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

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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.

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[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*”.

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[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.

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[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

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

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 $\overline{d\overline{K} > 0}, d\overline{L} = 0$, 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=readexcel(''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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