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 $\pi_j = p_j f_j(l_j^*) - wl_j^*$ (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:

$$\frac{dW}{V_y} = -\sum_{j=1}^{n} x_j dg_j + dy^g. \tag{8}$$

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:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^{n} \frac{\partial \pi_j}{\partial p_j} dp_j = \sum_{j=1}^{n} x_j^s \, dp_j. \tag{9}$$

By substituting this result into expression (8), and assuming all product markets clear, $x_j = x_j^s$:

$$\frac{dW}{V_y} = -\sum_{j=1}^{n} x_j dp_j + \sum_{j=1}^{n} x_j^s dp_j = 0, \tag{10}$$

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:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^{n} w \frac{\partial \pi_j}{\partial t_j} dt_j = \sum_{j=1}^{n} w \left(p_j \frac{\partial f_j(l_j^*)}{\partial l_j} - w \right) \frac{\partial l_j}{\partial t_j} dt_j, \tag{11}$$

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), $\frac{1}{2}\left(g_j^0 - g_r^{1d}\right)x_j^d$, 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:

$$\Delta W_j^d = \frac{1}{2}\left(g_j^0 - g_r^{1d}\right)x_j^d + p_r^1 x_j^d. \tag{19}$$

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:

$$\Delta W^e = (v_r t_r^0 - v_r t_r^1)x_r^0, \tag{20}$$

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:

$$\Delta W_j^d = \frac{1}{2}\left(g_j^0 + g_r^{1d}\right)x_j^d - v_j t_r^1 x_j^d. \tag{21}$$

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]

$$\Delta W_j^d = \frac{1}{2} v_j (t_j^0 - t_r^1) x_j^d + \frac{1}{2} (p_r^1 - p_j) x_j^d + c_j x_j^d =$$

$$= \frac{1}{2} v_j (t_j^0 - t_r^1) x_j^d + \frac{1}{2} (p_r^1 - p_j) x_j^d + p_j^0 x_j^d =$$

$$= \tfrac{1}{2} (v_j t_j^0 - v_j t_r^1) x_j^d + \tfrac{1}{2} (p_r^1 + p_j) x_j^d = \tfrac{1}{2} \left(g_j^0 + g_r^{1d} \right) x_j^d - v_j t_r^1 x_j^d, \qquad (25)$$

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:

$$max_{X_i,A_i,K_i,LST_i}\left(P_iX_{a,i}\right)-\left(P_{A_i}Ar_{a,i}+P_{VA_i}VAr_{a,i}\right)$$

$$subject\ to: X_{a,i}=f\left(A_{a,i},VA_{a,i}\right)=A_{a,i}{}^{\alpha_i^{ar}}VA_{a,i}{}^{\alpha_i^{va}}$$

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:

$$max_{L_{TR_{LS}},L_{LS}}\left(\sum \alpha_{LS}{L_{TR_{LS}}}^{\sigma_{T_{LS}}}+(1-\alpha_{LS}){L_{LS}}^{\sigma_{T_{LS}}}\right)^{1/\sigma_{T_{LS}}}$$

$$subject\ to\colon P_{L_{TR_{LS}}}L_{TR_{LS}}+P_{L_{LS}}L_{LS}=P_L\overline{L_{LS}}$$

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

$$max_{Gov,A_{Gov,i}}(P_{Gov}Gov) - \sum_i P_{A_i}A_{Gov,i}$$

$$subject\ to: Gov = f(A_{Gov,i}) = \prod_i A_{Gov,i}^{\alpha_{Gov_i}}$$

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:

$$max_{Tou,A_{tou,i}}(P_{tou}Tou) - \sum_i P_{A_{tou}}A_{tou,i}$$

$$subject\ to: Y_{tou} = f\left(A_{tou,i}\right) = min_i\left(\frac{Ar_{tou,i}}{\alpha_{tou_i}}\right)$$

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 (%)

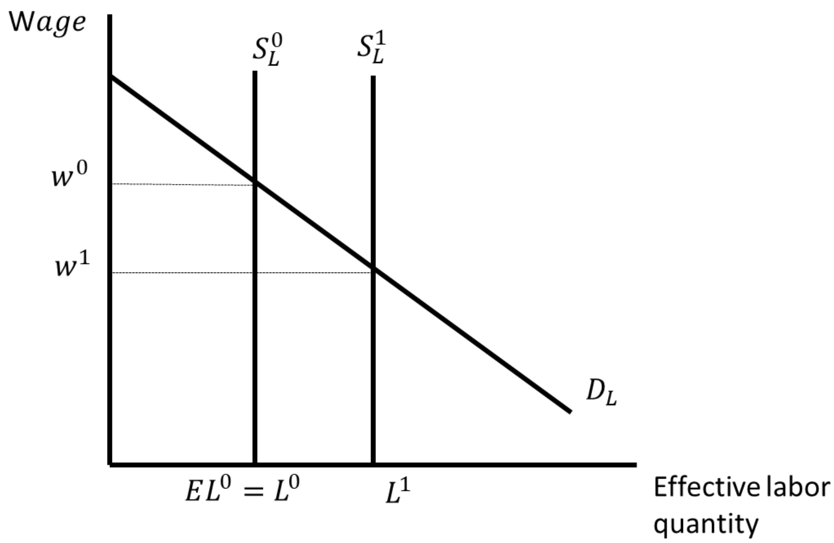
	High demand	Low demand
Agriculture and fishing	0.044	0.019
Energy, water and minery	0.093	0.041
Industry	0.051	0.022
Construction	0.013	0.006
Trade	0.098	0.046
Accommodation	0.123	0.056
Other road transport	-1.545	-0.709
Train	34.397	15.997
Bus	-5.629	-2.663
Maritime transport	0.099	0.045
Air transport	-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, $j = 1,\dots, n$; 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:

$$\begin{aligned} \frac{\partial L}{\partial x_j} &= \frac{\partial U(x^*)}{\partial x_j} - \lambda(g_j - wt_j) = 0, \\ \frac{\partial L}{\partial \lambda} &= \sum_{j=1}^{n} g_j x_j^* - \Pi - w\bar{l} = 0, \end{aligned} \tag{A7}$$

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.