumed to have the standard properties of an indirect utility function. Observe that I do not allow for imports of goods to the forestry sector, see Brännlund & Kriström (1997) for this extension.

Consider the program to remove a certain fraction of K^{f} from the market, using the project parameter α. To repeat, this may cause non-marginal price changes in the forestry sector, but only marginal price-changes elsewhere. To obtain a money measure of the welfare change I define compensating variation (CV) as follows;

$$V\left(p^{dh^1}, p^{st^1}, p^{pp^1}, \Pi^1 - CV, z^1\right) = V^0 \tag{26}$$

where V^0 is the welfare in the status quo and the price of the composite good is suppressed. It is important to note that we are evaluating the project at the initial utility level. Thus, the equilibrium prices correspond to compensated demand and supply curves, see Arrow-Hahn (1971). These prices are, in general, not necessarily the same as those would be observe in the markets, since we then consider Marshallian demand and supply curves. It will be convenient to assume that the Marshallian and the Hicksian demand curves are sufficiently similar over the price ranges considered.

Insofar as there are important non-use values attached to the change of forest conservation, the only possible method is a direct method, i.e., by asking individuals about their WTP. This entails presenting a scenario that encapsulates the welfare measure in equation (26), i.e., a counterfactual with new prices and the sum of profits at the new equilibrium. Johansson (1993) shows how the application of a direct method can be simplified. In a way, it allows us to separate the estimation of the benefits and the costs. Johansson (1993) constructs a partial measure CV^p, which in this case will be;

$$V\left(p^{dh^1}, p^{st^1}, p^{pp^1}, \Pi^0 - CV^p, z^1\right) = V^0 \tag{27}$$

Notice that this CV-measure needs considerably less information, since it is to be computed at the benchmark income level. Furthermore, $CV = CV^p + \Delta\Pi$, where $\Delta\Pi = \Pi^1 - \Pi^0$ (the marginal profit change is assumed zero zero in the rest of the economy, given that price is equal to marginal costs in all markets not described here). The respondent is asked about CV^p and the profit changes in the sector are added to get the total value. Finally, note that if income is roughly constant across states of the world, then $CV^p \approx CV$, the usual assumption employed when using a stated preference method. Of course, the question used in the questionnaire will be rather difficult to answer in practice. One would have to detail the consequences for the prices of consumer goods emanating from forestry, explicitly stating that other prices will not change in any material way. At any rate, it will be useful to spell out exactly how the project is supposed to affect the economy, when describing it to the household in the survey.

I now turn to the empirical analysis and begin with the data I used for the costs and the benefits of preservation of forests in Sweden.

9.3 Data

I begin with a broad overview of the data and then turn to details. According to www.skogsindustrierna.se, the Swedish forest industries organization, 115.000 persons are employed in forestry/forest industry. 320,000 or some 3% of the Swedish population are forest owners. 11% of the value of Swedish exports is comprised of forest products (2019). Computations presented in Kriström (2016) using the Balassa index also suggests that Sweden has a comparative advantage in pulp & paper production, in particular. A summary of key data appears in table 1.

Table 1. Forest sector data for Sweden.

Forest-area	$28 \cdot 10^6$ ha (69% of Sweden's landmass)
Gross growth	$115 \cdot 10^6\ m^3$
Fellings	$85 \cdot 10^6\ m^3$
Net stumpage value	$21 \cdot 10^9$ *SEK* (2019)
Value added	$36 \cdot 10^9$ *SEK* (about 8% of value added in industry)

Source: Brännlund (2021)

Value added per hectar is $\frac{36 \cdot 10^9}{28 \cdot 10^6} \approx 1300$ SEK $\cdot\ ha^{(-1)}$, a useful number to keep in mind, given the project studied here. At any rate, these statistics support the idea that the forest sector is important for Sweden's economy. Furthermore, it is widely acknowledged that the forest sector provides substantial non-market values. The non-market benefits generated by Sweden's forests are more difficult to estimate for many reasons, but the idea that they are material is supported by data presented below. I stress that some of the numbers are controversial. For example, net growth of the forest stock results in about 40 mill. ton of CO_2 being sequestered (gross emissions is about 46 mill. ton CO_2-equivalents in Sweden 2020, according to www.scb.se). Carbon locked up in various forest products such as wood furniture are sometimes added suggesting that Sweden's net carbon emission is close to zero. The key controversy regards carbon capture across policies; is a moratorium on cuttings better or worse for the climate compared to intensive forestry? This question is not addressed in this paper, even though a CBA would be of much interest. I now turn to detailed data on the forest sector. I use them to estimate the benefits and costs of the conservation measure that was outlined above.

9.3.1 Market data for the Swedish forest sector

Given the intricate data construction based on Geijer et al (2011), which I will use below, I cite them at length regarding data construction:

> Gross felling destined for sawmills, the pulp industry and the heating industry is used as the supplied (and demanded) quantities. The corresponding prices

> are the average domestic price for sawtimber, pulpwood and wood fuel. Unfortunately, data for the supply of wood fuel has not been collected annually. To fill the gaps, the agency responsible for collecting these data (the Swedish Forest Agency) has chosen to present the same amount over multiple years rather than attempting to approximate the change using other sources of information. This problem is handled in two steps. First, for the last seven years, we approximate the change in the total supply of wood fuel based on the change in wood fuel usage in the heating sector. Secondly, we add a variable for last year's supply of wood fuel to its supply function. The price for both energy and labour in the wood-using industries is calculated implicitly from industry-specific cost and quantities, except for the last years where data concerning wages within different occupations have been used to approximate the wage rate. Since we lack data on the wage rate within forestry, the wage rate from the sawmill industry is used as a proxy. Export prices for (sawn and planed) softwood and wood pulp (sulphate - unbleached) are used as output prices for sawmills and the pulp industry. For the energy industry we have used an implicit output price defined as the ratio between the total revenue from delivered. heating and the delivered quantities. All prices are normalized with respect to the consumer price index. Standing inventory of timber is used as real capital stock for the forest owners. In the demand side real capital to each industry consists of the value of machines and buildings. For the heating sector we have used (one tenth of) the value of the entire energy industry's capital as a proxy for the development of capital in the heating industry. Geijer et al (2011, p. 13)

Regarding their data, the capital stocks (except forestry) is not in real terms. Furthermore, the data on the capital stock in district heating needs to be scaled by a factor of 10. But other than that, I use the data in Geijer et al as is, see table 2.

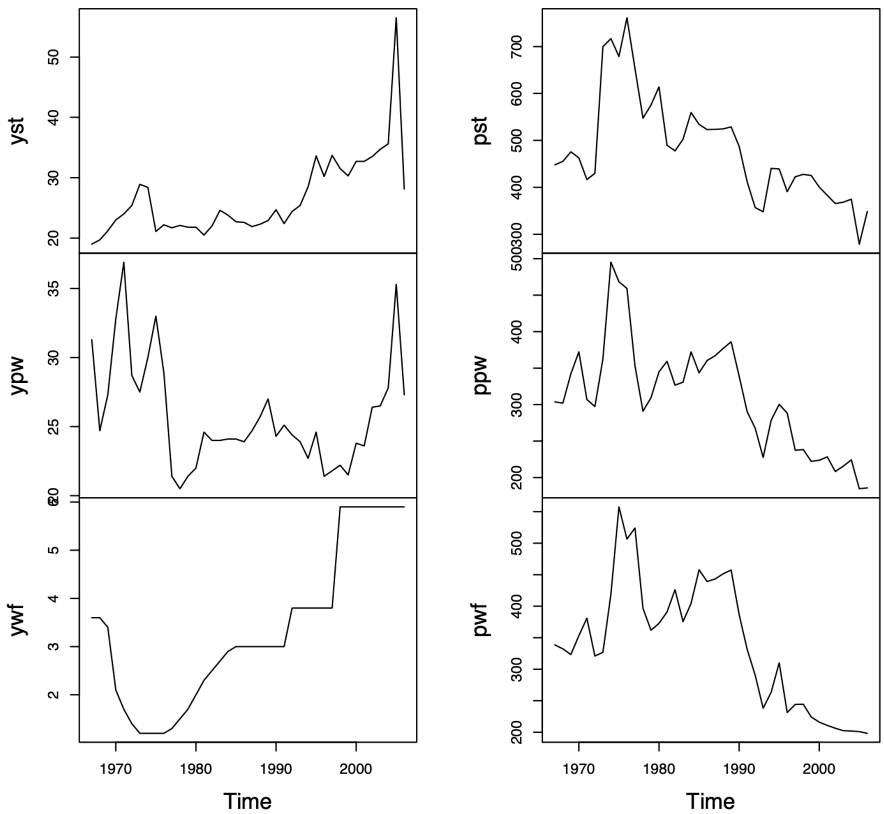
Table 2. Summary statistics of Swedish forest sector 1967-2006

	Mean	sd	Min	Max
Forestry				
y^{st}	26.55	6.80	19.00	56.50
y^{pw}	25.78	3.89	20.50	36.90
y^{fw}	3.36	1.62	1.20	5.90
p^{st}	481.69	110.77	279.11	761.25
p^{pw}	309.81	74.86	184.68	495.12
p^{fw}	339.08	100.19	198.23	557.69
K^{f}	2701.80	269.06	2330.74	3230.00
Sawmills				
p^{sm}	1850.00	273.17	1437.65	2647.44
e^{sm}	41.14	9.32	21.96	54.76
w^{sm}	97.56	9.75	71.96	115.45
K^{sm}	20843.87	5938.30	8326.05	28972.21
Pulpindustry				
p^{pp}	4141.38	918.86	2882.30	6649.35
e^{pp}	25.57	4.89	18.63	38.47
w^{pp}	116.02	14.65	75.77	139.94
K^{pp}	40403.59	9429.93	18892.95	49023.22
District Heating				
p^{dh}	324.17	73.70	211.40	448.52
e^{dh}	107.61	44.21	37.64	211.96
w^{dh}	115.76	14.46	81.66	144.90
K^{dh}	33367.94	10254.68	15688.72	45649.20

Source Geijer et al (2011). Price (e^i, p^i, w^i) data are in 2000 prices using the CPI. Forestry data are in $10^6 m^3$ *and SEK* $\cdot (m^3)^-1$*, Sawmills data are in* SEK $\cdot (m^3)^-1$, SEK $\cdot (MWh)^{(-1)}$, SEK $\cdot (hour)^{(-1)}$, *and million* SEK, *pulp industry data in* SEK $\cdot (10^3 kg)^{(-1)}$, SEK $\cdot (MWh)^{(-1)}$, SEK$\cdot (hour)^{(-1)}$, *and million* SEK. *Finally heating industry data has units* SEK $\cdot (MWh)^{(-1)}$, SEK$\cdot (MWh)^-1$, SEK$\cdot (hour)^{(-1)}$, *and million* SEK

Table 2 provides summary statistics on prices and quantities of the three outputs from the forestry sector. We can see that the fuelwood market constitutes only a very small portion of the yearly cut. Furthermore, the dominant part of what is cut every year is more or less equally divided between pulp- and sawnwood. Figure 1 shows price and quantity over time for the three forestry markets. It is of interest to note that the real price is downward trending, most likely due to productivity gains, whence the volumes are generally up. Notice also the dramatic year 2005, when the storm Gudrun felled roughly a normal year's total cut in two days. 70-75 (estimates vary) mill. m^3 of standing forest became victim of the storm (about 4 years of cut in southern Sweden, where the storm was intense). This natural disaster depressed prices on the forestry markets. The government subsequently imposed price-supports to help the forest-owners to "ride out the storm". Furthermore, as suggested above, the quality of the data on fuelwood is in question, but I have no other data at the moment.

Figure 1. Prices and quantities in the sawlogs, pulpwood and fuelwood markets, 1967-2006, in 2000 prices.



Data from Geijer et al (2011)

Table 3 displays the cross-correlations.

Table 3. Cross-correlations for quantity and price in the forestry markets

	y^{st}	y^{pw}	y^{fw}	p^{st}	p^{pw}	pwf
y^{st}	1.00	0.18	0.64	-0.51	-0.59	-0.67
y^{pw}	0.18	1.00	-0.12	-0.02	0.20	0.10
y^{fw}	0.64	-0.12	1.00	-0.77	-0.81	-0.81
p^{st}	-0.51	-0.02	-0.77	1.00	0.87	0.79
p^{pw}	-0.59	0.20	-0.81	0.87	1.00	0.88
pwf	-0.67	0.10	-0.81	0.79	0.88	1.00

As expected, the supply of the three qualities of wood is positively correlated. This is also expected for the prices. Note, however, that the own-prices for saw-logs and fuelwood are negatively correlated with their own-prices. This is an indication, however weak, that we are identifying the demand function, see Leamer (1981) who gives some conditions on when such an interpretation is valid. Leamer (1981) cites an analysis of Houthakker (1979), in which the latter finds 5 out 59 correlations between output and price to be positive; prices are therefore argued to be more affected by supply than demand. This is intuitively plausible in the application, whence e.g., a pulp-mill is a 24/7 operation that typically runs as long as variable costs are covered, i.e., the own-price demand elasticity is likely to be small (in absolute value). Since I estimate a system of equations, I need not interpret a "quantity versus price regression" in the way that Houthakker suggests.

9.3.2 The ESAB (2018) study

The forest sector analysis by ESAB (2018) is similar to the approach here. While their multi-market model focuses the costs of conservation policy in Sweden, the benefits are assumed constant across their scenarios. The scenario is based on the state-owned company Sveaskog, that swapped 100,000 ha of its forest land to obtain 64,500 ha of preservation-worthy forests owned by forest companies. See Johansson & Kriström (2021) for a conceptual analysis of this program. ESAB (2018) use an updated version of the Geijer et al (2014) model to estimate the market effects. Table 4 presents the estimated price and quantity effects on the markets.

Table 4. Estimated impact on the forestry markets of preserving 64,500 ha old-growth forest in year 2015.

Market	Before	After
Sawtimber quantity	$35.5 \cdot 10^6 m^3$	$35{,}47 \cdot 10^6 m^3$
Sawtimber price	$504 \quad \text{SEK} \cdot (m^3)^{-1}$	$504.2 \quad \text{SEK} \cdot (m^3)^{-1}$
Pulpwood quantity	$30.4 \cdot 10^6 m^3$	$29.3 \cdot 10^6 m^3$
Pulpwood price	$277.1 \quad \text{SEK} \cdot (m^3)^{-1}$	$336 \quad \text{SEK} \cdot (m^3)^{-1}$
Fuelwood quantity	$6 \cdot 10^6 m^3$	$5.98 \cdot 10^6 m^3$
Fuelwood price	$287 \quad \text{SEK} \cdot (m^3)^{-1}$	$290 \quad \text{SEK} \cdot (m^3)^{-1}$

Source: ESAB (2018)

The effects on the sawtimber and fuelwood markets are small. The pulpwood markets are significantly impacted, with a quantity change of almost 1 million m^3 and a 21% price increase. During the years 2015-2018, pulpwood prices increased by 15%, while sawtimber prices remained roughly constant. It is of some interest to note that the model predicts a similar structure of price changes as actually occurred on the market. As noted, the predicted price changes are not unreasonable, given that a pulpmill should be rather price-inelastic in the short-run. It is very costly to shut down operations, not the least compared to sawmills and district heating plants.

9.3.3 Non-market data for the Swedish forest sector

Forest ecosystems provide an array of "ecoservices" that contribute to human well-being, even though such services do not necessarily fetch any market price. For a review of payments for ecosystem services from forests, see e.g. Alix-Garcia & Wolff(2014). A comprehensive review of the concept of ecosystem services is in Gomez-Baggethun (2010). Techniques to value non-market goods have been rapidly developed over the past decades. The portfolio of useful approaches has been expanded, and the strengths and weaknesses of each valuation methods are now better understood, after more than

50 years of applying them. For a non-technical survey of valuation techniques, see e.g., Johansson & Kriström (2018). For a meta-analysis of studies focusing forests ecosystem services using contingent valuation, see e.g., Barrio & Loureiro (2010). A guideline for carrying out such studies in the case of forestry is in Riera et al (2012).

Ideally, the paper would have been built off a valuation survey that mimics the model, but since I do not have such data, I will use some rough approximations. In the calculation, I simply scale down the stock of standing timber, taking no account of the geography. Needless to say, the conservation values will likely depend on precisely which forests that are to be saved. As against that, the political goal regarding forest conservation in Sweden is expressed as a certain number of hectares to be preserved, making no reference to geography (see Johansson & Kriström (2021)).

To obtain the estimate of the value of preserving a fraction of the standing stock of timber in Sweden, consider some studies that have been made on the topic. I will focus on Sweden for natural reasons[5]. It is to be noted that non-market valuation focussing Swedish forests was very active from about the mid 1980s until about 2000, after which there is only a few studies. Indeed, the survey by Lindhjem (2007) on 20 years of valuation research on forest ecosystem services in the Nordic countries is still quite comprehensive.

Hultkrantz (1991) made an attempt to adjust the sectoral forest accounts in Sweden by including several non-priced services provided by forests. To the extent possible, Hultkrantz (1991) utilizes market prices to evaluate each component. Market data is available for timber, berries and mushrooms. The value of meat from hunting and recreational values are obtained from a contingent valuation study. Biodiversity is valued by considering the area of protected land that must be set aside to protect biological diversity. Hydrological effects, e.g., forest absorption of water that could have been used for power generation, are not valued explicitly. Carbon fixing is valued by using the effluent fee of carbon dioxide. Note that Hultkrantz (1991) counts the increase of growing forest stock twice. First, the timber value and then the value of carbon fixing. The annual depletion of exchangeable cations in forest soils can be compensated by liming, and this cost is used as a proxy. For lack of data, nitrogen

[5] There are many similar studies from other countries, see e.g., Campos & Caparrós (2006) for an application to Spain

leaking is not considered explicitly. Forests (in the North of Sweden) also provide reindeer forage. Because changes in lichen stocks are not included in the current accounts, Hultkrantz (1991) utilizes studies on opportunity costs to obtain a value of the change in stocks. Note that the consumption of reindeer forage is already included in the national accounts, because the availability of reindeer forage will affect profits in this industry. Hultkrantz (1991) obtains a "green" NNP for the Swedish forest sector; the ecosystem services add roughly 20% to the value of forestry output. This is an indication, however weak, that the market values may be larger than the non-market ones. Updates of Hultkrantz(1991) are available in Eliasson (1995) and Kriström & Skånberg (2001) with similar results.

While there are a few studies of green accounting using national data, there are now a large number of studies of non-market forest benefits that uses household data. A significant number of studies focus on the recreational value of forests. Bojö (1985) applied both the travel cost method and the contingent valuation method to estimate the environmental benefits from the preservation of a forest area in the Vålå Valley in Northern Sweden. Both valuation methods indicated that a preservation alternative was preferable. The area was subsequently protected from forest harvesting. Kriström (1990) asked a sample of 1100 Swedish households about their WTP for the preservation of 11 pristine (old-growth) woodlands in Sweden. A lower bound estimate of the aggregate WTP for all Swedish households was found to be *SEK* 3.8 billion (*SEK* 1 ≈ USD 1/11 in 2022). This was compared to the value of a cutting alternative, suggesting that the benefits of preservation may outweigh the costs for the areas under study. Mattson & Li (1993) used the contingent valuation method to study non-timber values in the county of Västerbotten in northern Sweden. They attempted to quantify the non-timber value from on-site consumptive use (berry- and mushroom-picking), on-site non-consumptive use (hiking, camping, etc.), and off-site visual experience. Perhaps the study that comes closest to the project envisioned here, is Broberg's (2007) about Swede's WTP for preserving old-growth forests in North-West of Sweden. His scenario is similar to a proposal made in a remit (SOU 2020:73) of preserving 500 000 ha of forests in the north-west. He uses CVM and reports a total value of 9 billion *SEK* for the preservation program.

There are a number of databases that collate valuation studies. ValuebaseSWE for Sweden (Kinell et al (2009)) and its aggregate, e.g. the Nordic valuation studies database (*http://norden.diva-portal.org/smash/get/diva2:700735/FULLTEXT01.pdf*) and global EVRI database (*www.evri.ca*). The report by Kinell et al (2009) derives estimates about the value of preservation of forests. It is difficult to convert these estimates to something that can be compared to the cost of taking away a percentage of the standing stock of timber. One reason is that the object of valuation differs substantially between the different studies. At any rate, at the individual level, the lower bound is 2372 *SEK* as a one-time payment to 5 685 *SEK* per year, the latter being converted to an aggregate estimate of about 1 billion per year (Mattsson & Li (1993)), although this number pertains only to a fraction of Swedish forest land.

Brännlund et al (2015) provide a CBA of "Intensive cultivation" compared to "conventional" forest use in Sweden, accounting for various non-market goods. Intensive cultivation are productivity-enhancing measures within forestry, such as reforestation of agricultural lands, increased use of fertilizer and proactive measures that limit damage to seedlings by moose and other wild game. The authors include carbon sequestration, acidification and nutrient loading, landscape changes and recreational value (including hunting) among the non-market goods, but not biodiversity. The market effects of more intensive forest management include larger harvests, as well as increased use of bioenergy that substitutes away from fossile fuels.

According to the remit to the government carried out by the Swedish University of Agricultural Sciences (ESAB (2018)) mentioned above, non-market values appreciated by a forest owner amounts to 350 $\text{SEK} \cdot ha^{-1} \cdot year^{-1}$. This value is based on literature surveys and numerical analysis undertaken by the remit. Whether or not this can be taken to be a reasonable approximation of a non-owner's valuation is not clear.

The most recent data has been collated by Brännlund (2021). He considered the benefits and costs of "shutting down" forestry operations in Sweden. The value of biodiversity is not estimated, given the measurement difficulties. Tourism values are assumed not to be much affected, given that Sweden already has a number of national parks and otherwise protected forests. Recreation is also not necessarily only negatively affected by forestry, whence forestry activities have allowed access to many remote areas by the construction of roads. Since more than 90% of the Swedish population visits a forest every year in present conditions [6], it seems reasonable to assume that there is a recreation value even when forestry is operative. Furthermore, certain berries are affected positively by clear-cuttings. Finally, moose-hunting, a traditionally very popular type of hunting in Sweden, has actually benefited from forestry, whence the stock of moose has increased, most likely via increased forestry. Consequently, there are several difficulties involved when trying to find a good estimate of the benefits of preservation. The contingent valuation study carried out by Kriström (1990) included a scenario that effectively proposed to save some 700000 hectares of old-growth forest. The willingness-to-pay (EV) was found to be 1000-3000 SEK per person as a lumpsum, depending on the estimation method. This is approximately 0.001-0.004 SEK per ha and person. Multiplying by the number of inhabitants in Sweden ($10 million$) today I obtain about 29000 SEK per ha using the midpoint. Converting to a yearly payment using a discount factor of 5%, I get 1450 SEK per ha. This value includes use and non-use values. The uncertainty is, of course, huge, but the results are comparable to Brännlund (2021).

Table 5 summarizes the above discussion about benefit estimations.

Table 5. Selected studies of conservation non-market values

Study	Non-market value	Good
Kriström (1990)	3.8 billion SEK	conserving 700 000 ha (EV)
Hultkrantz (1991)	20% of value added	Ecosystem services. Green national accounts for forestry
Mattsson & Li (1993)	50% of production value	Forest recreation, County of Vasterbotten
NiER (1999)	20 billion SEK $\cdot yr^{(-1)}$	Forest recreation, Sweden
Broberg (2007)	9 Billion SEK	Preservation of old-growth forest in Northwestern Sweden

[6] See https://www.slu.se/globalassets/ew/ew-centrala/forskn/popvet-dok/faktaskog/faktaskog96/fs1996018.pdf

9.4 The Econometric model

The objective next is to estimate demand and supply curves in the forest sector. There are several useful functional forms, here we want to cater for multioutput technologies and quasi-fixed inputs. Behrman et al (1992) proposed a CET-CES-GL profit function, which refers to the constant elasticity of transformation and constant elasticity of substitution between pairs of outputs and inputs. I will use a special case of this function; an augmented Generalized Leontief (GL) to cater for quasi-fixed capital inputs, following Diewert (1973), see also Bergman (1995). Standard properties of a profit function include homogenenity of degree one in prices, I will also require that it is homogenous of degree one in $K^s \forall s \in \mathtt{f,nf}$ see Diewert (1973). This implies constant returns to scale in all factors, see Bergman & Brännlund (1995) for extensions to the non-homogenous case.

For estimation purposes, I divide each equation by the capital stock, to obtain:

$$\begin{aligned}
\frac{y^{fw}}{K^{\mathrm{f}}} &= \beta_{11} + \beta_{12} \cdot \sqrt{\frac{p^{pw}}{p^{fw}}} + \beta_{13} \cdot \sqrt{\frac{p^{st}}{p^{fw}}} + \beta_{14} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{fw}}} \\
\frac{y^{pw}}{K^{\mathrm{f}}} &= \beta_{22} + \beta_{21} \cdot \sqrt{\frac{p^{fw}}{p^{pw}}} + \beta_{23} \cdot \sqrt{\frac{p^{st}}{p^{pw}}} + \beta_{24} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{pw}}} \\
\frac{y^{st}}{K^{\mathrm{f}}} &= \beta_{33} + \beta_{31} \cdot \sqrt{\frac{p^{fw}}{p^{st}}} + \beta_{32} \cdot \sqrt{\frac{p^{pw}}{p^{st}}} + \beta_{34} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{st}}}
\end{aligned}$$

For the demand of forestry products I obtain

$$\begin{aligned}
\frac{x^{fw}}{K^{\mathrm{dh}}} &= -\left(b_{11} + b_{12} \cdot \sqrt{\frac{\overline{p^{dh}}}{p^{fw}}} + b_{13} \cdot \sqrt{\frac{\overline{e^{df}}}{p^{fw}}} + b_{14} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{fw}}} \right) \\
\frac{x^{pw}}{K^{\mathrm{pp}}} &= -\left(b_{22} + b_{21} \cdot \sqrt{\frac{\overline{p^{pp}}}{p^{pw}}} + b_{23} \cdot \sqrt{\frac{\overline{e^{pp}}}{p^{pw}}} + b_{24} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{pw}}} \right) \\
\frac{x^{st}}{K^{\mathrm{sm}}} &= -\left(b_{33} + b_{31} \cdot \sqrt{\frac{\overline{p^{ps}}}{p^{st}}} + b_{32} \cdot \sqrt{\frac{\overline{e^{st}}}{p^{st}}} + b_{34} \cdot \sqrt{\frac{\overline{w^{l}}}{p^{st}}} \right)
\end{aligned}$$

Symmetry requires that the mixed partials of the profit functions are identical, which implies the parameter restrictions $a_{ij} = a_{ji}, i \neq j$, where a is a parameter of the supply equations, and the same for the demand equations, referring to the mixed partial of each profit function in the model.

Estimation results

Due to lack of data, wages in sawmills are used as an approximation of wages in forestry. I include a dummy-variable for the storm Gudrun in 2005. The estimation results are on the whole disheartening, whence the data refuses to fit the theory. Among other things, we find negatively sloped supply curves and other violations of the basic assumptions. Therefore, I am going to use the Geijer et al (2011) model, that is not as tightly linked to theory as the preferred one here. This means that the welfare measures do not have a straightforward interpretation, so they will have to be considered as simply illustrative of the basic idea. Better data and further exploration of suitable econometric models are useful future research tasks to develop this methodology.

Geijer et al (2011) use an econometric model very similar to that proposed here. The essential difference is that they add the capital stock linearly and add some other exogenous variables. Their approach can be considered an approximation of the GL-strategy employed here, in which we made a point of including the capital stocks in a formally correct manner. For ease of comparison, I use their notation for the parameters. Their econometric specification can be written as

$$y_t^i = \sum_j \alpha_{ij} \sqrt{\frac{p_t^j}{p_t^i}} + \alpha_i \cdot t, \quad \{i = fw, pw, st\}, \{j = fw, pw, st, w_f^l\} \tag{34}$$

$$-x^{fw} = \sum_j \delta_j \sqrt{\frac{p_t^j}{p_t^{fw}}} + \delta_k \cdot K_t^{dh} + \delta_{x-1} \cdot x_{t-1}^{fw}, \quad \{j = dh, fw, pw, w_{dh}^l\} \tag{35}$$

$$-x^{pw} = -\sum_j \lambda_j \cdot \sqrt{\frac{p_t^j}{p_t^{pw}}} + \lambda_k \cdot K_t^{pp} + \lambda_{x-1} \cdot x_{t-1}^{fw} + \lambda_t \cdot t, \quad \{j = dh, w_{pp}^l, e^{pp}\} \tag{36}$$

$$-x^{st} = -\sum_j \beta_j \sqrt{\frac{p_t^j}{p_t^{st}}} + \beta_k \cdot K_t^{sm} + \beta_{x-1} \cdot x_{t-1}^{st} + \beta_t \cdot t, \quad \{j = ps, st, w_{sm}^l\} \tag{37}$$

Thus, there are additional variables, e.g., lagged dependent variables that are difficult to align with the standard theory. It can be integrated, but not with the theory used here. But this set-up can be considered a rough approximation of the underlying technologies, even though I prefer my first set-up. Be that as it may, the estimation results are lifted from the Geijer et al (2020) paper and reproduced in Figure 2. The parameters are estimated with three stage least squares (3SLS), where all the exogenous variables are used as instruments. Furthermore, Prior to estimating the system, a dummy variable for the 2005 storm "Gudrun" were added to the supply functions. A dummy for the first oil crisis (1973-1974) in the supply function for wood fuel, and a dummy for the Swedish financial crisis (1992-1994) was added to the demand function for forest fuel. Symmetry in the supply functions of forestry products was imposed, by requiring that $a\alpha_{ij} = \alpha_{ij}$. Variance and standard errors were computed by White's heteroscedasticity corrected standard errors.

Figure 2. Reproduction of the estimation results in Geijer et al (2011)

Sawtimber			Pulpwood			Wood fuel		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
α_{ss}	74.82	519.53	α_{pp}	1753.9	511.7*	α_{wb}	21.00	7.20*
α_{sp}	-1.02	5.09	α_{ps}	-1.02	5.09	α_{ws}	-20.0	4.00*
α_{sw}	-20.0	4.00*	α_{pw}	-1.84	3.55	α_{wp}	-1.84	3.55
α_{sl}	-5.00	20.06	α_{pl}	-5.95	14.58	α_{wl}	29.32	8.47*
α_{sk}	0.015	0.014	α_{pk}	0.037	0.013*	α_{wk}	-.37E-2	0.002*
α_{st}	-0.035	0.278	α_{pt}	-0.92	0.27*	α_{y-1}	0.99	0.16*
α_{sG}	23.11	1.83*	α_{pG}	7.81	1.35*	α_{wG}	-4.78	0.96*
						α_{wOC}	3.92	0.93*
$R^2 = 0.88$			$R^2 = 0,45$			$R^2 = 0.75$		

Sawmills			Pulp Industry			Heating Industry		
Par.	Est.	s.e.	Par.	Est.	s.e	Par.	Est.	s.e.
β_{st}	-179.0	635.0	γ_{pw}	333.5	376.0	δ_{wf}	1.74	0.85*
β_{s}	-10.0	7.87	γ_{p}	-2.90	1.10*	δ_{h}	-1.17	1.17
β_{se}	100.3.	31.9*	γ_{pe}	-14.5	16.6	δ_{hf}	-0.32	0.86
β_{sl}	-98.85	41.60*	γ_{pl}	13.9	17.4	δ_{hl}	-1.29	1.39
β_{k}	.37E-3	.31E-3	γ_{k}	.30E-3	.12E-3*	δ_{k}	-.92E-5	.86E-5
β_{x-1}	-0.05	0.13	γ_{x-1}	-0.19	0.07*	δ_{x-1}	-0.85	0.14*
β_{t}	0.09	0.33	γ_{t}	-0.18	0.19	δ_{hV}	0.13	0.33
$R^2 = 0. 66$			$R^2 = 0.48$			$R^2 = 0.95$		

Observe that the demand parameters have a negative sign in front of them, given the way the equation system is set-up. Overall, about 50% of the parameters are significant. Geijer et al (2010, p. 17) observes that:

> Capital appears to be a substitute for wood input in both the sawmills and the pulp industry, but is a complement in the heating industry. According to the estimates, the storm Gudrun caused a rather big increase in the supply of saw timber and pulpwood, but decreased the supply of wood fuel. This seemingly

strange result for the wood fuel supply might partly be explained by the high average temperature during 2005, which might have decreased the overall need for heating and thus demand for all types of primary energy.

I am going to use the parameters to evaluate the reform discussed above. Again, these computations are made only to illustrate a possible approach to CBA in multimarket equilibrium models, it is not an attempt to evaluate Swedish policy per se.

9.5 Cost-benefit analysis

For the purpose of comparison with the Government proposal, we use numbers in Kriström (1990), see also Broberg (2007). One of the areas considered in Kriström's (1990) analysis for conservation is in the north-west of Sweden and coincides fairly closely with the government proposal. It contains, according to his estimate 574400 ha (Kriström (1990, p. 114)), with a forest content in the range 73-85 $m^3 ha^{-1}$. Given the rather difficult terrain, with a significant share of low-productive land, a fairly low net conversion value of 70 $SEKm^{-3}$ was used. The opportunity cost in Kriström's (1990) timber mining alternative was estimated to be 2.9-3.4 10^9 SEK in 1990 prices. These estimates are thus based on the assumption that the project is marginal. A very rough estimate would then be $\frac{5.744}{7}(2.9 - 3.4) = 2.4 - 2.8$ billion SEK for the government proposal (in 1990 prices). Geijer et al (2011) considers a slightly larger conservation project, amounting to setting aside 3% of the forest capital stock, calibrating to the year 2000. The find a total loss of roundwood in total at about 5.37 million m^3 in the short-run, but do not compute the change in profits in the sector. Valuing their (short-run result) by share-weighted prices, an upper-bound estimate since it ignores the opportunity costs, the total value is about 1.7 billion SEK in 2000 prices, which is about 1.35 billion SEK in 1990 prices [7]. This estimate is also on the assumption of "timber-mining", as if the forest would be a non-renewable resource. As in the Geijer et al (2011) paper, I am going to use the situation in the year 2000, as a starting point for my simulation. When computing the elasticities (which values depend on the data), they use average values on observed data 2000-2004, which could partly explain any

[7] Using CPI and https://www.scb.se/hitta-statistik/sverige-i-siffror/prisomraknaren/

differences between this my result and theirs. At any rate, the parameters for my simulation is in table 6.

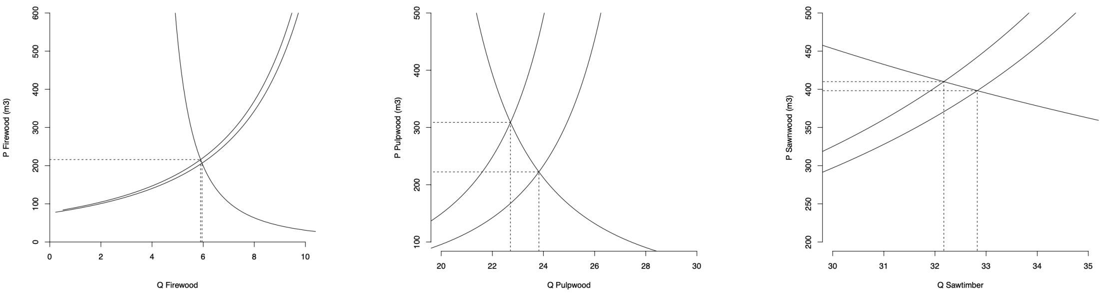
Table 6. Parameter values for the simulation.

(For units, see table 2)

	parameter	value
1	year	2000
2	y^{st}	32.7
3	y^{pw}	23.8
4	y^{fw}	5.9
5	p^{st}	400.5
6	p^{pw}	223.7
7	p^{fw}	216
8	w^{f}	102.3
9	K^{f}	3008
10	p^{sm}	1622
11	e^{sm}	25.2
12	l^{sm}	102.3
13	K^{sm}	27464.4
14	p^{pp}	4640
15	e^{pp}	20.1
16	w^{pp}	120.5
17	K^{pp}	48997.4
18	p^{dh}	344.7
19	e^{dh}	107.5
20	w^{dh}	130.9
21	K^{dh}	4403

Calibrating to the year 2000, we can perturb the multimarket equilibrium by setting $\alpha = 0.98$, i.e., removing 2% of the standing stock of timber K^f. The consequences on the roundwood markets for the chosen path of integration is displayed in figure 3.

Figure 3. Roundwood market consequences of conserving 2% of the Swedish standing stock of timber on productive forest lands, for the path $\{\mathbf{p^{fw}} \rightarrow \mathbf{p^{pw}} \rightarrow \mathbf{p^{st}}\}$



Observe that we compute the equilibria sequentially, arbitrarily beginning with the fuelwood market and then computing the equilibrium in the pulpwood market, conditional on the new price of firewood. Lastly, we compute the equilibrium in the sawtimber market, given the other two new equilibrium prices.

An integral is path-independent, if the value of the path-integral is independent of the chosen path. In this case, if we compute the sum of the profit changes, we must do that for some chosen path in $\Re^3$, since we have assumed that other prices remain constant. It remains to be shown in this particular case, that the sum of consumer and producer surplus is independent of the chosen path. I will proceed in a simpler way, given the limited objective of this exercise. Thus, in each market we compute the sum of consumer and producer surplus, using a linear approximation $dp^i \cdot dy^i, i \in \{fw, pw, st\}$, essentially a version of the rule-of-one-half (we sum two triangles rather than one and assume symmetry). The result of the simulation is

Table 7. Profit, quantity and value of quantity changes valued at the new equilibrium using linear approximation of the relevant areas, for the path $\{\mathbf{p^{fw}} \rightarrow \mathbf{p^{pw}} \rightarrow \mathbf{p^{st}}\}$

$\Delta\Pi^{fw}$	-0.52
$\Delta\Pi^{pw}$	-96.39
$\Delta\Pi^{st}$	-6.74
$\sum\Delta\Pi$	-103.65
$\sum\Delta y$	-1.78
Δy^{fw}	0.06
Δy^{pw}	-1.13
Δy^{st}	-0.70
$p^{fw} \cdot \Delta y^{fw}$	11.44
$p^{pw}\dot{\Delta} y^{pw}$	-349.34
$p^{st}\dot{\Delta} y^{st}$	-289.03

From the point of view of society, I estimate that about 1.78 million m^3 less is sold at the three roundwood markets. Overall, the structure of the results is similar to Geijer et al (2011), although for this illustration I obtain a different result on the firewood market. The data on firewood is notoriously of bad quality, but since it is such a small portion of the roundwood markets it will not matter much for the overall results. For the chosen path, my results are generally lower than what Geijer et al (2011). They do look at a more significant change (900,000 ha withdrawn, rather than about 500,000 here), but there is still a larger difference than what I expected. What is more, as Geijer (2010) and ESAB (2018), among others, have noted, the main effect will be seen at the pulpwood market. The industry is price-inelastic and have few alternatives to simply running their factories in the short-run. In my illustrative simulation, the larger quantitative effect is rather on the pulpwood market.

I will abstain from making any comment on whether the proposed government policy is socially profitable, whence it has not been my aim to address this question. It is still of some interest to note that the benefits and the costs are in the same ballpark, which perhaps is one explanation why the conflicts about the husbandry of our forests remains a topic for intense discussion.

9.6 Conclusion

When both income and an externality is changing with a project, welfare evaluation becomes more difficult. In such cases, it might be of interest to consider the multimarket equilibrium approach. I argue here that Johansson's (1993) separation result can be used within this setting, although his result is derived within a full general equilibrium setting. I necessarily then have to make stringent assumption about e.g., price changes outside of the sector under scrutiny. It would seem that there are cases when a particular sector is of focal interest for policy analysis. Consider, for example, the planned windpower expansion in many countries. Expansion of windpower might well have effects that are limited to a small number of markets. In addition, such expansion do have an impact on the environment. Perhaps the suggested approach can have merit in this case. Alternatively, one might consider a CGE-approach, if the project is "large enough" – the electrification of economies in the EU might be a case in point. My view is that project analysis should begin with the "small project" assumption and be based on received welfare measurement in general equilibrium. In many cases, this will be a useful starting point. There are cases, such as the one studied in this paper, when a multi-market analysis seems natural. But overall, it is useful to have a broad toolkit when doing project analysis, and multi-market welfare measurement is, I would argue, one useful tool in this endeavour.

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10 Case study: Urban rejuvenation of a tourist destination

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10.1 Introduction

This paper corresponds to a case study that seeks further understanding of the differences between Cost-Benefit Analysis (CBA) and Computable General Equilibrium (CGE) methodologies, in terms of project appraisal. The case study consists in the evaluation of the rejuvenation of a tourism destination. The purpose is to measure with CBA and CGE the social welfare obtained from the implementation of the project. CBA is approached with surpluses, whereas CGE employs the equivalent variation after project implementation. Specifically, it addresses the following key issues:

i) The valuation of non-market goods or services in a spatial context.
ii) The spatial spillover effects on nearby areas.
iii) Undesirable crowding-out effects on residents.
iv) The relevance of the induced effects in an economy with involuntary unemployment.

Rejuvenation may be required to restore the attractiveness of the urban environment and the competitiveness of a tourism destination. However, the quality of the urban environment is subjective and, more importantly, it belongs to the family of non-market goods. If the urban environment of a tourist destination improves, then tourists enjoy a better experience, and they are more willing to pay more at the destination. At the same time, businesses can grow, and may improve their sales. Hedonic price models are useful to deduce the role that the characteristics of certain products play in price setting. At tourism destinations, some key urban environments are far from hotels, or the relationship between them may be blurred. In contrast, this application employs this method in a novel way, by working with the prices of drinks served in the establishments. This has two advantages: the number of establishments is large and are more similar than hotels. Additionally, because the drinks chosen had to be homogeneous, the prices of coffee, water, beer, and coke are employed. Spatial econometric models are developed to estimate the willingness to pay for this qualitative improvement.

This application works on the spatial spillover effects of a project. It operates with two competing areas, meaning that a quality improvement in one also affects demand in the other. This spatial relationship is considered in the application of both CBA and CGE models. Additionally, if a tourist destination improves its quality and the tourists are willing to pay more for a better service, then it may crowd out local visitors who face higher prices. However, they may spend a similar amount somewhere else in the region. This is an issue explored in this application with both models.

Finally, this application also deals with induced effects. These effects are the result of an increase in production and income which are also partially consumed in local products and imports. They imply a second-round production effect, which is relevant for the project's impact, and must be taken into account to compare with the counterfactual for the net welfare effect under involuntary unemployment.

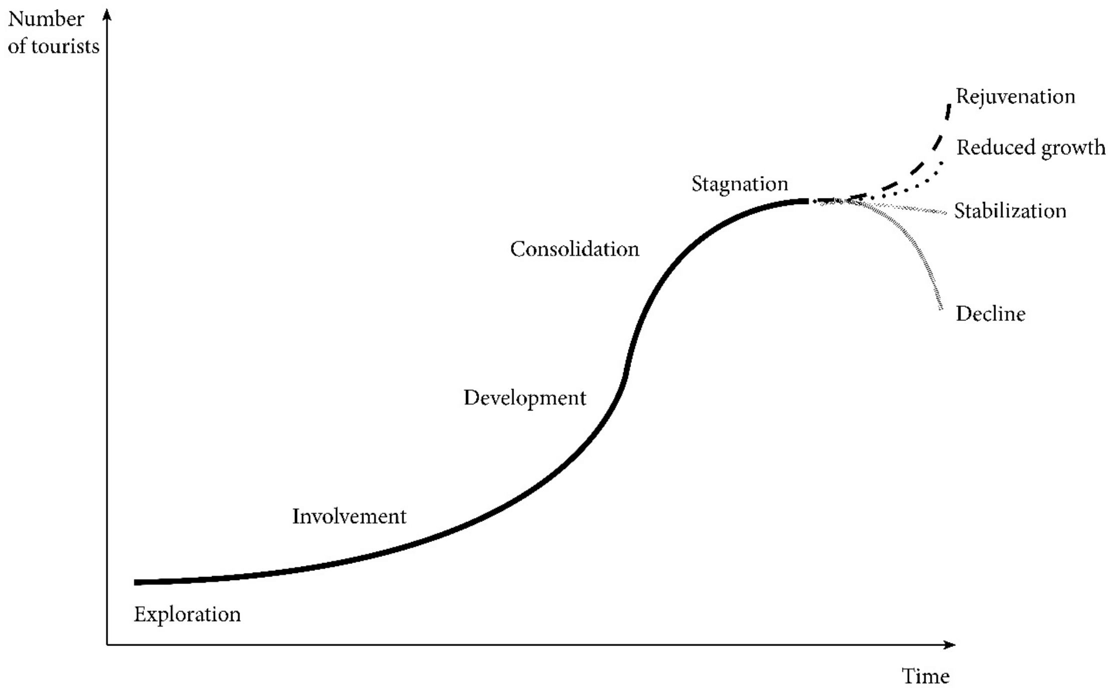
The tourism sector is of particular importance for many European regions. According to UNWTO (2018), in the European Union (EU), in 2014, the direct contribution of the industry contributed to value added at a factor cost of 2,734,494 million euros and required the employment of more than 57 million people. The tourism sector represents a significant share of the Gross Domestic Product (GDP) of many regional European economies. The most relevant countries are located in or around the Mediterranean Sea, i.e. Spain (10.9%), Portugal (9.2%), France (7.0%) and Italy (6.0%). The Covid-19 crisis aside, in recent decades tourist arrivals have shown a solid yearly growth of about 4% (UNWTO, 2018).

GDP partly depends on aggregate tourism expenditure at destinations. Such expenditure is the result of multiplying the number of arrivals, length of stay and daily expenditure per tourist. Tourism policies usually pursue the increase or sustainability of these three variables. Tourist arrivals depend on the relationship between each origin and destination in terms of distance and relative prices, but also on destination competitiveness, which in turn depends on destination accessibility, infrastructure, safety, attractiveness, climate conditions, or education, among many other factors.

Butler (1980) developed the Tourist Area Life Cycle (TALC) concept, which describes the stages that destinations usually experience over time (see Figure 1). Tourists starts visiting a destination as explorers, while later, the destination may be developed, and eventually may be consolidated. Eventually, the locations enter a stagnation period, which is usually followed by a decline, unless a rejuvenation process is applied.

In terms of the relevant literature, this paper is novel for three reasons. As far as we know, this is the first time that a rejuvenation project is assessed, the first time that a hedonic price model is applied to assess a local impact with the willingness to pay for drinking or eating and the first time that a tourism project appraisal (not economic impact) is assessed with CGE, and furtherly compared with CBA.

Figure 1. Butler's (1980) Tourist Area Life Cycle



10.2 Literature review

There is a lack of research related to economic valuation in tourism in comparison with other fields in the economy. Moreover, among the few works on economic evaluation, the literature has focused on the economic impact approach. According to Burgan and Mules (2001), in most sectors of the economy, public expenditure should be justified by measuring welfare changes through Cost-Benefit Analysis (CBA). However, government expenditure in tourism is usually justified in terms of economic impacts measured through a growth-based paradigm. As stated by Dwyer, Jago and Forsyth (2016) the traditional approach of impact analysis through Input-Output analysis (I-O) and Computable General Equilibrium (CGE) is not able to isolate the net effects on the economy. CGE models were not originally built for project appraisal, and further adaptation is required.

CBA has practically been inexistent in the tourism literature, and most of its applications are related to other sectors. For example, Raybould and Mules (1999) evaluated the protection of the northern beaches of Australia's Gold Coast with a CBA approach. The authors concluded that the loss in tourism receipts due to the beach erosion far exceeded the cost of protecting the beaches. Another economic evaluation of environmental impacts on tourism can be found in Tervo-Kankare, Kaján and Saarinen (2017), who analyzed changes in welfare resulting from shifting environmental conditions in Arctic Finland. Additionally, Hefner, Crotts and Flowers (2001) employed CBA to evaluate a 'fee-in-lieu of property tax' in South Carolina (United States), which consisted in tax incentives to attract the tourism industry. The cost and benefits were measured according to the Board of Economic Advisors (BEA) model, with some adaptations to include the particularities of the tourism sector such as the direct and indirect effects of tourism expenditure and taxes from the hospitality sector.

However, as aforementioned, most of the research related to economic evaluations has focused on the economic impacts of the events. Among those works, the use of CGE and I-O (Wood and Weng, 2020) are the most common. For instance, the literature has analyzed the effects of hosting a mega-event such as the Olympics. Specifically, Li, Blake and Cooper (2011) and Li, Blake and Thomas (2013) addressed the impact of the 2008 Beijing Olympics though a CGE model and concluded that the impact was not significant in comparison with the size of the economy and the ex-ante analysis. It shows how difficult it is to assess a local event with national accounts. However, Allan, Lecca and Swales (2017) successfully employed a CGE model to investigate the impact of the Glasgow 2014 Commonwealth Games on the local economy.

Events are not the only tourism activities evaluated in the literature, as policies have also been studied. Inchausti-Sintes and Voltes-Dorta (2020), for example, analyzed the impact of the 'tourism moratoria' in Spain's Canary Islands. This policy consisted in prohibiting the building of any kind of tourist accommodation, except 5-star hotels. Further, some authors have also applied economic evaluation to public investment on tourism infrastructure. Banerjee, Cicowicz and Moreda (2019) combined CGE and CBA methods to evaluate, from the perspective of a multilateral bank, an investment project in tourism infrastructure in Uruguay.

The combined vision of CGE and CBA can be of particular interest to tourism researchers. On the one hand, it provides information about the economic impacts, such as changes in tourism expenditure, number of visitors, employment, or GDP, which governments and other stakeholders are interested in. On the other, assessments in terms of net welfare (event, policy, or infrastructure) provides a measurement of the project's social desirability. To date, the two methods have been applied separately and CGE has not been employed as a tool for welfare appraisal in the tourism literature (see Table 1). In contrast, our work considers CGE as a method for policy appraisal and compares its assumptions and results with CBA.

Table 1. Summary of main economic evaluation studies in tourism related projects

Authors	Year	Country	Methodology	Topic
Raybould and Mules	1999	Australia	CBA	Beach protection and its effect on tourism receipts
Hefner *et al*.	2001	USA	CBA	Tax incentives to the tourism industry
Li *et al*.	2011	China	CGE	2008 Beijing Olympics
Li *et al*.	2013	China	CGE	2008 Beijing Olympics
Tervo-Kankare *et al*.	2017	Finland	CBA	Response of tourism industry to environmental changes
Allan *et al*.	2017	UK	CGE	Glasgow 2014 Commonwealth Games
Banerjee *et al*.	2019	Uruguay	CGE+CBA	Evaluation of public investment in tourism
Wood and Meng	2020	Korea	I-O	2018 Pyeongchang Winter Olympics
Inchausti-Sintes and Voltes-Dorta	2020	Spain	CGE	Restrictions to building new accommodation

10.3 Methodology

10.3.1 Non-market valuation with hedonic price models

This paper relies on the hedonic price model to estimate the willingness to pay (WTP) of tourists to improve the urban environment of a destination. These kinds of models have a long tradition in the environmental valuation literature, especially to estimate the value of air quality within the real estate market (Smith and Huang, 1993). In tourism, they have been employed to identify what underpins accommodation choice. For instance, Latinopoulos (2018) estimates valued added for sea views on hotel rates, and Rui and Soora (2022) estimate the value of streetscape features for P2P accommodation. In sum, it is a well-known and established method in the literature (Papatheodorou, Lei and Apostolakis, 2012).

Urban rejuvenation has an impact on WTP for the whole tourist experience, especially for leisure walking, but also when eating and drinking outside. However, this type of regeneration may have a local impact, which sometimes may not extend further. Hence, in order to deal with this, we have decided to specifically consider price impact on eating and drinking establishments. This approach has two advantages: on the one hand the spatial impact can be identified and, on the other, the products served can be perfectly compared. We employ the prices of a small black coffee, coke, water, and beer, because they are standard products that can easily be compared among establishments. Moreover, control variables such as size, container, brand, kind of establishment and location are taken into account. The equilibrium hedonic price function takes the following form:

$$p = h(z, \alpha), \tag{1}$$

where p is the price of a standard drink, z is the vector of attributes and α is a vector of parameters describing the shape of the hedonic price function; while α is usually unknown and its uncertainty is part of the random error. Since the hedonic equation is an outcome of a market equilibrium, several implications can be taken from that. Haab and McConnell (2002) state that the welfare change after a variation in the vector of attributes takes place is the following:

$$WTP = h(z^*) - h(z), \tag{2}$$

where $h(.)$ represents the hedonic price function and z^* denotes the new vector of attributes. More precisely, the amount that tourists will gain is given by the following implicit WTP:

$$u(y - h(z) - WTP, z^*; \beta) = u(y - h(z), z; \beta). \qquad (3)$$

where u denotes the utility function, β denotes the parameter of the preference function and y denotes the household income. Thus, WTP is the maximum amount of income that the tourists will give up to obtain the new vector, provided the hedonic function remains the same and βs are known. However, the βs are subjected to an identification problem because they cannot be identified from the equilibrium conditions. According to Haab and McConnell (2002), a feasible procedure is to employ a 'bid function' instead, which is the solution to the following expression:

$$u(y - B(y, z; \beta), z; \beta) = u^0, \qquad (4)$$

where $B(y, z; \beta)$ represents the 'bid function', i.e. the amount that the household with preferences β will pay for the bundle z when their alternative choices allow them utility level u^0. Moreover, they conclude that:

$$\frac{\frac{\partial u(x, z; \beta)}{\partial z_c}}{\lambda} \equiv B_c(x, z; \beta) = \frac{\partial h(z)}{\partial z_c}, \qquad (5)$$

where λ denotes the marginal utility of income and z_c denotes the marginal cost of z. Hence, in practice, the estimated WTP can be approximated as the marginal change of the hedonic price function, i.e.:

$$\widehat{WTP} = \Delta z_c \frac{\partial h(z)}{\partial z_c}. \qquad (6)$$

Two conditions need to be met in order to obtain reliable WTP values. On the one hand the $h(z)$ function needs to be properly specified, and on the other, the marginal change should not imply the need for a new hedonic function (Bartik, 1988).

Hedonic price models of tourism establishments

The model specification is critical to obtain unbiased estimates of the WTP. We believe that the experience of drinking a coffee, or a beer, goes beyond swallowing the products. We assume that three sets of variables matter: i) the environment; ii) location; and iii) product characteristics.

10.3.1.1 The environment

The whole environment makes a difference to the enjoyment experienced. The environment comprises:

- The natural environment, such as the beauty of the natural surroundings or sightseeing.
- The urban environment, in terms of cleanliness, safety or tidiness, as well as its beauty and integration with the natural environment.
- The local environment, where the quality of the establishment in architectural terms, furniture, and/or service is important.

In particular, the relevance of the urban environment is the key determinant to be estimated. However, this parameter may be subject to an identification problem, especially if the different kinds of environment are related. When multicollinearity is present, the parameter estimates cannot show reliable values to be treated independently of the other parameters. A solution to this problem is the application of instrumental variables.

10.3.1.2 Location

If the establishment is close to a tourist destination, then it has got a spatial advantage with respect to other establishments. The result of this particular equilibrium raises prices, meaning that this proximity factor needs to be considered in controlling prices. Moreover, nearby establishments may belong to a spatial cluster that may share a common characteristic that is not easily measured, but that exists. To control for such latent spatial effects, the error component is spatially lagged according to a spatial weight matrix that employs an inverse-distance weight.

10.3.1.3 Product characteristics

The volume size of the product, the brand, and the bottling quality matters for the price, so that they are considered to control for the product characteristics.

Hence, the hedonic price function is the following:

$$h(z_e) = f(l_e, u_e(n_e, b), x, W\varepsilon), \qquad (7)$$

where l denotes the local environment of establishment e, u_e denotes the urban environment of establishment e, which is instrumented with the natural environment n and whether it is located at the seafront or not (b), x denotes the product characteristics, W denotes the spatial weight matrix and ε denotes the error term, so that $W\varepsilon$ denotes the spatially weighted error term. This hedonic price function may be estimated with an instrumental variables spatial model regression with spatially lagged error term. From this model, the WTP can be estimated and employed as an input for the CBA analysis and for the CGE model, as shown below.

10.3.2 Cost-Benefit Analysis

Let us consider a representative consumption good of a tourism market. It is expected that the initial demand shifts upward, which is caused by generated demand and the increase in WTP thanks to the project. Three effects will take place simultaneously:

- New tourists and residents will be attracted to the destination.
- Some of the current tourists and residents will remain and consume at the destination, at higher prices.
- Some of the current tourists and residents will leave to go to other destinations. Thus, other destinations will face a similar but smaller shift in demand. This effect occurs depending on the degree of substitutability between both destinations (which is relevant only if there is distortion).

10.3.2.1 Producer surplus in the main market

The demand shift implies an increase of the prices charged to all current tourists and residents. Moreover, this effect is distributed to both producers and taxpayers. The change in the producer surplus (*PS*) can be measured as:

$$\Delta PS = \int_{p_0}^{p_1} q_s(p)\, dp, \qquad (8)$$

where $q_s(.)$ denotes the supply function of a consumption good of the tourism market, while p denotes prices, using a subscript 1(0) to denote the final (initial) level of prices.

Assuming a lineal approximation and the introduction of an *ad-valorem* tax (t), we can apply the following expression:

$$\Delta PS = \left(\frac{1}{1+t}\right)\frac{1}{2}(p_1 - p_0)(q_0 + q_1). \qquad (9)$$

where q_0 and q_1 denotes quantity demanded at prices p_1 and p_0, respectively.

10.3.2.2 Consumer surplus in the main market

The new tourists and residents will be willing to pay higher prices to enjoy a better quality experience. The same happens with some of the current tourists and residents who remain paying higher prices as well. This demand shift implies an increase in the consumer surplus. It should be noted that if the tourists belong to a population that is out of the scope of interest for the welfare function, they should not be considered. For instance, if the tourists are foreigners they may be excluded (Johansson and de Rus, 2019). However, in tourist destinations, since part of the consumption corresponds to residents, the effects on the residents' consumer surplus cannot be ignored. Let's denote the share of residents' consumption with respect to tourists by α. Thus, after the rejuvenation, the consumer surplus of the residents can be approximated as follows:

$$\Delta CS = \alpha\left(\int_{p_1}^{\overline{p_1}} q_{d_1}(p)\, dp - \int_{p_0}^{\overline{p_0}} q_{d_0}(p)\, dp\right), \qquad (10)$$

where $q_{d1}(.)$ and $q_{d0}(.)$ denotes the demand function of a consumption good of the tourism market with the project (with reservation price $\overline{p_1}$) and without the project (with reservation price $\overline{p_0}$) respectively.

If the demand function is linear:

$$\Delta CS = \alpha\left[\frac{1}{2}(\overline{p_1} - p_1)q_1 - \frac{1}{2}(\overline{p_0} - p_0)q_0\right]. \qquad (11)$$

10.3.2.3 Taxpayers' surplus

From a local perspective, the taxes accrued from the tourists represent a cash inflow for the economy. The change in the taxpayers' surplus can be measured as follows:

$$\Delta TS = (1-\alpha)\left[\frac{t}{1+t}(p_1 - p_0)(q_1 - q_0)\right]. \quad (12)$$

10.3.2.4 The crowding out effect over other goods consumed by the local population

The tourists consume local products. This means that an increase in the number of tourists also shifts demand on these products, increasing the price of these goods and reducing local consumption, while the quantities supplied go up, i.e., tourism demand is supplied with new production and with the crowding out of some local consumption. According to Johansson and de Rus (2019), the net welfare effect on this local market is positive.

10.3.2.5 Mature destinations versus developing destinations, the relevance of shadow pricing

Since the tourism destinations are assumed to have unemployment, this means that wages do not reflect the social opportunity costs of labour. In these cases, the net benefits exceed the aforementioned positive welfare effect because we should correct the supply function to count only the opportunity cost of workers employed after the expansion of production.

10.3.2.6 Non-resident owned businesses

Most international guidelines omit foreign business from the welfare analysis. In the case of tourism, the share of business owned by non-residents could be significant, especially in the accommodation sector in developing destinations. This idea is fully discussed in Johansson and de Rus (2019).

10.3.3 Computable General Equilibrium approach

The model has been calibrated according to Canary Islands economy Input-Output tables for 2005, programmed in MPSGE (Rutherford, 1999) and adapted from Inchausti-Sintes and Voltes-Dorta (2020). Briefly, it is composed of 21 sectors providing the following goods/services: “Agriculture and fishing”, “Energy and mining”, “Processed food, beverages and tobacco”, “Textiles”, “Industry”, "Construction", "Trade", "Accommodation", "Catering services", "Road transport", "Maritime transport", "Air transport", "Other transport services", "Travel agencies", "Real estate", "Rent a car", "Entertainment", "Other services", "Public services", "Education" and "I+D". In terms of economic agents, the model assumes a central government, a representative household and tourists. Government demand is assumed to behave according to a Leontief function, predominantly because it faces rigid demand. However, for the household and tourists, demand is assumed to be a Cobb-Douglas function because it allows for a more flexible substitution among alternative goods and services.

Both domestic and import goods are assumed to behave as imperfect substitutes. Hence, the intermediate and final demands of this economy are satisfied with Armington goods (Armington, 1969). Labour (L) and capital (K) are perfectly mobile among sectors, while all markets operate under competitive market postulates. Regarding *model closure,* it is assumed that the government deficit and the current account deficit are fixed (small-open economy assumption), the labour market operates with involuntary unemployment and the model follows a savings-driven investment decision. The elasticities of imports and domestic goods, and the elasticities of capital and labour in the production function are sourced from Hertel (1997). The main equations of the model are summarized in the following subsections:[1]

10.3.3.1 Armington goods

Armington goods are defined according to the following expression:

$$A_i = \gamma \left(\chi_i D_i^{1-\frac{1}{\sigma_{dm}}} + (1-\chi_i) M_i^{1-\frac{1}{\sigma_{dm}}} \right)^{\frac{1}{\sigma_{dm}-1}}, \tag{13}$$

where A_i represents a vector of Armington goods (Armington, 1969), which allows for imperfect substitution between domestic and import goods. Subscript i refers to commodities, which are generated by combining both imports (M_i) and domestic goods (D_i) for each good i into a composite Armington good. This good can be either demanded as intermediate (*inputs*) or final demand (consumed or devoted to investment by the representative household and government). Thus, all the goods in the economy

[1] Taxes have been omitted from the equations for the sake of clarity.

are demanded to generate Armington goods. Such aggregation is carried out according to a constant elasticity of substitution (CES) function (equation 13), where γ, χ_i and σ_{dm} denote the scale parameter, the value share of domestic goods, and the elasticity of substitution of domestic and imported products, respectively.

10.3.3.2 Sectoral production

When Armington goods are demanded as intermediate goods, they are transformed according to a nested production function (see equations 14 and 15). In the first nest, each activity (a) demands capital (K_a) and labour (L_a) according to a CES function to form a composite good (va_a). η, ϕ and ρ denote the scale parameter, the value share of capital and the elasticity of substitution by activities, respectively. In the second one, intermediate goods ($id_{i,a}$) are demanded together with va_a according to a Leontief function to determine the total production by activities ($actv_a$).

$$actv_a = min\left\{\min \frac{id_{i,a}}{\beta_{i,a}}, \frac{va_a}{\alpha_a}\right\}, \tag{14}$$

$$va_a = \eta_a(\phi_a {K_a}^{\rho} + (1-\phi_a){L_a}^{\rho})^{\frac{1}{\rho}} \text{ being } \rho = \frac{\sigma_{va}-1}{\sigma_{va}}. \tag{15}$$

For each activity, production is disentangled into domestic (D_i) and export goods (X_i) by using a Constant Elasticity of Transformation function (CET) (Gilbert and Tower, 2013) (see equation 16). However, a previous step should be taken by aggregating the commodities production of each activity according to the following equation: $Y_{i,} = \sum_a \psi_{i,a} actv_a$, where $\psi_{i,a}$ represents the value share by goods and activities. The parameters ε_i, δ_i and T of equation 16 denote the scale parameter, the value share of domestic goods and the elasticity of transformation between domestic and export goods, respectively.

$$Y_{i,t} = \varepsilon_i\left(\delta_i {D_{i,t}}^{(1+T)} + (1-\delta_i){X_{i,t}}^{(1+T)}\right)^{\frac{1}{T}}, \tag{16}$$

10.3.3.3 Households and government

As already noted, Armington goods (A_i) can also be demanded by the representative household (H) and the government (G) as final goods (final consumption and investment). Both are assumed to be rational agents that take the optimal decision within their respective income constraints. In the case of households, they are constrained by the fixed endowment of capital ($\overline{K_H}$) and labour ($\bar{L}$), and the current account deficit ($\overline{CC}_H$), so that $H = r\bar{K}_H + w\bar{L} + rer\overline{CC}_H$, where r, w and rer denote the cost of capital, wage and real exchange rate, respectively.

In the case of the government, its income constraint comes from its fixed endowment of capital ($\bar{K}_G$), current account deficit - that is assumed to be fixed ($\overline{CC}_G$) - and the collection of taxes (net of subsidies): $G = r\bar{K}_G + rer\overline{CC}_G + taxes$. Thus, the total capital endowment is $\bar{K} = \bar{K}_H + \bar{K}_G$. The total endowment of labour and capital are demanded by the economic activities, such that $\bar{L} = \sum_a L_a$ and $\bar{K} = \sum_a K_a$, which generate incomes for both agents. The sectoral demand of both factors is defined as follows, where $Pactv_a$ denotes the price by sectors:

$$K_a = {\eta_a}^{\sigma_{va}-1}\left(\frac{(1-\phi_a)Pactv_a}{r}\right)^{\sigma_{va}} actv_a\ , \quad (17)$$

$$L_a = {\eta_a}^{\sigma_{va}-1}\left(\frac{\phi_a Pactv_a}{w}\right)^{\sigma_{va}} actv_a\ . \quad (18)$$

Given the rents obtained from the endowment, the representative household demands investment (INV^H) and consumes goods (C^H), fulfilling its income constraint such that: $Inv^H + C^H = H$. The total demand of goods follows a Cobb-Douglas demand function: $C^H = \frac{\lambda^H}{P_H}H$, where λ^G denotes the share of total consumption in the total budget and P_H represents the final price of the household's total consumption. At the same time, the total consumption is composed by the i goods and services demanded by the representative household (c_i^H), which follow a Cobb-Douglas demand function ($c_i^H = \frac{\alpha_i}{Pa_i}C^H$), where α_i is the share of good i in the basket of goods, whereas Pa_i denotes the Armington price of good i. P_H is obtained using a Cobb-Douglas cost function ($P_H = \prod_{i=1}^{19}\left(\frac{Pa_i}{\alpha_i}\right)^{\alpha_i} C^H$) and represents the consumer price index.

Following with the representative household, its total investment demand is: $INV^H = \frac{(1-\lambda^H)}{P_{inv}}H$, where $(1-\lambda^H)$ denotes the share of the total investment in the income constraint and P_{inv} is the price of the investment. As in the case of the total consumption, the total investment is composed of i goods, demanded as investment. In this case, these investment goods follow a Leontief demand function: $inv_i^H = \mu_i INV^H$, where μ_i denotes the share of investment good i in the total investment demand (INV^H). Similarly, the price of the investment is obtained algebraically as P_{inv}=$\sum_{i=1}^{19} \mu_i\ Pa_i INV$, with $INV = INV^H + INV^G$, where INV^G denotes the total investment demand of the government.

In terms of the government, its income constraint is devoted to demanding investment (INV^G) and consumption (C^G), such that ($INV^G + C^G = G$). However, in this case, its behaviour follows a Leontief demand function (fixed proportions). As a result, the total demand of goods and investment is: $C^G = \lambda^G G$ and $INV^G = (1 - \lambda^G)G$, where λ^G and $(1 - \lambda^G)$ denote the share of total consumption and total investment in the budget of the government, respectively. Hence, the consumption and investment by goods are: $c_i^G = \vartheta_i C^G$ and $inv_i^G = \tau_i INV^G$, where ϑ_i and τ_i denotes the share of good i in the total basket of goods and the share of the investment good i in the total investment, respectively. The price of government goods is obtained as P_{gov}=$\sum_{i=1}^{19} \vartheta_i\ Pa_i C^G$. The cost of investment (P_{inv}) is similar to the case of the representative household, as previously shown.

10.3.3.4 Tourists

In line with the objectives of this research, we consider an additional agent in this economy, which are the tourists. This agent demands goods and services (c_i^{Tour}) according to the following Cobb-Douglas demand function:

$$c_i^{Tour} = \frac{\theta_i}{Pa_i} C^{tour}\ , \qquad (19)$$

where θ_i denotes the share of good i in the total basket of tourists' goods. The income balance constraint is their expenditure level multiplied by the real exchange rate such as $C^{tour} = rer \cdot exp$. Information about tourist expenditure is collected from the Canarian Statistical Institute (ISTAC), which draws on information from the Tourism Satellite Account (TSA).

10.3.3.5 Unemployment

Finally, the model also assumes the existence of unemployment, which is modelled according to the following condition: $w \geq P_H$ or, similarly $\frac{w}{P_H} \geq 1$. This introduces a minimum wage constraint (real wage curve): an unemployed person is willing to work if the real wage (w) compensates, at least, the consumer price (P_H), already defined above as $P_H = \prod_{i=1}^{19} \left(\frac{Pa_i}{\alpha_i}\right)^{\alpha_i} C^H$. As noted by Rutherford and Light (2001) when modelling unemployment in the Colombian economy, this real wage curve is obtained from $\frac{w}{P_H} = U^{-1/\theta}$. When θ approaches ∞, the real wage curve shows a downward-rigid real wage, as stated in the neoclassical approach. Mathematically, unemployment is introduced into the model as follows: $H = r\overline{K}_H + rer\overline{CC}_H + w\left(\frac{\bar{L}}{(1-\overline{U_0})}\right) - w\left(\frac{\bar{L}}{(1-\overline{U_0})}\right) U$, where U is a variable denoting the unemployment rate, whereas $\overline{U_0}$ is a parameter denoting the initial unemployment level, which is equal to 0.189.

10.3.4 Comparing CBA and CGE

It should be noted that CBA and CGE are both rooted in the same economic theory[2] (Arrow-Debreu). However, in practice, there are empirical concerns that may cause divergence between both methodologies. More specifically, they use different "starting points". In the case of our example, the rejuvenation policy occurs at local level where CBA operates efficiently. However, the CGE model is calibrated with the regional Inputs-Outputs Tables of the Canary Islands' economy. Hence, we must reconcile and combine both methodologies because CBA works at local level, whereas CGE represents the whole regional economy. For this case study, the following issues are discussed: a) induced effects; b) linearization; c) re-scaling; and d) elasticities.

10.3.4.1 Induced effects and involuntary unemployment

Most economies experience some degree of involuntary unemployment. When assessing the social welfare impact of an investment project this situation may matter for the analysis. According to Johansson and Kriström (2022), the reservation wage overestimates the social cost of unemployment, such that careful analysis is required. In order to understand the role of unemployment on the social welfare variation, the

[2] See de Rus (2023) and Inchausti *et al.* (2023) for details.

authors show that, under certain assumptions, the effects are located among: i) the unemployed; ii) the firm; and iii) the government.

i) Net new employees

The social welfare variation considering net new employees depends on three issues: net wage, unemployment benefits (m^B) and the opportunity cost of working ($CV^L > 0$). Thus, their social welfare variation is summarized by the following expression: $[(1-t)wL - m^B - CV^L]$, where *t* denotes income tax, *w* denotes hourly wage and L denotes the number of working hours. In other words, the current unemployed will be willing to work if the net wage is higher than unemployment benefits and the opportunity cost of working.

ii) The firm

The firm is expected to increase production (*x*), which increases income depending on the price level (*p*). Thus, their social welfare grows according to the following expression: $[p\Delta x - wL]$.

iii) The government

Once an unemployed person is employed, the government stops paying unemployment benefits and starts accruing income taxes, so that its social welfare varies according to the following expression: $[twL + m^B]$.

Hence, by totalling all changes in social welfare for all agents, we obtain that:

$$\Delta S = [(1-t)wL - m^B - CV^L] + [p\Delta x - wL] + [twL + m^B] = p\Delta x - CV^L \quad (20)$$

It can be easily proved that $p\Delta x - CV^L > 0$ by considering the role of wL. It should be noted that $p\Delta x > wL$ is a condition that needs to be met by firms to increase production. Moreover, $CV^L < wL$ is a condition that needs to be met by the unemployed to be willing to work. Hence, $p\Delta x > wL > CV^L$ and $p\Delta x - CV^L > 0$, which means that by decreasing unemployment, social welfare increases. This matters for the induced effects triggered by any project.

The induced effects are a second-round income effect that occur in the economy after any shock in consumption. In this case study, following rejuvenation, income rises because unemployment is reduced, and firms earn higher profits. This higher income leads to higher consumption and increases production and income, which is known as the induced effect. This effect happens across the whole economy and not necessarily only in the project's markets of interest. However, this induced effect does not have to be measured in CBA when the counterfactual is expected to have similar effects. In CGE, the induced effects are computationally always part of the results, so that, for a net welfare effect estimation using CGE, and an adequate comparison between CGE and CBA, they have to be ignored.

10.3.4.2 Linearization

In this paper, CBA analysis is performed by calculating the changes in net surpluses of all involved agents. For simplicity, the demand and supply functions are assumed to be linear. However, CGE models assume non-linear functions for the demand and supply (e.g. Cobb-Douglas demand function). For some specifications, the asymptotic behaviour of the non-linear functions may imply a large difference with respect to the linearized version.

10.3.4.3 Re-scaling

CGE models are built to represent the national or regional economy. They can accommodate and evaluate shocks to an initial equilibrium, given certain parameters and elasticities that govern the whole economy. However, when the impact is local, CGE models may not be applied straightaway and certain adjustments may need to be considered. For instance, in this paper, demand and supply at the location of interest are close to full capacity, so that the market responds by increasing prices and redistributing any rise in demand among close local competitors. However, this 'expected reaction' is not obtained from CGE straightaway. In some cases, the aggregate result may be the same, but not necessarily. For local impacts, it is recommended that satellite modelling and accounting provides feedback to the CGE model instead. The models need to be properly calibrated and integrated with the CGE model and this process may cause an additional source of divergence with respect to CBA.

For instance, in this application, the project is expected to attract more tourists, which increases the demand and price of domestic and imported goods in these areas. However, these economic changes are marginal at the regional level exerting, in this instance, no impact on the regional economy's 'foreign position' (imports and exports) or inflation level. Hence, the CGE model must be accommodated to capture the economic circumstances that take place at micro level.

10.3.4.4 Elasticities and model closure

The choice of elasticities and model closure in the CGE modelling condition the results obtained. In this application we assume the following key elasticities. For instance, the elasticity of transformation between domestic production and exports is assumed to be equal to zero (Leontief function) to control for the adjustment made by the change in imports and exports. Moreover, for the household and tourists, the demand is assumed to be a Cobb-Douglas function because it allows for a more flexible substitution among alternative goods and services.

10.4 Case study: Rejuvenation of Playa del Inglés beach

10.4.1 The investment project

The project under study is a simulation in which a micro-destination is rejuvenated. The rejuvenation investment project is applied at a sun and beach mature tourism destination in the Canary Islands known as Playa del Inglés. The total simulated investment is 676 million euros, which is equivalent to the *"Plan de Infraestructuras Turísticas de Canarias (PITCAN) 2021"*. For simplicity, we assume that the project will be finished within one year. The distribution of investment costs will be 70% for capital and 30% for labour. Capital is taxed at the general VAT rate of 7% in the Canary Islands while income tax is levied at 20%. This simulation assumes that the public sector will not incur additional costs to maintain the refurbished infrastructures, so maintenance costs are omitted from the analysis. Finally, it should be mentioned that the residual value after the project is finished is assumed to be null.

10.4.2 Survey

The tourism destination chosen comprises several micro-destinations with different degrees of rejuvenation. These differences are key to estimating WTP for the quality of the urban development. The method allows us to assess WTP for the highest available quality at present. A full sample of all establishments in the area was undertaken, which included a price survey of black coffee, water, beer and coke. The survey comprised 418 establishments in the areas of Meloneras, Maspalomas, Sonneland, Playa del Inglés, Las Burras, San Agustín and Bahía Feliz. Nine establishments refused to provide the prices requested. A team of three tourist experts assessed the natural, urban and local quality of all the establishments on a 5-point Likert scale, which had a predetermined uniform distribution. The spatial distribution of this quality assessment is shown in the figures below. Figure 2 illustrates the spatial distribution of the quality of the natural environment and shows that the coastal establishments have the most valued natural features. The darker dots represent higher quality.

Figure 2. Spatial distribution of the quality of the natural environment of all establishments surveyed

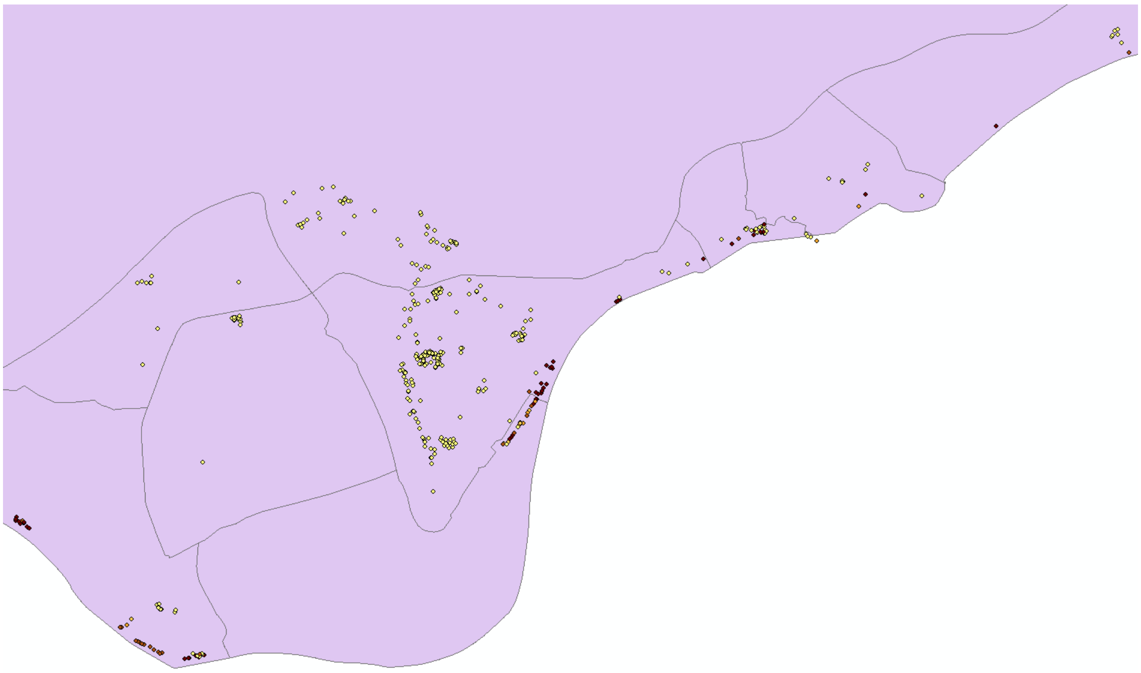


Figure 3 illustrates the heterogeneous spatial distribution of the quality of the local environment. The darker dots represent establishments with high quality in terms of local environment. Similarly, Figure 4 shows that the spatial distribution of the quality of the urban environment presents spatial clusters, depending on the current development or rejuvenation stage. This responds to different phases of the urban development in the past. Figure 5 shows the Kernel distributions of the prices of coffee, water, beer and coke. It shows that coffee is the lowest (at an average of 1.54 euros), followed by water (1.87 euros); whereas the highest prices correspond to coke (2.39 euros) and beer (2.43 euros). Concerning the width of distribution, it seems to have tails that double the mean, like a Gaussian distribution. Such differences are due to the location, kind of establishment, volume size and container, which are found to be relevant in the regression.

Figure 3. Spatial distribution of the quality of the local environment of all establishments surveyed

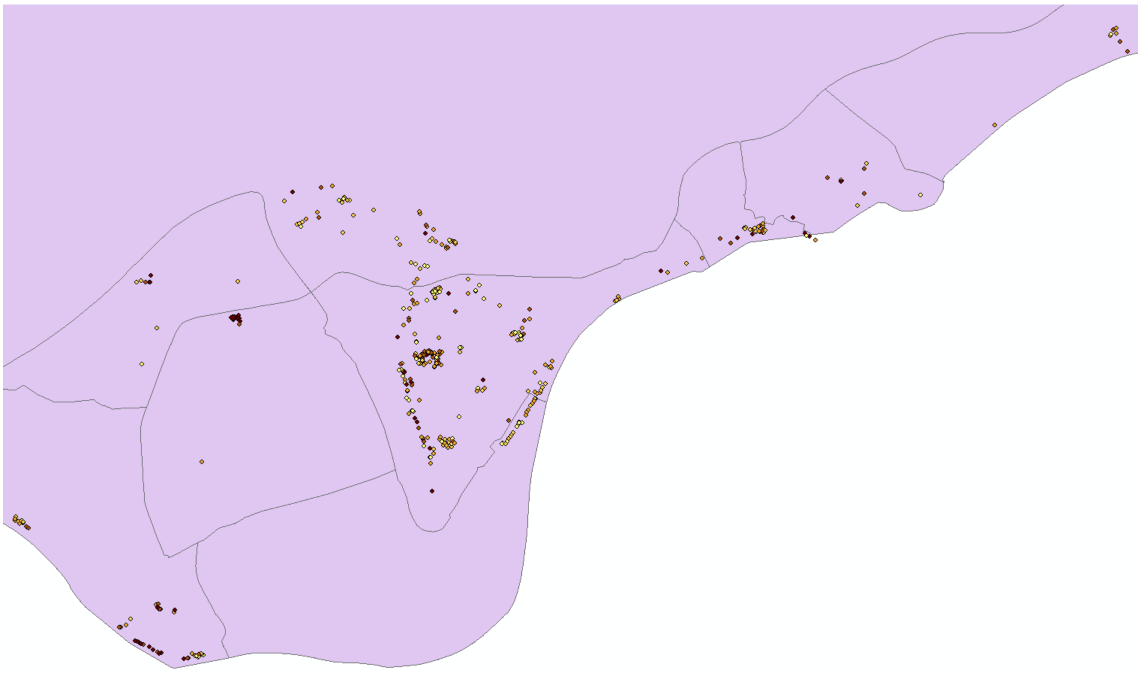


Figure 4. Spatial distribution of the quality of the urban environment of all establishments surveyed

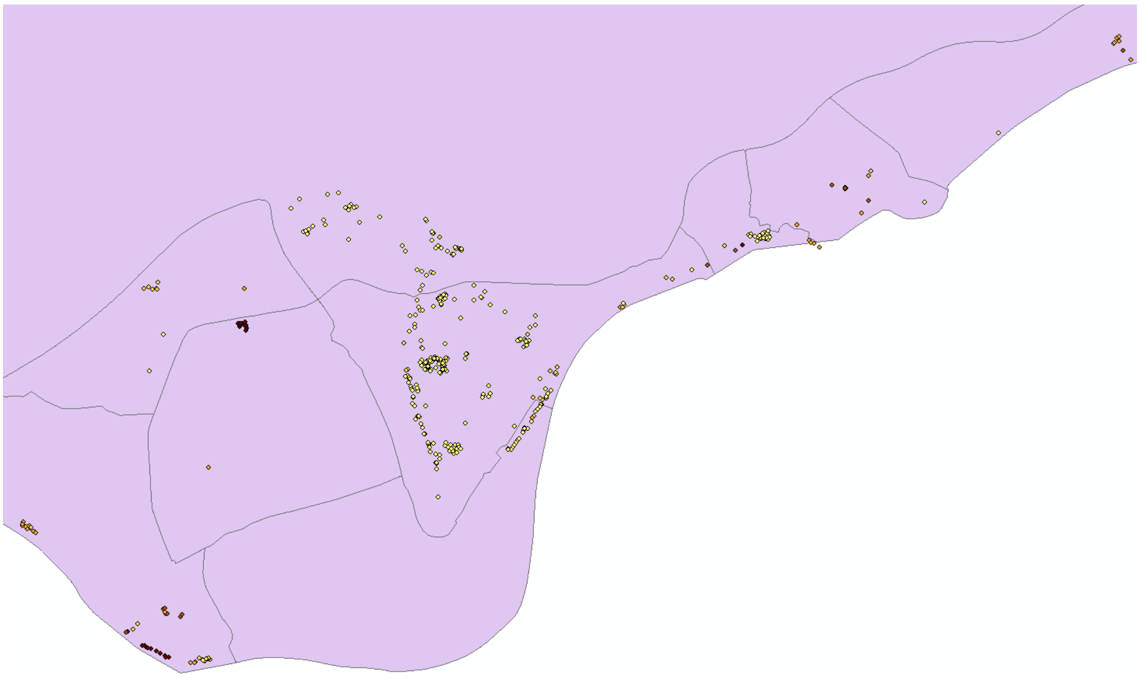
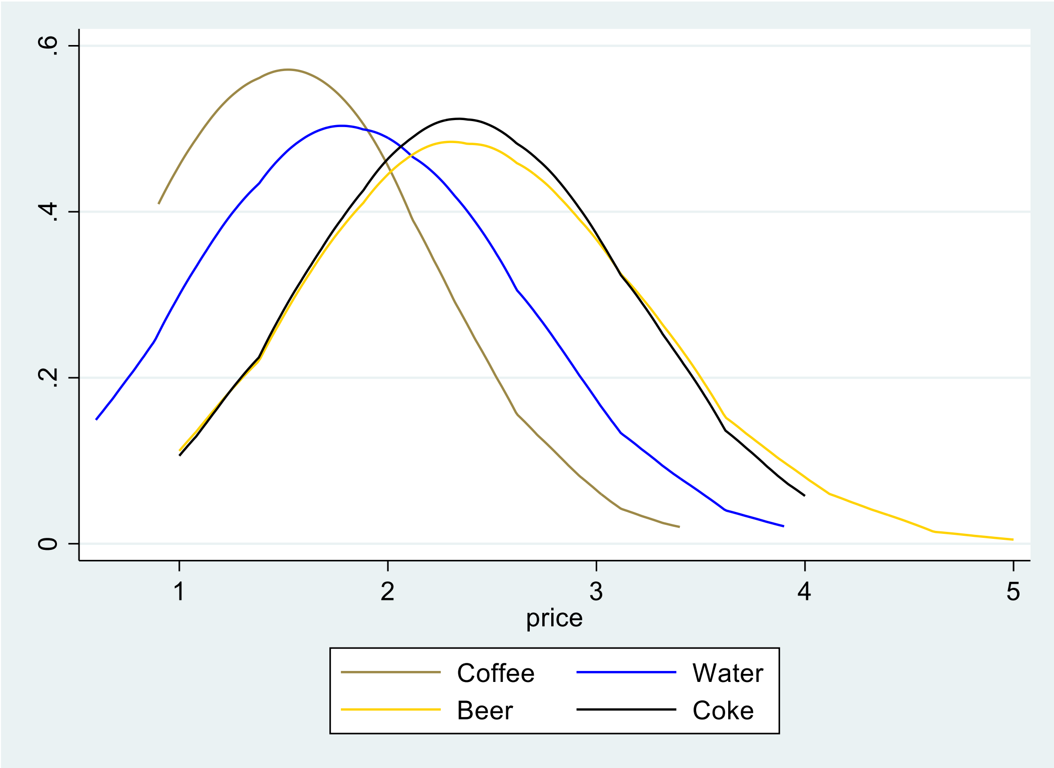


Figure 5. Coffee, water, beer and coke price Kernel distributions



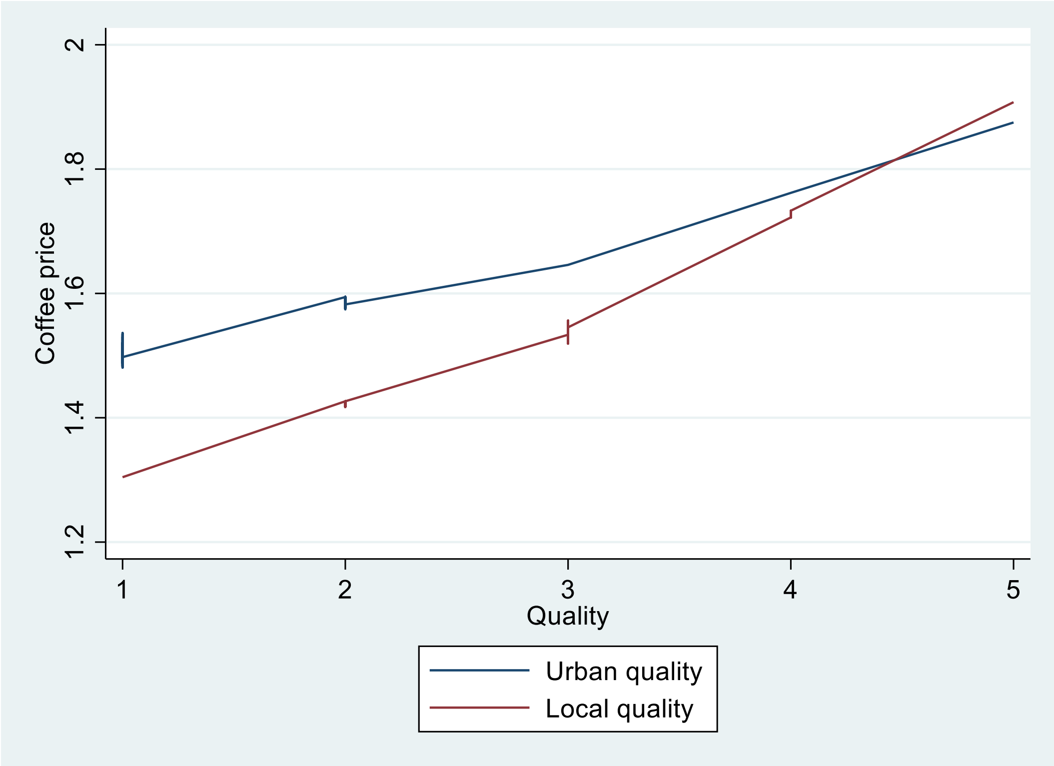
The project consists of improving the urban quality of the surrounding of all establishments that have not achieved the maximum score (5 points), at present, at destination. This maximum score was achieved by 6.46% of the establishments, whereas most (71.05%) got the lowest score (1 point).

10.5 Non-market valuation results

10.5.1 Endogeneity and the identification problem

A locally-weighted regression between two key variables provides the non-linear relationship between them. Figure 6 illustrates the semi-parametric moving window regression between the coffee price and urban and local quality and shows that the price grows with both. At the same time, a similar relationship may cause identification problems when estimating regression parameters, due to multicollinearity.

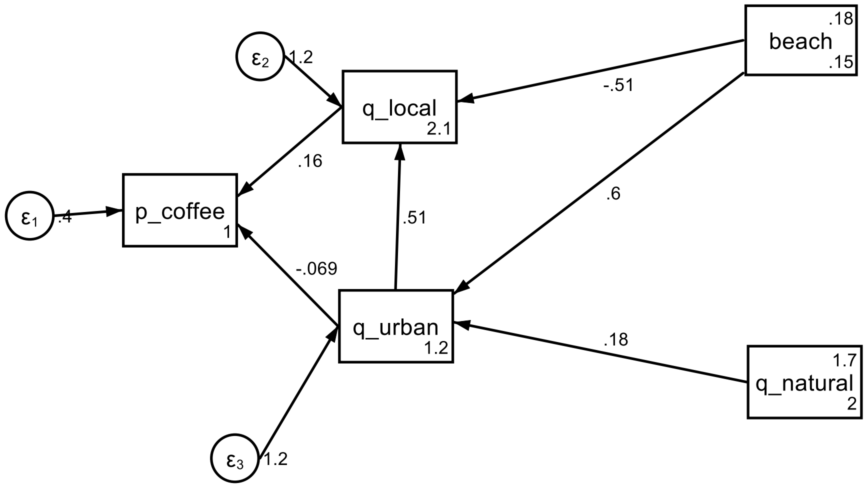
Figure 6. A semi-parametric analysis of the relationship between coffee price with urban and local quality



The Wu-Hausman F test and the Durbin-Wu-Hausman Chi squared tests of endogeneity show that the urban quality is endogenous in a coffee hedonic price model at 5%. This implies that the model requires instrumental variables to estimate the unbiased parameters of interest.

A preliminary structural equation model is performed to anticipate the endogenous relationship among the variables. The estimated parameters suggest the relationship shown in Figure 7. Thus, when the natural environment is good and/or has sea views, the public institution has invested in a better urban environment. This good urban environment has pushed entrepreneurs to improve the quality of their establishments. Both the presence of high establishment (local) quality and high urban quality increases the coffee price.

Figure 7. Structural Equation Model of the coffee price



This Structural Equation Modeling (SEM) does not consider the spatial relationship among all establishments. A better model is obtained with spatial regressions, but this endogenous relationship needs to be controlled by instrumental variables.

10.5.2 Instrumental Variables Spatial Hedonic Price Regression

Urban quality is instrumented with the natural quality and sea views. These variables prove to be useful instruments because they are significantly related to urban quality and are not significantly related to price. This way the relationship between urban and local quality is better controlled, and the multicollinearity effect is reduced.

Drinks other than coffee show a marked effect in nightlife pubs, so this needs to be controlled. However, it is also endogenous with local quality, so it is instrumented with a variable that takes into account the concentration of supply. This variable counts the number of establishments within 1,000 meters. Nightlife is usually concentrated in specific spaces with large numbers of close establishments. Moreover, beer and coke price are conditioned by size, container, and brand.

Table 2. IV Spatial hedonic price models of drinks

	Coffee	Beer	Coke	Water
Urban quality	0.1619**	0.2628***	0.2651***	0.1499***
	[0.034]	[0.000]	[0.000]	[0.007]
Local quality	0.0702*	0.0371	0.0364	0.0840**
	[0.074]	[0.251]	[0.305]	[0.011]
Nightlife pub		1.1069***	1.1806***	1.3566***
		[0.000]	[0.002]	[0.000]
Bar	-0.1868*	-0.1219	-0.1150	0.0064
	[0.097]	[0.328]	[0.399]	[0.962]
Restaurant	-0.0479	0.1265	0.2383***	0.2939***
	[0.645]	[0.162]	[0.008]	[0.001]
Can		-1.0779*		
		[0.069]		
25 cl.		2.4189***	1.0603***	
		[0.001]	[0.002]	
33 cl.		2.8789***	1.4109***	
		[0.000]	[0.000]	
Tropical brand		-0.2026**		
		[0.048]		
Bottle			0.5702*	
			[0.064]	
Constant	0.9447***	-0.4242	1.6215***	0.6759
	[0.000]	[0.291]	[0.000]	[0.115]
Spatial effect	1.8946***	1.3251**	0.7810	1.0010*
	[0.000]	[0.031]	[0.139]	[0.059]
Pseudo R^2	0.0132	0.3306	0.3049	0.1590

Urban quality parameters are key to understanding increases in WTP. In relative terms, they reveal that for each improvement level, coffee price increases by 11.88%. It is obtained by dividing the marginal price increase suggested by the parameter associated with the urban quality level for the coffee equation with respect to the average coffee price. Similarly, it can be obtained that, beer prices increase by 10.84%, coke by 7.34% and water by 8.03%. On average, one level urban quality improvement increases the price of drinks by 9.53%.

Some establishments can benefit from different levels of improvement, from one to four levels, depending on their present development. For instance, 71.05% of the establishments are located at urban quality level 1 and could benefit from improvements up to level 5. However, 6.46% of establishments already have level 5 development, so cannot benefit from any rejuvenation policy. Thus, an improvement in urban quality up to level 5 in all areas studied implies an average increase of 28% in prices. We assume that this can be extended to other food or drinks. The welfare considerations of such an impact are shown below by CBA and CGE approaches.

10.6 Welfare results

This section highlights the economic and welfare impact of the rejuvenation tourism policy with CBA and CGE. Specifically, the analysis focuses on the project's first year to stress the potential welfare divergences when applying both methodologies. Given the different approaches, the rejuvenation policy simulation requires different adjustments, as now explained. The welfare analysis focuses on the Food and Beverages (F&B) market in the tourist locations affected by the project.

10.6.1 Data

10.6.1.1 Local satellite modeling

In this case study, it is very important to work with data and parameters that are the same for both approaches. The main market under analysis is that of food and beverage at Playa del Inglés beach, which is classified as a tourism micro-destination. Thus, this is a project that affects a local area rather than a whole region. This difference matters for the CGE analysis, which is based on regional data. The structure of the economy and the parameters employed for a region are weighted averaged of the different localities that comprise the region. It should be noted that the regional parameters may or may not be suitable for the analysis of a local area. This depends on how different the local area is with respect to such average values. In this case, we think that the local area differs sufficiently, so that the strategy is to tackle the differences with a local satellite model that will feed the CGE model.

A satellite model offers both advantages and disadvantages. The main advantage is that the parameters, such as elasticities of demand and supply functions, are defined for the local area rather than those of the region. This permits a more precise analysis of market impacts. Another advantage is its flexibility to consider particular cross-elasticities with respect to other local areas that are competitors. The way it works is that the shock is initially modelled with the satellite model, which provides information on the new market equilibrium. Once the new market equilibrium is estimated, it enters the CGE model as an expenditure shock. The main disadvantage is that the satellite model works exogenously with respect to the rest of the CGE model, but this disassociation simultaneously permits greater accuracy (see Dwyer, Forsyth and Spurr, 2007). However, since the satellite model results enter the CGE model endogenously, all tourism sectoral linkages remain active anyway.

10.6.1.2 Scale and market definition

It is important to distinguish data applicable to the local area and that of the region. Thus, proper scale parameters need to be considered to feed each other. The main variable of interest is total expenditure, which comprises arrivals, length of stay and daily expenditure. The number of arrivals times the length of stay provides the total number of night stays, which is defined as the ‘quantity’ variable in this case study. Daily expenditure comprises various kinds of expenses, but this study focuses on daily food and beverages expenses, which is defined as the ‘price’ variable. Thus, the multiplication of price and quantity provides the tourism expenditure on food and beverages.

Two different markets are considered. On the one hand, Playa del Inglés destination (D1), which is where the rejuvenation takes place and on the other, the other destinations (D2) on Gran Canaria island that are competing with D1. According to ISTAC (the Canary Islands Statistics Institute), D1 represents 17.87% of the whole region’s night stays, so that D2 represents the remaining 82.13%. The year 2019 is employed for the analysis because that is the most recent year before Covid-19. Covid-19 caused considerable distress to tourism markets and the analysis of such equilibria should be avoided.

10.6.1.3 Data concerning the initial market equilibrium

According to ISTAC, the initial price of D1 is 13.97 euros, which corresponds to average daily expenditure on food and beverages in Playa del Inglés. The initial price of D2 is 12.39 euros. According to ISTAC, the initial quantity of D1 is 17,086,835 night stays, which corresponds to the whole year 2019, and will be referred to as 17.086

million night stays, for simplicity. The initial quantity of D2 is 78,530 million night stays.

10.6.1.4 Data concerning the new equilibria in the main market

Once D1 improves its urban quality, it is expected that tourists and residents will be willing to pay more. An improvement would shift demand, resulting in a price increase of about 28%, as estimated by the hedonic price model. Thus, this implies a price increase in D1 to 17.88 euros.

Moreover, as demand grows, it needs to be estimated. In order to capture such growth, we compared two different micro-destinations in the south of Gran Canaria island. On the one hand, Puerto Rico beach, one of the island's oldest but unrejuvenated (since 2000) micro-destinations, is taken as the control. On the other, Meloneras beach, which is the island's most recent and modern micro-destination, is employed as the treatment. We calculated the average growth rate in demand between 2009 (the first year available) and 2019, and found that Meloneras grew annually by about 0.4 percentage points more than Puerto Rico (2.2% vs 1.8%). This suggests that the rejuvenated destinations keep growing at a higher rate than mature destinations. This percentage is employed to estimate the expected growth of D1 after rejuvenation.

10.6.1.5 Data concerning the new equilibria in the other markets

At regional level, such 0.4% local yearly growth represents 0.071%. Adding this figure to the price increase provides the final tourism expenditure growth percentage, that reaches 0.581% for the whole region. This figure represents the expenditure shock that enters the CGE model. After the shock is simulated in the model, it provides information concerning the ex-post values of prices and quantities for the whole region.

Specifically, the CGE model works with a Cobb-Douglas demand function that is represented by the following expression:

$$q_d = \alpha \frac{m}{p}, \tag{21}$$

where α is a scale parameter calibrated by the CGE model, *m* denotes the income level, and p denotes prices. The CGE model shows that ex-post prices in the region grow by

0.329%. Application of the market rate adjustment leaves the D2 price at 12.40 euros and the number of night stays at about 78.669 million.

10.6.1.6 Linearization of the supply and demand functions

In order to quantify consumer surplus, we need to measure the area above the new equilibrium price (p_1) and below the demand function. Before the calculation of this area, it is necessary to calculate the reservation price with the project ($\overline{p_1}$). For this purpose, the derivative of the demand function is calculated, so that:

$$\frac{dq_d}{dp} = -\alpha \frac{m}{p^2}. \tag{22}$$

Once the slope of the demand function is calculated, it is straightforward to obtain $\overline{p_1}$ which takes the value of 45.12 euros for D1 (ex-post) and 39.58 for D2. Applying the same slope reveals the values of $\overline{p_0}$ in a similar fashion. In this way, it is also straightforward to calculate the consumer surplus (see section 10.6.3 below).

10.6.2 CGE results

At the macro-economic level, a 0.518% increase in tourism expenditure triggers three classical economic impacts (see, for instance, Copeland, 1991; Adams and Parmenter, 1995; Zhou, Yanagida and Chakravorty, 1997; Narayan, 2004; Chao, Hazari, Laffargue, Sgro and Yu, 2006; Blake, Durbarry, Eugenio-Martin, Gooroochurn, Hay, Lennon and Yeoman, 2006; Capó, Font and Nadal, 2007; Parilla, Font and Nadal, 2007; Pham, Jago, Spurr, and Marshall, 2015; or Inchausti-Sintes, 2015 and 2020).

First, it produces an increase in the demand of non-tradable/tourism sectors (Accommodation, Catering services, Travel agencies, Real estate, or Entertainment) (see, Table 3). However, in this case, the rest of the sectors also benefit from the tourism shock; stressing this economy's tourism dependency. This positive impact reduces the unemployment rate from 18.9% to 18.6%, whereas imports rise to 0.37%. Finally, the real exchange rate appreciates to 0.5%.

Table 3. Sectoral economic impacts for the first year (%)

Agriculture and fishing	0.174
Energy and mining	0.298
Processed food, beverages and tobacco	0.498
Textiles	0.795
Industry	0.436
Construction	0.265
Trade	0.267
Accommodation	0.167
Catering services	0.15
Road transport	0.267
Maritime transport	0.345
Air transport	0.344
Other transport services	0.340
Travel agencies	0.175
Real estate	0.022
Rent a car	0.019
Entertainment	0.152
Other services	0.277
Public services	0.130
Education	0.115
I+D	0.027

10.6.3 CBA results

The Cost-benefit Analysis focuses on the food and beverages (F&B) sector in the tourist locations in the south of Gran Canaria (primary markets). Table 4 summarizes the main data employed for the CBA.

Table 4. Main data used for the analysis

	Without project	With Project
Investment (€)	-	676,000,000
Overnights Stays	17,086,835	+0.4% yearly
Tourism F&B daily expenditure (€)	13.97	17.88

In order to proceed with the surplus calculations, we need to estimate the demand functions, and specifically, the slope of the demand function. For instance, as an illustration, the slope of the Playa del Inglés demand function takes the following value:

$$\frac{dq_d(PI)}{dp} = -\alpha\frac{m}{p^2} = -0.11\frac{0.1787 \cdot 10{,}238{,}940{,}000}{319.69} = 629{,}568.779$$

It can be easily verified that:

$$\overline{p_1} = \frac{q_1}{\frac{dq_d(PI)}{dp}} + p_1 = \frac{17{,}155{,}182.7}{629{,}568.779} + 17.88 = 45.12$$

A similar procedure is carried out for $\overline{p_0}$ and for both markets. For the calculation of the consumer surplus, recall that since most clients are foreigners, they may be ruled out of the consumer surplus calculation. In fact, the consumer surplus is adjusted by the share of the residents in the demand function, which takes the value of 22.9%. This figure is obtained from the tourism satellite account. The calculations of the producer and taxpayers' surpluses are straightforward.

Table 5 displays the results of the CBA calculations. It shows that most benefits are in the micro-destination of interest (Playa del Inglés), whereas some spillover effects also occur, but at a lower rate. It also illustrates that the agents that obtain most benefits are the producers, followed by the taxpayers. The increase in the consumer surplus of residents is very low.

Table 5. Economic welfare of the project in Year 1 disentangled by changes in surpluses (million euros)

Playa del Inglés	
Consumer Surplus	0.206
Producer surplus (existing demand)	62.464
Producer surplus (generated demand)	0.097
Taxpayers' surplus (existing demand)	4.373
Taxpayers' surplus (generated demand)	0.062
Remaining micro-destinations on the Canary Islands	
Consumer Surplus	0.412
Producer surplus (existing demand)	0.838
Producer surplus (generated demand)	0.000
Taxpayers' surplus (existing demand)	0.059
Taxpayers' surplus (generated demand)	0.087
Agricultural sector	
Consumer Surplus	-4.094
Producer surplus (existing demand)	3.832
Producer surplus (generated demand)	0.003
Taxpayers' surplus (existing demand)	0.268
Taxpayers' surplus (generated demand)	0.107
Total Welfare	68.743

Additionally, so as to illustrate the effect over non-tourism goods consumed by residents, we introduced the effect of the project on the agricultural sector. In order to ensure comparability with CGE, the change in prices and quantities in the agricultural sectors obtained from the CGE model are also used in the CBA analysis. For the calculations it was assumed that residents are already consuming agricultural products. Thus, the new demand derived from the project is considered to increase due to foreigners, meaning that the surplus of these consumers is omitted.

10.6.4 Comparing CGE and CBA results

The welfare obtained from the project reaches 68.743 million euros when measured with CBA, and arrives at 72.038 million euros when measured with CGE. However, the latter figure is obtained when we deduct the induced effects, which reaches about 20.319 million euros. Most of this difference is triggered out due to the presence of unemployment. If the induced effects are equivalent to those obtained in similar alternative projects, then they should be deducted. The effects were obtained from Schallenberg-Rodriguez and Inchausti-Sintes (2021), who found that the induced effects represented about 22% of the total impact shock to the Canary Islands' economy.

The remaining difference between the two approaches is explained because in CGE welfare is measured through equivalent variation and non-linear supply and demand functions, whereas in this CBA exercise it has been calculated through variations in surpluses of linearized demand and supply functions. Finally, it should be remembered that the choice of model closure in CGE, as well as the elasticities provided, also condition the results obtained.

10.7 Conclusions

Despite both CGE and CBA being rooted in the same economic theory, implementation of the methodologies may diverge in practice. This paper has shown some of the key differences between both approaches when applied to a tourism investment project.

This case study implies a local impact, as is the case of many investment projects. CGE is challenged here because the model is calibrated according to national or regional accounts that employ standard functions based on national or regional elasticities. When simulating a local shock in CGE, the national or regional functions and elasticities may not respond with sufficient accuracy to the implications. For this reason, we had to employ a satellite model that could measure the local shock properly and then input this shock into the CGE model.

CGE models consider all sectors of the economy simultaneously, which is helpful in measuring its induced effects. For an economic appraisal, it is particularly relevant when there exists involuntary unemployment because, if the project reduces the unemployment, then social welfare increases. This welfare increase relates to changes in prices and production, as well as the opportunity cost of labour. CGE models consider the induced effects in their results. However, such effects may also be triggered out under any other counterfactual scenario. Provided those effects are similar, then it is necessary to deduct them to obtain a net welfare measure from CGE models.

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11 Conclusions

The project team

- Only projects with net social benefits should be approved. This simple idea is the reason why projects' appraisal can contribute to economic growth and welfare, and the rationale for the existence of Cost-Benefit Analysis (CBA) as a tool for guiding the selection of projects.

- Computable General Equilibrium (CGE) models have been used for large shocks, like the estimation of the economic effects of global climate change, elimination of trade barriers or the spread of human diseases. Such models can be used to calculate the *impact* on Gross Value Added (GVA), employment, the government deficit, balance of trade, and other macro indicators, as well as Hicksian welfare measures (typically Equivalent Variation, or EV).

- All projects subject to welfare assessment, regardless of method, should begin with a careful assessment of the project impacts using general equilibrium cost-benefit rules. This will clarify which items need to be measured and what the appropriate method may be (CGE/CBA). For example, such rules clarify the need to include effects on markets other than the one most directly affected by the project.

- The differences between CBA and CGE models, and how such differences may condition the economic appraisal of projects, have been analyzed. CBA is particularly useful for "small" projects (that can include many markets). It is important to stress that CBA is not a simple partial equilibrium exercise (ceteris paribus), and some observable market demands incorporate the effects on other affected markets, such as the derived demand for transport under some conditions.

- When a CGE model is used for the social appraisal of projects, such as the construction of a new railway line, an existing CGE model built for large economic impacts would require further modelling that incorporates the specificities of the project under evaluation. A standard CGE model designed to capture the effects of changes in international trade, or similar, will barely identify differences between the net welfare effects of an investment in urban commuting or high-speed rail. Both projects will trigger the induced effect from the transport sector on the rest of the economy, but their direct effects and wider economic benefits are very different.

- In the absence of distortions, CBA and CGE should give the same net welfare. However, with distortions in secondary markets, results might differ. This research project tested differences between CBA and CGE on three projects in three different sectors of the economy. The case studies show that in the presence of the usual type of distortions that normally characterize markets, differences between CGE and CBA would be in the region of 5-10 % of the project value.

- These results should not be generalized and are to be taken as indicative orders of magnitude, specific to the CGE models included in this project. More complex models especially designed for these projects might produce different results. However, should a secondary market show a substantial distortion, there is no reason why CBA could not model such distortion. Therefore, under normal circumstances, properly conducted CBAs and CGEs should not produce meaningful differences.

- Indirect effects (beyond the main group of strongly interrelated markets) may be ignored (i) if the project is not going to produce large price changes in the rest of the economy and there are no distortions; and (ii) if they are large in absolute terms but not expected to be significantly different compared with the counterfactual.

- The multiplier effect can be ignored if it similarly affects both the project and the alternative. The absolute value of the multiplier effect of the project is not incremental and therefore is irrelevant to the estimation of its net present value.

- A health, education or transport project must be judged for its potential to improve health status, increase human capital or reduce generalized cost. Including multiplier effects in the net present value confuses the social appraisal of projects with impact studies, and may hide poor value for money.

- A project with negative social net present value reduces social welfare (in efficiency terms). Adding the multiplier effect is not going to change its net social value. Nevertheless, when choosing between mutually exclusive projects, both with positive net present value, and when there is evidence of a significantly different multiplier effect between them, the net difference of these effects should be included. Even in this case, only the price-marginal social cost gap applies.

- Both CBA and CGE are based on simplifications of the actual economy. It is practically impossible to cover all possible impacts of a project under evaluation. The case of agglomeration benefits is illustrative. Both conventional CBA and CGE need to be supplemented when changes in proximity increase productivity in a significant way.

- It is crucial to distinguish between redistribution and growth, i.e. gross and net effects. CBA aims to calculate the net welfare effect of a project, and the inclusion of transfers and gross benefits artificially inflates the value of the project. CBA is strictly constructed on an incremental basis, and double-counting must be avoided. CGE can be used to calculate a project's net welfare effects, but the counterfactual must account for the indirect and induced effects of the resources in the alternative use.

- The treatment of labour is possibly one of the main sources of potential divergence between CBA and CGE in a practical application. In contexts of high unemployment, it is easy to forget that any welfare effect of a fall in unemployment must be net of its social opportunity cost. The way CBA deals with job creation is through shadow pricing. The value of these accounting prices varies substantially with the specificities of the labour market. Again, the key is to begin any assessment with a general equilibrium cost-benefit rule.

- In the case of high unemployment, the successive round of effects (employment multiplier) might imply additional benefits related to the creation of additional jobs, but the distinction of net effects (both net of opportunity cost and with respect to the alternative) is crucial to avoid a gross overestimation of the welfare effect of the project.

- Distributional and location effects are challenges both for CBA and CGE. Standard models must be supplemented with a more specific treatment of the interactions between initial gains and the existence of fixed factors and labour heterogeneity. Though, in principle, CGE models are useful for studying the distribution of surpluses, the difficulties of identifying the final beneficiaries and the spatial distribution of efficiency gains, when multiple equilibria are possible, require further research efforts.

- A useful way to deal with distributional issues is to display how different groups are affected by the project. Another is to use a specific social welfare function. Displaying how different groups are affected should be a part of project appraisal.

- Uncertainty pervades most assessments and presents a challenge for both CBA and CGE. There are doubts in various dimensions; not least when it comes to parameters (such as discount rates) and other data. But uncertainty may also pertain to specifics of the project itself, e.g. irreversibility. To date, we lack methods to estimate such values with any precision, regardless of the measurement approach.