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# Cost-benefit analysis of transport projects: theoretical framework and practical rules\*

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**ABSTRACT:** The economic appraisal of transport projects is commonly based on the calculation of time savings, operating cost reduction, avoiding accidents, quality improvements, and project costs. This approach is based on the measurement of the change in willingness to pay and resources. This paper describes this method for the assessment of the economic effects of any project and then addresses an alternative approach based on the aggregation of changes in surpluses. The analysis is based on a simple model to avoid the mechanical application of rules of thumb from different sources, helping to find some practical ways to avoid common pitfalls and double counting in the measurement of benefits and costs of transport projects. The narrative on how the transport sector works and how the government intervention affects social welfare is supported by an analytical approach from which the rules and measurement criteria are derived, always explaining the assumptions and conditions under which they hold.

**Keywords:** cost-benefit analysis, economic evaluation, transport, infrastructure.

**JEL classification:** H43, L38, L91.

## Forthcoming in Transport Policy

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## 1. Introduction

Transport improvements can be typically contemplated as exogenous interventions in transport markets, which move the economy from one equilibrium to another, commonly through the reduction of the generalized price (composed of monetary price, time, and other disutility components) borne by transport users. Even projects aimed to provide new capacity and, of course, transport policies such as subsidies to passengers, can be analysed as a reduction in the generalized price of transport. Although there are different reasons that, in principle, could justify these public interventions (e.g., increasing accessibility, improving safety, decreasing congestion and scarcity, or reducing negative environmental externalities), the question is not whether there are social benefits from public intervention, but whether these potential benefits are large enough to offset the opportunity cost of the resources diverted from other uses to obtain those benefits. This is the challenge of the economic evaluation of projects and policies, whose main objective is to assess changes in the well-being of individuals directly or indirectly affected by their implementation.

Practitioners have different tools at their disposal to meet this challenge. The main ones are cost-benefit analysis (CBA), multicriteria analysis (MCA), and computable general equilibrium models (CGE).<sup>1</sup> This paper focuses on CBA, the common methodology in the main supranational and national economic evaluation guidelines, which can be defined as the quantification in monetary terms of the incremental changes in welfare resulting from the implementation of a project relative to a counterfactual (the economy without the project), with the ultimate aim of examining whether the society is better off with the intervention.

In this paper, we use cost-benefit analysis to evaluate transport projects (Mackie *et al*, 2014). Our narrative on how the transport sector works and how government intervention affects social welfare is supported by an analytical approach from which our rules and

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<sup>1</sup> MCA is mostly used in evaluating projects under conflicting criteria. CGE is gaining status in transport and is particularly recommended in the case of megaprojects where some of the requirements for the application of CBA are not satisfied. However, the use of the CGE models for the economic appraisal of projects requires distinguishing between the incremental effect in welfare (the CBA approach) and the economic impact analysis of a typical CGE model. The measurement of effects on gross value added or employment, as the main outputs of these models, has to be adapted to produce something that can be interpreted as a monetary measure of the change in welfare due to the project, as it is the case in CBA. For additional details, see the C-Bridge Project, funded by the European Investment Bank Institute, on "Improving the measurement of the indirect effects of investment projects: Specifying and calibrating EIA methods to maximize compatibility with CBA" (available at <https://c-bridge.ulpgc.es/>).

criteria of measurement are derived, always explaining the assumptions and conditions under which our policy recommendations apply.

Social welfare changes can be approximated through the sum of the changes in the surpluses of the agents affected by the project, or through the sum of the changes in willingness to pay (*WTP*) and in the use of real resources, ignoring income transfers. The measurement of the effect of a reduction in the generalized price of transport is different in the case of a unimodal or multimodal analysis. This paper follows Mohring (1971, 1993) and covers alternative ways of dealing with the economic evaluation of transport projects, explaining the rationale of the different options. Although the alternative methods aimed to measure the change in social welfare are equivalent, when practical rules are not supported by a robust theoretical framework, there is a high risk of double counting or measurement errors.<sup>2</sup>

The CBA of transport projects is commonly conducted using a few measurement rules that are simply obtained from changes in prices and quantities of the derived demand for transport. We follow the theoretical framework developed by Johansson (1993) and Johansson and Kriström (2016) and for the measurement of the effects of transport projects we follow Johansson and de Rus (2018) and de Rus and Johansson (2019). Our model includes the explicit consideration of time in the generalized prices of goods and services, and the corresponding budget constraint given the time endowment of the individual, with the emphasis on the rigorous derivation of the CBA rules.

There are other economic impacts linked to the response of the private sector to changes in proximity, and these effects could be significant in specific contexts affecting productivity effects and land development. Nevertheless, the main components of transport projects are those accruing to users and only when prices deviate from marginal costs in secondary markets, other benefits not fully internalized like agglomeration economies should be considered (Laird and Venables, 2017; Mackie *et al*, 2011). Although the paper briefly discusses these project effects, the main target is the analysis of the alternative ways to deal with the cost-benefit analysis of transport projects and the derivation of consistent rules for the practical assessment of projects.

Although we follow the conventional CBA methodology, the analysis in this paper is based on the model presented in **Section 2**, which aims to derive the fundamentals of these measurement rules, explain their assumptions, and clarify the conditions under which they hold. This helps to derive consistent criteria for project evaluation, avoiding

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<sup>2</sup> See Mackie and Preston (1998) for other errors and biases in CBA.

pitfalls such as double counting or measurement errors. **Section 3** discusses some CBA rules and policy recommendations, as well as the equivalence between the aforementioned alternative approaches to project appraisal. In this context, the use and misuse of shadow prices are also discussed, as well as a brief discussion of indirect effects and wider economic benefits. **Section 4** provides an example of the methodologies and compares them. **Section 5** concludes.

## 2. Cost-Benefit Analysis of transport projects: theoretical framework

### 2.1. A basic model to measure social welfare changes due to transport projects<sup>3</sup>

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,  $U(x_1, \dots, x_n)$ , where  $x_j$  represents the quantity of good or service  $j$ , with  $j = 1, \dots, n$ . This individual chooses his optimal set of consumption activities by maximizing his utility given his budget constraint. This constraint delimits all the combinations of goods and services, including leisure, that may be obtained at any given time, according to their (exogenous) market prices and individual's income, which has two components (wage and profits).

Firstly, this individual obtains income by working. Let us denote by  $\bar{l}$  the maximum time endowment available for the consumer (for example, 24 hours per day, or 365 days per year), and by  $t_j$  the time required to consume each unit of good or service  $j$ .<sup>4</sup> Denoting by  $w$  the wage received per unit of working time, individual's labour income is given by  $wl$ , where  $l$  represents the working time chosen by the individual, which is defined by the difference:

$$l = \bar{l} - \sum_{j=1}^n t_j x_j. \quad (1)$$

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<sup>3</sup> This section draws on the approach by Johansson (1993), Johansson and Kriström (2016), Johansson and de Rus (2018), and de Rus and Johansson (2019) for the measurement of the effects of transport projects. Our model explicitly considers the role of time in the generalized prices of goods and the corresponding budget constraint, given the time endowment of the individual.

<sup>4</sup> Everyday life activities are time-consuming and should be explicitly included in the analysis because individuals make their travel decisions both in terms of market prices and the opportunity cost of the travel time.

Secondly, we will assume that all firms are ultimately owned by this representative individual and that they distribute all their profits; thus, the individual's total income obtained from profits is given by:

$$\Pi = \sum_{j=1}^n \pi_j, \quad (2)$$

where  $\pi_j$  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:

$$\max_{l_j} \pi_j = p_j x_j^s - w l_j = p_j f_j(l_j) - w l_j, \quad (3)$$

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  $f_j(l_j)$ . If all the required equilibrium properties hold, the first order condition of this problem is given by:

$$\frac{\partial \pi_j}{\partial l_j} = p_j \frac{df_j(l_j^*)}{dl_j} - w = 0, \quad (4)$$

and it allows us to obtain as a solution  $\pi_j = p_j f_j(l_j^*) - w l_j^*$ . Note that, in this equilibrium, the sum of all labour inputs used by firms must be equal to the working time offered by the representative individual, that is,

$$\sum_{j=1}^n l_j^* = l.$$

We can now use these results to finally define the individual's budget constraint, which is given by:

$$\sum_{j=1}^n p_j x_j \leq \Pi + w l, \quad (5)$$

which can be also rewritten as:

$$\sum_{j=1}^n p_j x_j \leq \Pi + w(\bar{l} - \sum_{j=1}^n t_j x_j),$$

that is:

$$\sum_{j=1}^n g_j x_j \leq \Pi + w \bar{l}, \quad (6)$$

where  $g_j = p_j + w t_j$  represents the generalized price of good or service  $j$ . For example, in the case of air transport,  $g$  includes the monetary price paid (e.g., the airline fare, airport

charges, etc.) and the users' time cost (access and egress time, waiting time and flying time).<sup>5</sup>

It can be noted that expressions (5) and (6) are equivalent and, thus, we can write individual's budget constraint in terms of market prices,  $p = (p_1, \dots, p_n)$ , and individual's income ( $y$ ),  $\Pi + wl$ , or in terms of the generalized prices,  $g = (g_1, \dots, g_n)$ , and the potential maximum income (profits income plus the value of time endowment),  $\Pi + w\bar{l}$ , named here as generalized income ( $y^g$ ).

We are now ready to solve the individual's decision problem. If the utility function satisfies the local non-satiation property, the budget constraint is binding, and the individual's maximization problem reduces to:

$$\begin{aligned} & \max_{x_1, \dots, x_n} U(x_1, \dots, x_n) \\ \text{s.t.} \quad & \sum_{j=1}^n p_j x_j = \Pi + wl, \end{aligned} \quad (7)$$

or, equivalently, in terms of generalized prices:

$$\begin{aligned} & \max_{x_1, \dots, x_n} U(x_1, \dots, x_n) \\ \text{s.t.} \quad & \sum_{j=1}^n g_j x_j = \Pi + w\bar{l}. \end{aligned} \quad (8)$$

This is the preferred expression of the problem when evaluating transport projects since most of them can be interpreted as changes in generalized prices (either due to changes in market prices and/or in travel time). 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 net monetary value of the goods that the individual has to give up to implement such a project.

The opportunity cost of travel time is the wage rate ( $w$ ) in our model. This is a simplifying assumption that does not affect the main results of the paper (see Hensher, 2011, for an overview of the major theoretical and empirical issues concerning the value of travel time savings). 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

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<sup>5</sup> It should be noted that 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.

job) the wage rate could 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).<sup>6</sup>

The corresponding Lagrange function used to solve problem (8) is then given by:

$$L = U(x_1, \dots, x_n) - \lambda(\sum_{j=1}^n g_j x_j - \Pi - w\bar{l}), \quad (9)$$

which can be also rewritten as:

$$L = U(x_1, \dots, x_n) - \lambda(\sum_{j=1}^n g_j x_j - \sum_{j=1}^n p_j f_j(l_j^*) - w \sum_{j=1}^n t_j x_j). \quad (10)$$

First order conditions are given by:

$$\begin{aligned} \frac{\partial L}{\partial x_j} &= \frac{\partial U(x^*)}{\partial x_j} - \lambda(g_j - wt_j) = 0, \\ \frac{\partial L}{\partial \lambda} &= \sum_{j=1}^n g_j x_j^* - \Pi - w\bar{l} = 0, \end{aligned} \quad (11)$$

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 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

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<sup>6</sup> There are several reasons why the value of time may empirically differ from the wage rate. This is the case when both work and travel affect utility directly (and not only the budget constraint, as in our model), or when working time is unaltered by travel time savings. In those situations, the value of time of each individual depends on the sort of travel they undertake, that is, the time at which the journey is made, the characteristics of the journey (congested, repetitive, or free flow), the journey purpose (commuting or leisure), the journey length, the mode of transport, or the size of the time saving (see Mackie *et al.*, 2001, for further details).



consumption).<sup>7</sup> 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.<sup>8</sup>

By substituting all these demands in the (direct) utility function, we obtain the individual's indirect utility function, defined as:

$$U(x_1^*, \dots, x_n^*) = V(g, y^g), \quad (12)$$

which gives the individual's maximal attainable utility when faced with a vector  $g$  of generalized prices and individual's generalized income  $y^g$ . 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, we have that, in equilibrium:

$$L^* = V(g, y^g) - \lambda(\sum_{j=1}^n g_j x_j^* - \Pi - w\bar{l}) = V(g, y^g), \quad (13)$$

and therefore:

$$\frac{\partial L^*}{\partial y^g} = \lambda = V_y = \frac{\partial V(g, y^g)}{\partial y^g}, \quad (14)$$

showing that the Lagrange multiplier can be interpreted as the individual's marginal utility of generalized income ( $V_y$ ).

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<sup>7</sup> The value of leisure is not necessarily equal to the wage rate for the reasons mentioned in footnote 6. In a recent empirical estimation with workers in the Canton of Zurich, Switzerland (Schmid *et al.*, 2021), the authors found the value of the ratio leisure/wage rate equal to 0.58 reflecting the leisure value relative to goods consumption. They also were able to estimate the value of time assigned to travel and, hence, the two components of the value of travel time savings by transport mode, equal to the value of leisure minus the value of time assigned to travel (this last value was, for example, found to be negative for carsharing and positive for bike and public transport).

<sup>8</sup> Once the spatial nature of transport activities is included in the model, the explicit treatment of changes in proximity and location could 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 **Section 3**).

## 2.2. Measuring the economic effects of transport projects

Let us now analyse the effects of a transport project, defined as an exogenous intervention that reduces the generalized price and/or increases the number of trips, 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 just given by the change in the individual's utility:  $dW = dU$  and, thus, considering the direct utility function evaluated in the initial equilibrium, we can write:<sup>9</sup>

$$dW = dU = \sum_{j=1}^n \frac{\partial U(x^*)}{\partial x_j} dx_j. \quad (15)$$

Then, substituting the first order condition of the individual's maximization program given by (11) into expression (15), we obtain:

$$\frac{dW}{V_y} = \sum_{j=1}^n (g_j - wt_j) dx_j = \sum_{j=1}^n p_j dx_j. \quad (16)$$

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  $WTP$  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:

$$dW = dV = \sum_{j=1}^n \frac{\partial V}{\partial g_j} dg_j + V_y dy^g. \quad (17)$$

Applying the envelope theorem, we obtain:

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<sup>9</sup>Leaving 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 means for unlimited and costless redistributions and, therefore, monetary gains and losses can be aggregated across individuals in order to determine whether the project is socially worthy. Nevertheless, 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).

$$\frac{\partial V}{\partial g_j} = -\lambda x_j = -V_y x_j, \quad (18)$$

which can be replaced into expression (17) to finally obtain a useable expression that allows us to evaluate the effects of transport projects:

$$\frac{dW}{V_y} = -\sum_{j=1}^n x_j dg_j + dy^g. \quad (19)$$

#### *A price reduction*

Now consider that the change in the generalized price of good or service  $j$  which we interpret as a transport project is only due to a change in the market price  $p_j$ , while the required (travel) time  $t_j$  remains constant, that is,  $dg_j = dp_j$ . In this case, we have:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^n \frac{\partial \pi_j}{\partial p_j} dp_j = \sum_{j=1}^n x_j^s dp_j. \quad (20)$$

By substituting this result into expression (19), and assuming that all product markets clear,  $x_j = x_j^s$ :

$$\frac{dW}{V_y} = -\sum_{j=1}^n x_j dp_j + \sum_{j=1}^n x_j^s dp_j = 0, \quad (21)$$

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 just a transfer between consumers and producers. Moreover, there are no other additional welfare effects to be considered in the rest of the economy.

#### *A time-saving*

Alternatively, 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,  $dg_j = w dt_j$ . In this case:

$$dy^g = d(\Pi + w\bar{l}) = \sum_{j=1}^n w \frac{\partial \pi_j}{\partial t_j} dt_j = \sum_{j=1}^n w \left( p_j \frac{\partial f_j(t_j^*)}{\partial l_j} - w \right) \frac{\partial l_j}{\partial t_j} dt_j, \quad (22)$$

which, according to the first order condition of the profit maximization program of firm  $j$  given by expression (4) is zero, i.e.,  $dy^g = 0$ . Then, by substituting this into expression (19), we finally obtain that:

$$\frac{dW}{V_y} = -\sum_{j=1}^n x_j w dt_j. \quad (23)$$

In other words, the increase in social welfare due to a marginal reduction in travel time is equal to the value of the time savings ( $dt_j < 0$ ) multiplied by the number of trips benefiting from that improvement.

Expressions (19) and (23) are derived by considering marginal changes with respect to the situation without the project. When the effect of a transport project is not marginal, the change in social welfare can be directly approached as the change in consumer's utility with the project with respect to the counterfactual. In our model, this change in social welfare is, thus, given by:

$$\Delta W = \Delta V = V(g^1, y^{g^1}) - V(g^0, y^{g^0}), \quad (24)$$

where superscript 1 indicates 'with the project' and superscript 0 denotes 'without the project'. Thus, the social benefit of the project is expressed as the difference in the individual's utility with and without the project.

Although this utility is not directly measurable, expression (24) 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 due to the project, we obtain a monetary measure of the change in his utility. This is the so-called 'compensating variation' ( $CV$ ), which can be also 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:

$$V(g^1, y^{g^1} - CV) = V(g^0, y^{g^0}). \quad (25)$$

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:

$$\Delta W = CV = \Delta WTP - \Delta Resources. \quad (26)$$

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. This is not important although, given the position of a generalized demand curve, 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 generated demand. For the existing traffic, the  $WTP$  (including time) has not changed and thus we can consider the value of time savings as a (positive) change in resources.

Suppose the representative individual is asked for his  $WTP$  for the transport project disregarding any effects on his profits income. Then, the maximum  $WTP$ ,  $CV$ , as defined in expression (25), and the new partial one, denoted by  $CV^P$  are given by:

$$CV = CV^P + \Delta PS, \quad (27)$$

where  $\Delta PS$  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 ( $CS$ ),<sup>10</sup> and then:

$$\Delta W = CV \approx \Delta CS + \Delta PS, \quad (28)$$

that is, social welfare changes can be approximated through the sum of the changes in the surpluses of consumers and producers affected by the project.

### 3. Practical rules for cost-benefit analysis

So far, we have described the foundations of the two main theoretical approaches to measure the net benefits of transport projects: adding the changes in  $WTP$  and the use of resources or adding the changes in consumers' and producers' surpluses. However, expressions (24) to (28) can be generalized to include other roles of the individual in the society. A practical disaggregation is to consider three owners of production factors: first, the 'owners of capital' ( $O$ ), generally called producers, who have a variety of equipment, infrastructure and facilities where goods and services are produced; second, the 'owners of labour' ( $L$ ) including for simplicity employees of different skills and productivity levels, and the landowners ( $R$ ).

The fixed factor 'land' is restricted here to soil for agriculture or land for residential or productive uses. We differentiate the 'landowners' ( $R$ ) from the common property of natural and environmental resources (also called 'natural capital'). Natural and environmental resources such as climate, water, air, flora and fauna and landscapes, which may be affected by projects, are included in 'rest of society' ( $E$ ). Adding consumers ( $C$ ) and taxpayers ( $G$ ), six roles for the representative individual are identified for

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<sup>10</sup> 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 the change in consumer surplus with respect to income, is small enough (Willig, 1976).

evaluation purposes (de Rus, 2021). The rationale for this disaggregation is both for minimizing the risk of double counting and for equity consideration.<sup>11</sup>

Following Johansson (1993), the individual's indirect utility function is now given by  $V(p, t, w, \Pi, \tau, z)$ , where  $p = (p_1, \dots, p_n)$  is the vector of market prices,  $t = (t_1, \dots, t_n)$  is the vector of the time required for consuming each good or service,  $w$  is the wage,  $\Pi$  is firms' profits,  $\tau$  is a lump-sum tax, and  $z$  represents a set of natural resources.

In this setup, the change in social welfare due to a transport project (which implies a reduction in transport generalized price) is given by:

$$\Delta W = \Delta V = V(p^1, t^1, w^1, \Pi^1, \tau^1, z^1) - V(p^0, t^0, w^0, \Pi^0, \tau^0, z^0), \quad (29)$$

and using the concept of compensating variation, we have that:

$$V(p^1, t^1, w^1, \Pi^1, \tau^1, z^1 - CV) = V(p^0, t^0, w^0, \Pi^0, \tau^0, z^0), \quad (30)$$

with:

$$CV = CV^P + \Delta OS + \Delta LS + \Delta RS + \Delta GS + \Delta E, \quad (31)$$

where  $CV^P$  can be approximated by changes in consumers' surplus;  $\Delta OS$  is the change in firm's revenues minus variable costs;  $\Delta LS$  refers to the change in workers' surplus;  $\Delta RS$  is the landowners' surplus, 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;  $\Delta GS$  is the change in taxpayers' surplus, equals tax revenues minus public expenditure; and  $\Delta E$  is the change in the surplus of the 'rest of society', i.e., the value of the externality minus the compensations received (if any).

Finally, adding the changes in surpluses, the income transfers net out and it is easy to show that the result is again equal to the change in *WTP* minus (plus) the value of the diverted (saved) goods and labour from other uses and the negative (or positive) external effects:<sup>12</sup>

$$\Delta W = \Delta CS + \Delta OS + \Delta LS + \Delta RS + \Delta GS + \Delta ES = \Delta WTP - \Delta Resources. \quad (32)$$

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<sup>11</sup> Important practical issues arise if capital or land are in foreign ownership and the scope of the CBA is considered to be a national one. This paper assumes a closed economy (see Johansson and de Rus, 2019).

<sup>12</sup> Notice that an external effect is a change in resources.

### 3.1. Guidelines for the measurement of the direct effects

For the sake of simplicity, consider a transport project without investment costs. The change in welfare with the project is measured with  $g(x)$ , the market inverse derived demand function for a transport activity in terms of its generalized price. The initial equilibrium is  $(g^0, x^0)$  and marginal operating costs are constant and equal to  $C$ . With the project, the generalized price of transport is reduced to  $g^1$ , and the number of trips increases to  $x^1$ .

Once the benefits and costs of the project are identified, the practitioner has to choose one of the available alternative approaches for the measurement of those costs and benefits. A clear understanding of the chosen method avoids common errors that may lead to the overestimation or underestimation of the net benefit.<sup>13</sup>

Adding the change in surpluses (expression 32) is straightforward and provides more information, but it is difficult to be applied in practice given the data usually available and the difficulty of the *ex ante* identification of the final beneficiaries. This leads to the following policy recommendation:

***Policy recommendation 1:** Although it, in principle, provides information on the distribution of benefits and cost, in practice the approach based on the sum of the change in the different agents' surpluses may be difficult or even misleading, due to lack of data and/or the difficulty to ex ante identify the final beneficiaries.*

The alternative consists in identifying and measuring the changes in *WTP* and resources, and though it seems, at first sight, easier, it has some pitfalls associated with its use.

CBA guidelines usually present a single graph for the transport mode directly affected by the project, showing the change in the generalized price and quantities, decomposed in benefits for the existing traffic and for deviated and generated demand. The analysis may look multimodal when deviated traffic is included but in practice is prone to errors when price deviates from marginal cost in other modes or activities where generated traffic comes from. This fact leads to the following policy recommendation.

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<sup>13</sup> There are all sorts of measurement/prediction errors, which apply to both methods (Mackie and Preston, 1998).

***Policy recommendation 2:*** *When generated demand is not significant or prices are equal to marginal social costs in the routes, times, transport modes or activity where the users come from, the single graph or unimodal analysis is enough.*

One easy way to proceed when in other affected parts of the transport system prices are not equal to marginal social costs is to consider a unique corridor where all transport alternatives operate and then add the changes in the surpluses of all the affected agents - expression (32)- and modes. Alternatively, using the change in *WTP* and resources, the corridor assumption is very helpful in the presence of taxes or market power. In a corridor between A and B, there is no change in *WTP* (no change in quality is assumed for simplicity) because the *WTP* depends on the purpose of the trip and it is not necessarily affected by the change of route, time or mode under the assumption of constant quality (transport is commonly a derived demand).

Therefore, the change from  $g^0$  to  $g^1$  only translates into the use of new resources absorbed by the project and the saving (substitutes) and consumption (complements) of additional resources in the rest of the modes affected within the corridor. This is even so in the case of generated demand coming from other consumption activities (and, hence, these activities need to be included in our corridor. In the initial equilibrium, the marginal unit of generated demand was indifferent between travelling and the other consumption activities, so the treatment is identical to any transport mode. As the effects in many secondary markets can be of different signs and many of them are simple relocation (OECD, 2007), the sensible way to proceed is to follow the corridor (or multimodal) analysis including some reasonable assumptions based on the best information available on the source of the generated traffic coming outside the transport market. All these ideas can be summarized in the following policy recommendation.

***Policy recommendation 3:*** *When there exist different tax rates, market power or any other distortion in alternative transport modes or activities, and since the effects in many secondary markets can be of different signs and many of them are simple relocation of economic activity, the corridor analysis is recommended.*

Hence, we can summarize the two alternative approaches: the first one, adding the surpluses of all the agents involved in all transport modes, and some other economic activities affected by the project. Nevertheless, when the price is equal to marginal cost in the rest of the economy, it is correct to concentrate only on the mode directly affected by the change in the generalized price, disregarding intermodal effects.

When the practitioner decides to follow the change in *WTP* and resources, ignoring transfers, there are two options: (i) the conventional single graph analysis, common to



many CBA guidelines, where the *WTP* is constant for existing users (assuming quality to be constant) but there is an increase in *WTP* of deviated and generated demand. In this case, we have to add any distortion (e.g. loss of profits or taxes) in the other modes and economic activities affected by the change in the primary market. In this case, it is incorrect to include the change in resources used or saved in the secondary markets. Moreover, if the practitioner ignores the effects due to taxes and market-power in the other modes and economic activities, there is a measurement error . (ii) The corridor analysis, where the change in *WTP* is limited to any change in quality or safety and only changes in resources are accounted for. In this case, the practitioner should include any change in resources used or saved in the original transport mode and any other included in the corridor. See **Appendix A** for a formal proof of the equivalence of the different approaches.

The distinction between the surpluses of different agents in expression (31) and (32) shows the difficulty of identifying *ex ante* the final beneficiaries of the transport improvement. The explicit consideration of a fixed factor (such as land) in the social surplus expression may help in the understanding of one of the main sources of double counting in transport appraisal, helping also to clarify the distribution of the social surplus. It is well known that land can capitalize most of the benefits of transport improvements. In the case of an infinitely elastic supply of homogeneous workers, the surplus of each group in expression (32), government surplus excepted, would be zero and the landowners would take the total surplus through higher land prices. This leads to another practical conclusion.

*Policy recommendation 4: It is easier to calculate the change in WTP and the change in resources than the actual distribution of the social surplus. The practitioner distinction between user and producer surplus may be quite different to the final beneficiaries of transport projects. The explicit consideration of land in the appraisal framework may also reduce the risk of double counting.*

Furthermore, Collier and Venables (2018) have shown that with heterogeneity, both in labour productivity and demand for housing, workers can gain a significant part of the surplus. The implication for the economic evaluation of transport improvements is that although a project increased the land value around the locations affected by the improvement, only in some extreme cases this increase would reflect the total benefits of the projects because a share of those benefits is captured by workers.

Thus, the conclusion that transport benefits could be measured in a competitive land market when this market is not affected by bubbles and speculation or any other exogenous factors only holds under some restrictive conditions. The following two policy

recommendations highlight the importance of avoiding rules of thumb from different sources and the combined use of different approaches.

***Policy recommendation 5:** The practitioner should be careful avoiding the combined use of the three possible approaches: change in surpluses, change in WTP and resources, or the increase in land prices.*

***Policy recommendation 6:** An analytical approach is required. Although the alternative methods aimed to measure the change in social welfare are equivalent, when practical rules are not supported by a robust theoretical framework, there is an avoidable high risk of double counting or measurement errors.*

### 3.2. Rules for the use of shadow prices

The social benefits achieved through the reduction of the generalized price of transport are not free. These benefits have an opportunity cost that is measured by the value of resources diverted from other uses to the project. This section deals with the inputs needed for the transport project and how to value them.<sup>14</sup>

The effects of a transport project on social welfare can be expressed as the maximum income the affected individuals are willing to pay to enjoy the corresponding benefits, net of the project costs. This is the value of the sum of the compensating variations (CV) as in the left-hand side of expression (32) for all the individuals of the society, which is net of project costs. The aggregation of the CV is then the sum of the individuals' WTP for the benefits of the project (positive sign) and the willingness to accept for giving up other goods to achieve those benefits (negative sign). This net value is approached with the right-hand side of expression (32).

Thus, the social opportunity cost of the project ( $C_j$ ) can be defined as the value of all the goods the society has to give up when those resources are deviated from other uses to implement the project, i.e., to enjoy the utility of good  $j$  (e.g., a faster transport service), as formally represented by:

$$C_j = \sum_{k=1}^s p_k dx_k, \quad (33)$$

an expression derived from the model in **Section 2**, with  $s \leq n$  goods or services, and where the only input, labour, is fully utilized to produce and consume goods and assuming that market prices reflect the value of the goods deviated to the project.

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<sup>14</sup> See Johansson (1993) and de Rus (2021). In particular, the section deals with inputs that can be purchased in markets. Non-market resources are not discussed here.

The problem is that this expression is not very useful for computing the net social benefit of a project. The practitioner generally does not know which goods (schools, housing, leisure facilities, etc.) the society gives up to achieve the benefits of the project under assessment. However, there is a way to circumvent this problem. To do so, we now consider that the production of any of the goods in this expression,  $x_k$ , requires labour, and the corresponding production function is then given by:

$$x_k = f_k(l_k), \quad (34)$$

whose total differential shows that any output variation depends on the change in the quantity of the input multiplied by its marginal productivity:

$$dx_k = \frac{df_k(l_k)}{dl_k} dl_k. \quad (35)$$

Replacing (35) in (33) and recalling that any profit maximizing firm uses additional units of input until its market price equals the value of its marginal productivity,  $w = p_k \frac{df_k(l_k)}{dl_k}$  (see expression (4) in Section 2), the cost of the project can be expressed as:

$$C_j = \sum_{k=1}^S w dl_k. \quad (36)$$

The cost of the project initially expressed in (33) as the social value of the diverted goods, to get the good provided by the project appears now in (36) as the quantity of labour required to produce those goods,  $dl_k$ , multiplied by the price of labour,  $w$ .

In practice, the validity and usefulness of expression (36) for identifying and assessing the costs of a project are conditioned by three underlying assumptions. Firstly, all the changes in input markets (in our case, labour market) are marginal; secondly, input markets are perfectly competitive, without distortions (such as indirect or income taxes); and thirdly, all the resources are fully utilized. Nevertheless, once these assumptions are abandoned to deal with more realistic project assessment situations (that include, among others, the presence of subsidies or taxes, or the use of unemployed labour in the project), expression (36) is no longer valid to calculate the opportunity cost of the project.

***Policy recommendation 7:** Shadow pricing consists of adjusting market prices to reflect the true social opportunity cost; the practitioner should be careful since this adjustment only applies in the change in WTP and resources approach.*

Recall that in our model we are considering that there is only one input: labour. Although in actual projects there may be more inputs (a transport project typically requires the use of some produced goods, such as vehicles, energy, spare parts, and other

materials),<sup>15</sup> the analysis of the shadow price of labour is virtually the same as the one applied to other inputs. Therefore, we will restrict our discussion to the shadow price of labour.

Labour is required in the design and construction of transport infrastructure, in its maintenance and operation, and in the provision of transport services using that infrastructure. The opportunity cost of labour in expression (36) is valued at its market price,  $w$ , but again this is only valid under several restrictive assumptions that usually do not hold in actual project assessments, particularly with unemployment. Thus, once the amount of labour required for the project is known, the next step is to identify where this input comes from. Suppose now that we refer to labour as the number of workers required for the project. In the analysis of the shadow price of labour it is advisable to distinguish three main possible sources of the labour demanded by a project: (a) workers already employed in other productive activities; (b) voluntarily unemployed at the current wage; and (c) involuntarily unemployed, willing to work at the current wage.

We will assume that the project will have a significant effect on the demand for labour and that there is a proportional income tax,  $\tau_w$ . Initially, without the project, the labour market is in equilibrium with the supply ( $S$ ) and demand ( $D^0$ ) determining a wage rate of  $w^0$  and a quantity of labour of  $L^0$ . The existence of a proportional income tax ( $\tau_w$ ) introduces a distinction between the market supply function ( $S$ ) and the opportunity cost of the labour supplier,  $S(1-\tau_w)$ . The function  $S(1-\tau_w)$  shows the marginal value of leisure to the workers and the demand function is the value of the marginal productivity of labour for the firm. At the equilibrium wage rate ( $w^0$ ), the value of the marginal productivity of labour for the firm is equal to the value of leisure for the marginal worker plus the income tax.

With the project, the demand for labour shifts from  $D^0$  to  $D^1$ , the wage rate goes up to  $w^1$  and the private demand for labour goes down until  $w^1$  is equal to the value of the marginal productivity of labour. The increase in the wage rate has also the effect of increasing the number of workers willing to work at this higher wage rate, and the equilibrium number of workers goes up. Now, we can calculate the opportunity cost of labour. The project needs  $dL$  units of labour. This quantity of labour required by the project has two components: new workers ( $dL_n$ ) that are willing to work at the new equilibrium wage, and workers already employed in the private sector ( $dL_p$ ), who shift to the project at the higher wage  $w^1$ . The opportunity cost of previously voluntarily unemployed

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<sup>15</sup> Note that the distinction between goods and inputs is somehow blurred in practice as the inputs to be purchased for the project, are indeed produced inputs (i.e., goods). Nevertheless, the distinction is useful for the discussion of the shadow price of inputs when those inputs deviate from the private sector.

workers ( $dL_n$ ), is the value of leisure forgone when they accept the new jobs. They are paid  $w^1(1 - \tau_w)dL_n$ , and their social opportunity cost is:

$$\left[ \frac{1}{2}(w^0 + w^1)(1 - \tau_w) \right] dL_n. \quad (37)$$

The opportunity cost of those already working in the private sector ( $dL_p$ ), who shift to the project at the higher wage  $w^1$ , is also  $w^1(1 - \tau_w)$ . However, the social opportunity cost of these workers is higher than the former expression and equal to the lost value of their marginal productivity in the private sector when the amount of labour ( $dL_p$ ) shifts to the project. They are paid  $w^1(1 - \tau_w)dL_p$ , but the social opportunity cost of these workers is, in principle:

$$\frac{1}{2}(w^0 + w^1)dL_p. \quad (38)$$

This is the opportunity cost of the deviated labour when  $w$  represents the unit cost of labour for the firm. In the case of a proportional social security contribution paid by employers ( $\alpha_w$ ) plus the existence of *ad valorem* indirect taxes (e.g., VAT) levied on the product market, the shadow price of the deviated labour has to reflect the social value lost as a consequence of displacing labour from other productive activities. This includes the tax revenues and any other charges lost in the process. The shadow price of labour is in this latter case:

$$(1 + \theta)(1 + \alpha_w) \left[ \frac{1}{2}(w^0 + w^1)dL_p \right]. \quad (39)$$

When the labour of the project is involuntarily unemployed, willing to work at the current wage, the supply has an infinite elasticity showing that the workers are willing to work at the equilibrium wage if they are hired by the firms. At the level of demand  $D^0$  there is involuntary unemployment. The project shifts the demand for labour from  $D^0$  to  $D^1$ . The project requires  $dL_n$  units of labour and this amount is supplied without any change in the initial wage rate. We assume here the existence of unemployment benefits equal to  $u$  and a proportional income tax ( $\tau_w$ ) if the individual accepts the job.

It is useful to distinguish between the worker opportunity cost and the social opportunity cost. When the worker receives unemployment benefits equal to  $u$ , and there is a proportional income tax ( $\tau_w$ ), the worker's reservation wage is  $w^0$  (he is not willing to work for less than this wage), so the workers' payment is equal to the value of leisure plus the unemployment benefits ( $u$ ) and the income tax ( $\tau_w$ ) the worker must pay if he accepts the job.

The individual opportunity cost is the value of leisure  $[w^0(1 - \tau_w) - u]$  plus the unemployment benefits ( $u$ ). However, the social opportunity cost does not include the unemployment benefits (which is a mere transfer) as a cost of the project because the real loss in resources when the individual is employed is simply the marginal value of leisure. The shadow price of labour is then  $w^0(1 - \tau_w) - u$ , and the social cost of these workers for the project is  $[w^0(1 - \tau_w) - u]dL_n$ .<sup>16</sup> Both values, private and social opportunity costs ( $[w^0(1 - \tau_w)]$  and  $[w^0(1 - \tau_w) - u]$ , respectively), can be used in the economic evaluation of projects. The point is to be consistent with the chosen approach, as highlighted in the following policy recommendation

***Policy recommendation 8:** In the case of adding the change in surpluses, the private opportunity cost is what matters, and the shadow price should be ignored, whereas the social opportunity cost must be used when the approach followed is the change in WTP and resources.*

For the sake of exposition, we assume that the project's good is provided free of charge. Let us add the change in surpluses: the change in consumer surplus is the total WTP, and the capital owners' surplus is equal to  $-w^0dL_n$ . Notice that there is no change in worker surplus as they are paid their private opportunity cost. Finally, the taxpayer surplus increases in the income tax collected  $\tau_w w^0dL_n$  and the unemployment benefit payments avoided  $udL_n$ . Therefore, the net social surplus is equal to the change in consumer surplus (WTP for the good provided by the project) plus the change in the capital owners' surplus ( $-w^0dL_n$ ) plus the change in taxpayer surplus  $(\tau_w w^0 + u)dL_n$ ; i.e., the change in WTP minus the social cost of the project,  $[w^0(1 - \tau_w) - u]dL_n$ .

### **3.3. Indirect benefits and wider economic benefits of transport projects. What to do?**

This section has no intention to review or comprehensively discuss the issue of indirect effects and wider economic benefits (WEBs). On the contrary, it only tries to warn of the risk of generalizing some empirical results, which are context-specific and of the unidirectional use of the economies of agglomeration; and also, of the use of any kind of additional benefits to justify projects with poor social value. This is also the case with CGE models looking for the total impact of the intervention instead of its incremental effect compared with the general equilibrium effect of the contrafactual.

***Policy recommendation 9:** Indirect effects and WEBs are context-specific, and the practitioner should avoid the undue generalization of previous empirical results. There are some general principles to avoid a mechanical and may be misleading use of WEBs.*

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<sup>16</sup> Assuming a shadow price of public funds equal to one.

The idea of the indirect effect is straightforward and have already been discussed in the treatment of the measurement of the direct benefits and the multimodal effects. The welfare effects of transport improvements should not ignore the possibility of significant indirect effects, beyond transfers and relocation, and even the presence of WEBs. The spatial nature of transport introduces other benefits from increases in productivity through different mechanisms, such as industrial reorganization and also changes in land use. In any case, the qualifications about the calculation of the social surplus using expression (32) still apply.

Indirect effects and WEBs need some market distortion to play some influence in the economic evaluation of projects. The effects of transport improvements in secondary markets can be ignored if the rest of the economy is perfectly competitive. The indirect effects in transport projects go from intermodal effects to the impacts on some secondary markets. In both cases, the products of the secondary markets are complements or substitutes of the primary transport market. The treatment of these so-called 'indirect effects' is similar for any secondary market (Harberger, 1965; Mohring, 1971).

The common practice is to ignore the indirect effects, under the assumption of perfectly competitive markets, or the existence of different effects in the economy, and the similar second-order general equilibrium effect of alternative investments. Intermodal effects could be treated within an integrated primary transport market (see **Subsection 3.1**), or if considered as separated markets, included carefully in the economic evaluation through the different approaches considered in **Subsection 3.1**. The intermodal secondary effects can be positive or negative depending on the sign of the distortion and the cross elasticity, but in the case of optimal pricing, like road congestion pricing or optimally designed airport congestion charges, there are no additional benefits (or costs) in these markets.

Changes in proximity derived from transport investments can cause increases in productivity through different mechanisms linked to the economies of agglomeration or changes in land use (see Venables, 2007; Laird *et al.*, 2014; Graham and Gibbons, 2019). These are the WEBs, and the risk, in this case, is to confuse relocation with growth. Relocation occurs when some benefits of the project come from deviation of the economic activity somewhere else, without any change in productivity, while growth occurs when the project adds value to the economy.

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

From this line of reasoning, it is clear that there may be consequences of transport investment that relate specifically to agglomeration. The rationale is that if there are increasing returns to spatial concentration, and if transport improvements partially explain the level of concentration or density experienced by firms and workers, then investment in transport may induce productivity gains thanks to the positive externalities of agglomeration.

Conventional CBA may underestimate the benefits of large infrastructure projects if economies of agglomeration are significant. This calls for its inclusion together with the direct user benefits. At the same time, the recent popularity of WEBs, as well as the use of impact studies, may also be revealing the interest of promoters to get the approval of projects with modest direct benefits. There are some general principles to avoid a mechanical and may be misleading use of WEBs (Venables, 2019): (i) Narrative: there should be a clear narrative of the main problem that policy is intended to address and the key market failure(s) that motivate the policy; (ii) transparency: the mechanisms underpinning both the quantity changes and their social value should be clear and explained in a manner that enables the key magnitudes to be understood from straightforward back-of-the-envelope calculation; (iii) sensitivity: there should be an analysis of the dependence of the quantity effects and their valuation on key assumptions about the economic environment. Scenarios outlining the quantitative importance of failure of these assumptions should be outlined; (iv) complementary policies: there should be a thorough consideration of complementary measures that are needed for a successful implementation of a project; (v) alternatives: any project should make a strong case that it provides the most cost-effective way to solve the main problem described in the narrative.

A practical approach for small projects is to work under the assumption that the WEBs are inexistent or unimportant. Although this approach faces the risk of ignoring them in the case where they are significant, there is consensus on the fact that this is a trade-off between the risk of ignoring a real effect and the risk of double counting and unnecessary delays in project evaluation. For large projects or for the evaluation of investment programmes it may be justified to undertake more complex analyses, though they may have problems detecting the direction of causality. In addition, there is some confusion about whether these studies measure wider economic effects, ignored in standard CBA, or whether they only measure the final impact of the direct effects already measured. All these ideas are summarized in the following policy recommendation.

***Policy recommendation 10:*** *A practical approach for small projects is to work under the assumption that the WEBs are inexistent or unimportant. For large projects or for the evaluation of investment programmes it may be justified to undertake more complex analyses.*



From the available empirical evidence and the evaluation of the experts on whether conventional CBA is sufficient to estimate the social profitability of a project, the general recommendation is to be extremely cautious since, although economists are advancing with the knowledge and measurement of WEBs, they are still far from turning the results into practical rules for their inclusion in CBA. It does not seem reasonable to transfer the results from other studies, using conversion factors or similar procedures, considering the variability of the value of wider economic effects, and even the sign when there are some negative effects like congestion and similar externalities. Moreover, when investment induces agglomeration, it may also induce additional negative externalities not fully captured in the analysis, as the negative political and social consequences of territorial inequalities (Rodriguez-Pose, 2018).

#### 4. The equivalence of the different approaches: an empirical illustration

This section aims to show the equivalence of the different approaches to evaluate changes in social welfare due to a transport project: the change in surpluses approach, the change in *WTP* and resources approach considering the unimodal or single graph analysis, and the change in *WTP* and resources approach considering the multimodal or the corridor analysis.

For this purpose, we use a stylized case that considers a rail project consisting of constructing and operating a new high-speed rail line (HSR) connecting two cities (*A* and *B*) by upgrading existing conventional infrastructure. The total length of the corridor is 400 km (by rail), and the cities are also served by air and road (cars and buses). Once the HSR line is in operation, the conventional train services will be discontinued. HSR is vertically unbundled and operated by two different companies: the infrastructure manager and the railways' operator.

We assume that construction works last from year 1 to year 5 and that the new infrastructure will be operative in year 6. The social net present value (NPV) of this project is calculated at the beginning of year 1, with an evaluation horizon of 30 years and using a social discount rate of 3%. All the benefits and costs are located at the end of the year. The project will be compared against a 'do-nothing' alternative, where the described corridor continues to be served by the four initial modes with the conventional train substituted by the HSR. Parameters are summarized in **Tables B.1** and **B.2** in **Appendix B**.<sup>17</sup>

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<sup>17</sup> This empirical illustration is roughly based on data from a Spanish line (de Rus et al., 2020; UIC, 2018; Campos and de Rus, 2009).

To show the equivalence of the alternative ways that can be followed in the evaluation, **Table 1** displays the changes in surpluses approach, whereas **Table 2 and Table 3** provide the results for the change in *WTP* and resources approach, considering the unimodal or single graph and the multimodal or the corridor analysis, respectively.

The use of one of these tables as a snapshot of how to guide the measurement of benefits and costs and, of course, for the presentation of results, depends essentially on data availability. Table 1 has the advantage of providing more information on the disaggregation of benefits and costs, but it is more demanding in terms of the information required. Table 2 is quite intuitive if multimodal effects are significant and it is difficult to trace the final winners and losers. Table 3 represents the easiest way to approach the appraisal when the effects on the rest of the economy can be safely ignored. Finally, when the information allows doing so, it is worth using the three ways simultaneously to minimize the probability of committing errors during the evaluation process: the final NPV has to be identical in the three tables.

**Table 1. CBA of the HRS line: Change in surpluses (thousands of €)**

(1)	<b>Consumer surplus of HSR users from:</b>	<b>1,246,668</b>
(2)	conventional train	604,568
(3)	air transport	452,408
(4)	bus	40,956
(5)	car	101,517
(6)	generated	47,219
(7)	<b>Owners of capital surplus</b>	<b>-4,595,515</b>
(8)	<i>HSR operator</i>	748,544
(9)	Revenues from:	4,974,567
(10)	conventional train	1,989,827
(11)	air transport	1,243,642
(12)	bus	497,457
(13)	car	994,913
(14)	generated	248,728
(15)	Rolling stock acquisition + operation and maintenance	-3,243,292
(16)	Infrastructure charges	-982,731
(17)	<i>Infrastructure manager</i>	-5,344,059
(18)	Infrastructure investment	-5,495,649
(19)	Infrastructure charges	982,731
(20)	Infrastructure operation and maintenance costs	-831,141
(21)	<i>Other transport modes</i>	0
(22)	Cost saved	4,064,241
(23)	conventional train	1,193,896
(24)	air transport	1,492,370
(25)	bus	248,728
(26)	car	926,035
(27)	generated	203,212
(28)	Revenues lost	-4,064,241
(29)	conventional train	-1,193,896
(30)	air transport	-1,492,370
(31)	bus	-248,728
(32)	car	-926,035
(33)	generated	-203,212
(34)	<b>Taxpayer surplus</b>	<b>748,332</b>
(35)	<i>Investment</i>	732,753
(36)	<i>Infrastructure operation and maintenance</i>	56,358
(37)	<i>Rolling stock acquisition + operation and maintenance</i>	63,143
(38)	<i>Taxes from other activities</i>	-601,379
(39)	conventional train	-119,390
(40)	air transport	-149,237
(41)	bus	-24,873
(42)	car	-277,810
(43)	generated	-30,069
(44)	<i>HSR taxes from</i>	497,457
(45)	conventional train	198,983
(46)	air transport	124,364
(47)	bus	49,746
(48)	car	99,491
(49)	generated	24,873
(50)	<b>Rest of society surplus</b>	<b>724,458</b>
(51)	$(1)+(7)+(34)+(50)$ NPV	-1,876,056

**Table 2. CBA of the HRS line: Change in *WTP* and resources (unimodal or single graph)  
(thousands of €)**

(52)	<b>Existing demand (conventional train)</b>	<b>2,673,988</b>
(53) = (2)+(10)+(29)+(39)+(45)	Time savings	1,480,092
(54) = (23)	Cost savings	1,193,896
(55)	<b>Change in <i>WTP</i> of users from:</b>	<b>9,846,139</b>
(56)	air transport	5,395,488
(57)	bus	1,064,834
(58)	car	2,625,952
(59)	generated	759,865
(60)	<b>Time costs of users from:</b>	<b>-5,920,825</b>
(61)	air transport	-3,575,074
(62)	bus	-476,677
(63)	car	-1,430,030
(64)	generated	-439,044
(65)	<b>Taxes in other modes:</b>	<b>242,469</b>
(66)	air transport	-149,237
(67)	bus	-24,873
(68)	car	-277,810
(69)	generated	-30,069
(70) = (50)	<b>Accident costs</b>	<b>724,458</b>
(71) = (18)+(35)	<b>Investment</b>	<b>-4,762,895</b>
(72) = (20)+(36)	<b>Infrastructure operation and maintenance</b>	<b>-774,783</b>
(73)	<b>Rolling stock acquisition</b>	<b>-315,714</b>
(74)	<b>Rolling stock operation and maintenance</b>	<b>-2,864,436</b>
(75) = (52)+(55)+(60)+(65)+(71)+(72)+(73)+(74)	NPV	-1,876,056

Other equivalences between the data provided in Table 1 and 2 are as follows:

$$(56)+(61)+(66) = (3)+(11)+(24)+(30)+(40)+(46),$$

$$(57)+(62)+(67) = (4)+(12)+(25)+(31)+(41)+(47),$$

$$(58)+(63)+(68) = (5)+(13)+(26)+(32)+(42)+(48),$$

$$(59)+(64)+(69) = (6)+(14)+(27)+(33)+(43)+(49),$$

$$(73)+(74) = (15)+(37).$$

**Table 3. CBA of the HRS line: Change in *WTP* and resources  
(multimodal or corridor)  
(thousands of €)**

(76)	<b>Time savings of users from:</b>	<b>2,053,072</b>
(77) = (2)+(10)+(29)+(39)+(45) = (53)	conventional train	1,480,092
(78) = (3)+(11)+(30)+(40)+(46)	air transport	178,807
(79) = (4)+(12)+(31)+(41)+(47)	bus	314,557
(80) = (5)+(13)+(32)+(42)+(48)	car	-7,923
(81) = (6)+(14)+(33)+(43)+(49)	generated	87,539
<b>(82)</b>	<b>Costs savings from:</b>	<b>4,064,241</b>
(83) = (23) = (54)	conventional train	1,193,896
(84) = (24)	air transport	1,492,370
(85) = (25)	bus	248,728
(86) = (26)	car	926,035
(87) = (27)	generated	203,212
<b>(88) = (50) = (70)</b>	<b>Accident costs</b>	<b>724,458</b>
<b>(89) = (18)+(35) = (71)</b>	<b>Infrastructure investment</b>	<b>-4,762,895</b>
<b>(90) = (20)+(36) = (72)</b>	<b>Infrastructure operation and maintenance</b>	<b>-774,783</b>
<b>(91)</b>	<b>Rolling stock acquisition</b>	<b>-315,714</b>
<b>(92)</b>	<b>Rolling stock operation and maintenance</b>	<b>-2,864,436</b>
(93) = (76)+(82)+(88)+(89)+(90)+(91)+(92)	NPV	-1,876,056

Other equivalences between the data provided in Table 2 and 3 is as follows:

- (78)+(84) = (56)+(61)+(66),  
 (79)+(85) = (57)+(62)+(67),  
 (80)+(86) = (58)+(63)+(68),  
 (81)+(87) = (59)+(64)+(69),  
 (91)+(92) = (73)+(74) = (15)+(37).

## 5. Conclusions

The economic evaluation of transport projects is well developed and there is a rich sample of applications by transport modes and policies. This paper aims to stress the importance of following an analytical approach in the evaluation of transport projects, instead of the mechanical application of the common rules of thumb applied in national or supranational main CBA analysis guidelines.

There are two key approaches for the calculation of the economic profitability of a project. One is based on the aggregation of the changes of the economic surpluses of the different groups in the society. Alternatively, the practitioner may ignore transfers between groups and concentrate on the change in willingness to pay and the use of resources with the project compared with the counterfactual. Both approaches lead to the same result but once the practitioner chooses one of them, the method must be strictly followed.

It is quite frequent that, due to lack of data and the difficulty to *ex ante* identify the final beneficiaries, the second approach is followed. In this case, there are two alternative options, especially relevant when, as usual, other modes or activities are subject to distortions, such as taxes or market power. These options are what we call the single graph analysis (unimodal), or the corridor analysis (multimodal). In the first one, the analyst can concentrate the effort on the primary market, adding the effects on taxes or market power in the secondary markets. In the second one, the multimodal or the corridor analysis, these effects can be overlooked and only changes in resources within the transport corridor are accounted for. Therefore, when generated demand is not significant or the price is equal to the social marginal cost in other transport modes or activities, the single graph is a good option. However, when there exist taxes or market power in other transport modes or activities, the corridor analysis is highly recommended.

In a nutshell, before applying any set of practical rules for the economic evaluation of any project, the practitioner should know the analytical model behind those rules, and whether the application of those rules is consistent with such a model, avoiding the combined use of different rules from different approaches.

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## Appendix A. Equivalence of the different approaches

Let us formally prove the equivalence of the different approaches. Consider a market with  $n$  modes of transport or activities, where a transport project reduces the generalized price of mode  $i$  ( $g_i^1 < g_i^0$ ) because of a reduction in travel time ( $t_i^1 < t_i^0$ ). Travel time includes access, waiting, in-vehicle and egress time. Note that, although there is a reduction in generalized price, it is possible to charge a higher price ( $p_i^1 > p_i^0$ ), though it must be lower than the reduction in the value of the time component. Let us denote by  $w_i$  the value of time of users initially travelling in mode  $i$ , by  $c_i$  the constant marginal operating cost of mode  $i$  (assumed to be different with the project), and by  $\tau_i$  the value of an *ad valorem* tax applied to mode  $i$ . Notice that, since there is an *ad valorem* tax, the price charged by producers ( $p_i^-$ ) does not coincide with the price paid by users ( $p_i$ ), where  $p_i = p_i^- (1 + \tau_i)$ .

We assume that the value of time for users initially choosing an alternative mode or activity  $j$  ( $w_j$ ) is different than the value of time for users initially travelling in mode  $i$ ; there are *ad valorem* taxes in all the alternatives ( $\tau_j$ ), so the price charged by producers ( $p_j^-$ ) does not coincide with the price paid by users ( $p_j$ ), where  $p_j = p_j^- (1 + \tau_j)$ ; and marginal operating cost is constant in each alternative mode or activity ( $c_j$ ), with  $j = 1, \dots, n$  and  $j \neq i$ . We also assume that alternative  $j$  generates an externality equal to  $E$  per passenger. Finally, income effects are not significant.

According to expression (32), the change in social welfare is the sum of the changes in surpluses of all the agents affected in all transport modes and in other economic activities, affected by the project, which can be easily calculated using the standard assumption of a linear approximation between the initial and the final generalized prices (the so called 'rule of a half').<sup>18</sup> We distinguish between existing traffic (users already travelling in mode  $i$ ), deviated traffic (users changing from an alternative mode with the project) and generated traffic (coming from other consumption activities). We follow the same procedure for deviated and generated demand since the former comes from other modes and the latter comes from other activities. Using the superscripts  $e$  and  $d$  to denote changes due to existing demand, and deviated and generated traffic from mode or activity  $j$ , respectively, the transport project implies a change in social welfare given by:

$$\Delta W = \Delta W^e + \sum_{\substack{j=1 \\ j \neq i}}^n \Delta W_j^d. \quad (\text{A1})$$

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<sup>18</sup> See Harberger (1965), Neuberger (1971) and Small (1999).

For existing demand ( $x_i^0$ ), the benefits of the project come from the change in consumer surplus of existing users, change in firm's revenues minus variable costs in this traffic and change in tax revenues (because of the price increase):<sup>19</sup>

$$\Delta CS^e = (g_i^0 - g_i^1)x_i^0 = (p_i^0 + w_i t_i^0)x_i^0 - (p_i^1 + w_i t_i^1)x_i^0, \quad (\text{A2})$$

$$\Delta OS^e = (p_i^{1-} - p_i^{0-})x_i^0 - (c_i^1 - c_i^0)x_i^0, \quad (\text{A3})$$

$$\Delta GS^e = \tau_i(p_i^{1-} - p_i^{0-})x_i^0, \quad (\text{A4})$$

$$\Delta ES^e = 0. \quad (\text{A5})$$

Hence, the change in social welfare due to the existing demand is given by:

$$\Delta W^e = \Delta CS^e + \Delta OS^e + \Delta GS^e + \Delta ES^e = w_i(t_i^0 - t_i^1)x_i^0 - (c_i^1 - c_i^0)x_i^0. \quad (\text{A6})$$

In the case of deviated traffic from mode or activity  $j$ ,  $g_j^0 = p_j + w_j t_j^0$  denotes the generalized price for the user indifferent between mode or activity  $j$  and mode  $i$  without the project, where  $t_j^0$  denotes the travel time of such an indifferent user. Notice that in the initial equilibrium  $g_j^0$  has to be equal to  $g_i^{0d} = p_i^0 + w_j t_i^0$ . All those users with generalised price in mode or activity  $j$  higher than the generalized price of the indifferent user  $g_j^0 = g_i^{0d}$  had chosen mode  $i$  instead of this alternative. On the contrary, all those users with generalised price in mode or activity  $j$  lower than the generalized price of the indifferent user  $g_j^0 = g_i^{0d}$  had chosen mode or alternative  $j$  instead of mode  $i$ . Once the project is implemented, the generalized price in mode  $i$  is reduced to  $g_i^{1d} = p_i^1 + w_j t_i^1$  and, due to this reduction, some users that preferred mode or activity  $j$  before the project now prefer mode  $i$ . Thus,  $x_j^d$  represents the deviated demand from mode or activity  $j$  to mode  $i$ , and total demand with the project ( $x_i^1$ ) is equal to  $x_i^0 + \sum_{j=1}^n x_j^d$ . Now, there is a new indifferent consumer, and his generalized price in the alternative is  $g_j^1 = p_j + w_j t_j^1$ , 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 than  $t_j^0$  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  $g_i^{1d} = p_i^1 + w_j t_i^1$  for the new one.

Adding the change in surpluses for deviated demand, the benefits of the project come from the change in consumer surplus of the deviated users from mode or activity  $j$  (linear approximation), change in firm's revenues minus variable costs (firms  $i$  and  $j$ ), change in

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<sup>19</sup> We assume no change in workers' surplus nor landowner' surplus.

collected taxes, and change in the surplus of the rest of society (equal to the value of the externality as, for simplicity, compensations are assumed to be zero).

$$\Delta CS_j^d = \frac{1}{2}(g_j^0 - g_i^{1d})x_j^d = \frac{1}{2}[(p_j + w_j t_j^0) - (p_i^1 + w_j t_i^1)]x_j^d, \quad (\text{A7})$$

$$\Delta OS_j^d = (p_i^{1-} - p_j^-)x_j^d - (c_i^1 - c_j)x_j^d, \quad (\text{A8})$$

$$\Delta GS_j^d = \tau_i p_i^{1-} x_j^d - \tau_j p_j^- x_j^d, \quad (\text{A9})$$

$$\Delta ES_j^d = -E x_j^d. \quad (\text{A10})$$

Hence, the change in social welfare due to the deviated demand from mode or activity  $j$  is:

$$\begin{aligned} \Delta W_j^d &= \Delta CS_j^d + \Delta OS_j^d + \Delta GS_j^d + \Delta ES_j^d = \\ &= \frac{1}{2}w_j(t_j^0 - t_i^1)x_j^d + \frac{1}{2}(p_i^1 - p_j)x_j^d - (c_i^1 - c_j)x_j^d - E x_j^d. \end{aligned} \quad (\text{A11})$$

Finally, following the change in surpluses approach, the change in social welfare for the whole traffic, adding **(A6)** and **(A11)** is:

$$\begin{aligned} \Delta W &= \Delta W^e + \sum_{\substack{j=1 \\ j \neq i}}^n \Delta W_j^d = \\ &= w_i(t_i^0 - t_i^1)x_i^0 - (c_i^1 - c_i^0)x_i^0 + \sum_{\substack{j=1 \\ j \neq i}}^n \left[ \frac{1}{2}w_j(t_j^0 - t_i^1)x_j^d + \frac{1}{2}(p_i^1 - p_j)x_j^d - (c_i^1 - c_j)x_j^d - \right. \\ &\quad \left. E x_j^d \right]. \end{aligned} \quad (\text{A12})$$

Adding the changes in  $WTP$  and resources following the unimodal or single graph analysis, the change in social welfare is equal to the change in  $WTP$  and the change in resources. First, for the existing demand, the change in  $WTP$  ( $\Delta WTP^e$ ) is zero, and the change in resources ( $\Delta Resources^e$ ) is equal to the value of the time invested (saved in our project because  $t_i^1 < t_i^0$ ) and the change in operating cost of existing trips, that is:

$$\Delta W^e = \Delta WTP^e - \Delta Resources^e = -w_i(t_i^1 - t_i^0)x_i^0 - (c_i^1 - c_i^0)x_i^0. \quad (\text{A13})$$

It is immediate to check that equations **(A6)** and **(A13)** coincide.

Second, the change in  $WTP$  and the change in resources due to the deviated demand from mode or activity  $j$  is equal to:

$$\Delta WTP_j^d - \Delta Resources_j^d = \frac{1}{2}(g_j^0 + g_i^{1d})x_j^d - w_j t_i^1 x_j^d - c_i^1 x_j^d - E x_j^d. \quad (\text{A14})$$

Expression **(A14)** shows the difference between the increase in the users' *WTP* for the new trips ( $\Delta WTP_j^d$ , deviated from mode or activity  $j$ ) and the resources required to obtain those benefits ( $\Delta Resources_j^d$ ), that is, the value of the time spent on the new trips and the operating cost of the new trips. Notice that expression **(A14)** does not coincide with the change in social welfare ( $\Delta W_j^d$ ) given by expression **(A11)**. There is a measurement error because the practitioner is ignoring the effects due to taxes in the other modes or economic activities. Adding such effects, the change in social welfare due to the deviated demand is given by:

$$\begin{aligned}
\Delta W_j^d &= \frac{1}{2}(g_j^0 + g_i^{1d})x_j^d - w_j t_i^1 x_j^d - c_i^1 x_j^d - E x_j^d - \tau_j p_j^- x_j^d \\
&= \frac{1}{2}(g_j^0 + g_i^{1d})x_j^d - w_j t_i^1 x_j^d - c_i^1 x_j^d - E x_j^d - (p_j - c_j)x_j^d = \\
&= \frac{1}{2}[(p_j + w_j t_j^0) + (p_i^1 + w_j t_i^1)]x_j^d - w_j t_i^1 x_j^d - c_i^1 x_j^d - E x_j^d - p_j x_j^d + c_j x_j^d = \\
&= \frac{1}{2}w_j(t_j^0 - t_i^1)x_j^d + \frac{1}{2}(p_i^1 - p_j)x_j^d - (c_i^1 - c_j)x_j^d - E x_j^d, \tag{A15}
\end{aligned}$$

which is equal to expression **(A11)**.

At this point we would like to highlight the importance of having a theoretical model as a reference for practical CBA, avoiding the mechanical application of rules of thumb from different sources that imply double counting and measurement errors.

Finally, the change in social welfare for the whole traffic, adding **(A13)** and **(A15)** is:

$$\begin{aligned}
\Delta W &= \Delta W^e + \sum_{\substack{j=1 \\ j \neq i}}^n \Delta W_j^d = \\
&= -w_i(t_i^1 - t_i^0)x_i^0 - (c_i^1 - c_i^0)x_i^0 + \sum_{\substack{j=1 \\ j \neq i}}^n \left[ \frac{1}{2}w_j(t_j^0 - t_i^1)x_j^d + \frac{1}{2}(p_i^1 - p_j)x_j^d - (c_i^1 - c_j)x_j^d - \right. \\
&\quad \left. E x_j^d \right], \tag{A16}
\end{aligned}$$

which is equal to expression **(A12)**.

Alternatively, we may add the changes in *WTP* and resources following the multimodal or the corridor analysis. The change in social welfare is equal to the saved operating cost plus 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 the corridor analysis is given by:

$$\Delta W^e = \Delta Resources^e = (c_i^0 - c_i^1)x_i^0 + w_i(t_i^0 - t_i^1)x_i^0, \tag{A17}$$

that is equal to **(A6)** and **(A13)**.

For deviated demand, to calculate the change in social surplus we have to take into account the cost and time saved in the alternative mode or activity  $j$ , and the cost and time spent in mode  $i$ . In other words, we must compute the cost and time saved by deviated traffic shifting from alternative mode or activity  $j$  to mode  $i$ . Finally, we have to consider the externality.

Regarding the time saved by each consumer shifting from alternative  $j$  to mode  $i$ , it should be highlighted that time savings are not the same for everyone who deviated from the alternative mode. Time savings for the indifferent consumer without the project are the highest and equal to  $w_j(t_j^0 - t_i^1)$ , while time savings for the new indifferent consumer with the project are the lowest and equal to  $w_j(t_j^1 - t_i^1)$ . Time savings are given by  $\frac{1}{2}w_j[(t_j^0 - t_i^1) + (t_j^1 - t_i^1)]x_j^d$ . Moreover, time savings could be also computed as:

$$\begin{aligned} & \frac{1}{2} \left[ \left( (g_j^0 - p_j) - (g_i^{1d} - p_i^1) \right) + \left( (g_j^1 - p_j) - (g_i^{1d} - p_i^1) \right) \right] x_j^d = \\ & = \frac{1}{2} w_j [(t_j^0 - t_i^1) + (t_j^1 - t_i^1)] x_j^d. \end{aligned} \quad (\text{A18})$$

Thus, adding cost saving and externalities, change in social welfare is:

$$\begin{aligned} \Delta W_j^d &= \Delta Resources_j^d = \\ &= \frac{1}{2} w_j (t_j^0 - t_i^1) x_j^d + \frac{1}{2} (t_j^1 - t_i^1) x_j^d + (c_j^0 - c_i^1) x_j^d - E x_j^d. \end{aligned} \quad (\text{A19})$$

Recall that for the new indifferent user the generalized price is  $g_j^1$  and equal to  $g_i^{1d}$ . Therefore, we can rewrite expression **(A18)** as:<sup>20</sup>

$$\begin{aligned} & \frac{1}{2} \left[ \left( (g_j^0 - p_j) - (g_i^{1d} - p_i^1) \right) + \left( (g_i^{1d} - p_j) - (g_i^{1d} - p_i^1) \right) \right] x_j^d = \\ & = \frac{1}{2} w_j (t_j^0 - t_i^1) x_j^d + \frac{1}{2} (p_i^1 - p_j) x_j^d. \end{aligned} \quad (\text{A20})$$

Thus, adding cost saving and externalities, the change in social welfare given by expression **(A19)** could be rewritten as:<sup>21</sup>

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<sup>20</sup> Notice that, since  $g_j^0 = g_i^{0d}$ , time savings given by expression **(A18)** may be also expressed as:  $\frac{1}{2} w_j (t_i^0 - t_i^1) x_j^d + \frac{1}{2} [(p_i^0 - p_j) + (p_i^1 - p_j)] x_j^d$ .

<sup>21</sup> It is common to consider that time savings of deviated traffic are given by  $\frac{1}{2} w_j (t_j^0 - t_i^1)$  but this is only the case if  $p_j = p_i^1$ .

$$\begin{aligned}
\Delta W_j^d &= \Delta Resources_j^d = \\
&= \frac{1}{2} w_j (t_j^0 - t_i^1) x_j^d + \frac{1}{2} (p_i^1 - p_j) x_j^d + (c_j^0 - c_i^1) x_j^d - E x_j^d, \tag{A21}
\end{aligned}$$

that is equal to **(A11)** and **(A15)**.

Finally, the change in social welfare for the whole traffic, adding **(A17)** and **(A21)** is:

$$\begin{aligned}
\Delta W &= \Delta W^e + \sum_{\substack{j=1 \\ j \neq i}}^n \Delta W_j^d = \\
&= (c_i^0 - c_i^1) x_i^0 + w_i (t_i^0 - t_i^1) x_i^0 + \sum_{\substack{j=1 \\ j \neq i}}^n \left[ \frac{1}{2} w_j (t_j^0 - t_i^1) x_j^d + \frac{1}{2} (p_i^1 - p_j) x_j^d + (c_j^0 - c_i^1) x_j^d - E x_j^d \right], \tag{A23}
\end{aligned}$$

which is equal to expression **(A12)** and **(A16)**.

## Appendix B. Basic data and assumptions

**Table B.1. Main assumptions for the numerical illustration**

Length: 400km.
First year of construction: 1.
Last year of construction: 5.
First year of operation: 6.
Project life: 30 years.
Discount rate: 3%.
Annual growth rate of the income: 2%.
Prices are deflated with the CPI.
Benefits and costs are located at the end of the year and expressed in real terms.
Shadow price of labour: 1.
Shadow price of public funds: 1.
Elasticity of labour costs with respect to income: 1.
Elasticity of the demand with respect to income: 1.
Elasticity of the value of time with respect to income: 0.7 (Mackie <i>et al.</i> , 2001; Heatco, 2006).
Elasticity of the accident costs with respect to income: 1.
VAT of investment and maintenance and operation costs: 20%.
Investment cost per km: €15,000,000.
Investment costs have been distributed during the construction period uniformly.
Labour share in investment costs: 20%.
Labour share in infrastructure maintenance costs: 50%.
Labour share in operation and maintenance costs of the rolling stock: 100%.
Residual value of the infrastructure: 0.
Maintenance cost of the infrastructure: 100,000 €/km.
Maintenance and operation cost per train: €10,000,000 per year.
Infrastructure charges: 11€ train-km.
Acquisition of rolling stock: €30,000,000.
Average capacity per train: 350 seats.
Train life: 30 years.
Number of daily services required is computed using demand, travel time, load factor, the length of the route and the hours of operation (Campos <i>et al.</i> 2007).
For the number of daily services required, it is assumed: contingency factor: 1.15; no maximum number of kilometres per year; headway: 0,5 hours; no seasonality; load factor: 0.7; hours of operation: 16;
The average avoidable cost in other activities is equal to their prices net of taxes.
First year demand: 5,000,000 passenger-trips.



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Demand is computed considering the number of passenger-trips of the previous year, the annual growth rate of the income and elasticity of the demand with respect to income.

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Modal split: from air transport 25%; from bus 10%; from car 20%; from conventional train 40%; generated 5%.

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The values for generated traffic are obtained according to the distribution of deviated traffic.

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VOT roughly follow the recommendations of HEATCO (2006) and EC (2015) and are expressed in real terms.

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Values of waiting time and access-egress: 1.5 times the values of in-vehicle time (EC, 2015).

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Accident costs roughly follow the recommendations of EC (2019) and are expressed in real terms.

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**Table B.2. Other parameters values**

<b>Mode</b>	<b>Travel time (hours)</b>	<b>Waiting time (hours)</b>	<b>Access and egress time (hours)</b>	<b>Value of travel time (€/h)</b>	<b>Prices (€) (VAT included)</b>	<b>VAT (%)</b>
Air transport	1.00	0.66	1.25	30	60	10
Bus	4.25	0.33	0.66	10	25	10
Car	3.50	0	0	15	55	30
Conventional train	3.50	0.33	0.66	15	30	10
HSR	1.80	0.33	0.66	-	50	10