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Measuring the economic effects of transport improvements

Ginés de Rus
(University of Las Palmas de G.C., FEDEA and University Carlos III de Madrid)

Per-Olov Johansson
(Stockholm School of Economics and CERE)

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ABSTRACT

The measurement of the economic effects of transport improvements is generally based on the rule of a half. Virtually all the projects have in common the reduction of the generalized cost of transport. The basic rule is derived from a simple indirect utility function, illustrating its use to measure changes in the main components of the generalized price of transport. The paper also addresses the issue of the indirect effects and the so-called wider economic benefits, and briefly discuss the content of these additional impacts with the aim of assessing the role of these impacts on the economic appraisal of transport projects.

1. Introduction

Transport improvements, like infrastructure investment facilitating the provision of faster services, reduce the generalized price of travel[1]. These types of projects are usually evaluated with the derived demand for transport and the so-called "rule of a half" (Neuberger, (1971; Jara-Díaz and Friesz, 1982). This shortcut is commonly used in the daily practice of cost-benefit analysis, as the main guidelines of national or supranational agencies show (see for example, EC, 2015; EIB, 2013; ADB, 2017, Commonwealth of Australia, 2006). The practical value of the input demand function is the possibility of obtaining information about changes in the willingness to pay of consumers in those primary product markets affected directly by the reduction of transport costs.

The winds seem to blow against conventional cost-benefit analysis in general (see for example, Independent Evaluation Group, 2019; Scott et al., 2016) and its application to the evaluation of transport projects in particular (see Laird and Venables, 2017; Lewis and Currie, 2018).). The attack comes from different fronts and the criticism is not always justified (see Mackie *et al*, 2014). Beyond the intrinsic difficulties in applying cost-benefit analysis (e.g., lack of relevant data and the measurement of non-marketed goods), the method is often criticized as a tool to justify projects decided beforehand (Mackie and Preston, 1998). This last problem requires an institutional framework which favour high standards and independence in the evaluation process (Engel et al., 2014). Another front of criticism is methodological. It is based on the idea of the limitation of CBA. A technique considered too narrow to account for the wide range of benefits derived from transport investment projects which can even modify the location and pattern of economic activity.

In a perfectly competitive economy, the rule of a half is an approximation to the change in social surplus, though once we look around and recognize that the real structure of the typical economy is far from the perfect competition model, it is necessary to address the effects of the existence of market power, externalities, taxation

[1] Price, time and other disutility components. The generalized price of transport is commonly called "the generalized cost of transport".

and other distortions for the measurement of transport impacts (the so-called “indirect effects” of transport). Moreover, research on the effects of urban transport improvements on city size and labour productivity (Venables, 2007) has shown the presence of agglomeration benefits or “wider economic benefits” which, in some contexts, are empirically significant (Graham, 2007) and are not captured with the rule of a half. Nevertheless, recent research (Holtkamp, 2018) casts some doubts on the potential additional benefits overlooked in the conventional CBA. To start with the idea of a positive sign for the wider impacts it is not justified. There are no rule of thumbs for the sign and magnitude of these effects and only specific project research could throw some light on this controversial issue (Vickerman, 2008, Holtkamp, 2018).

Moreover, the effects measured in the transport market favour cost reductions in the good markets, industrial reorganization, changes in land use and other economic impacts increasing productivity and growth. The challenge in the economic evaluation of projects is to disentangle relocation and growth or, more simply, to avoid double counting as well as the underestimation of genuine benefits. The econometrics of the effect of infrastructure on growth have tried to concentrate on how to overcome the problem of non-random assignment of infrastructure investment to different locations but has paid much less attention to the distinction between growth and reorganization (Redding and Turner, 2014).

In this paper, the economic effect of transport improvements is considered. There is a wide typology of transport projects. All have in common the reduction of the generalized cost of transport, in one of its component (typically time) or in several simultaneously (e.g. a time reduction coupled with an improvement in safety and a price rise). We try to see whether the actual approach, commonly used in the daily practice of the economic evaluation of transport projects, is theoretically justified or, if not, what is the nature and dimension of the potential biases.

The basic model to support the measurement of the direct benefits of transport improvements is explained in Section 2. The rule of a half is derived from an indirect utility function of a representative household in the economy. A graphical analysis is provided to show the use of the rule of a half under different circumstances and to show

how the measurement of transport benefits can be obtained through a change in surpluses or, alternatively, through changes in willingness to pay and resources.

To limit the direct economic benefits of transport improvements to those obtained with the demand for transport services has been criticized because of a potential underestimation of other additional benefits. Sections 3 and 4 address the issue of the so-called indirect and wider economic benefits, trying to see whether they are a simply relocation or double counting or, on the contrary, they are genuine additional benefits. Finally, section 5 concludes.

2. Transport projects and the rule of a half

There are many reasons why the government invest in transport projects. They have (or should have[2]) in common, the reduction of transport costs for goods and passengers, as well as the improvement of the quality of service in a wide sense. The objectives of the government can be wide: mainly, the reduction of congestion or scarcity, the improvement in travel safety, the reduction of pollution, noise, accidents and negative environmental externalities, or the increase in accessibility.

There is a wide range of projects designed to deal with those problems. The EC cost-benefit analysis guidelines, for example, distinguish the investment in new infrastructure capacity to attend demand growth, the completion and renovation of existing networks, investment in safety, better use of the existing networks and promotion of intermodality and interoperability and improvement of the management of the infrastructure investment (EC, 2015).

The heterogeneity within the described typology of transport projects somehow disappears when it is realized that all of them are the same in one aspect: they reduce the generalized cost of transport (in one or several of its components).[3] Usually, a transport project can be treated as an improvement of the *status quo*, which allows an easier incremental approach in the evaluation (i.e., change in surpluses instead or total

[2] White elephants are not uncommon in the transport sector.

[3] We discard projects which do not affect the generalized cost, like those increasing capacity without any previous problem of congestion or scarcity.

surpluses). Therefore, in this paper, we define a transport project as an exogenous intervention consisting in the reduction of the generalized price of transport (*g*) and/or an increase in the number of trips, through investment (e.g., increase in capacity) or a transport policy (e.g., better management). We simplify assuming that *g* has three components: monetary price (*p*), total travel time (*t*) and the value of time (*v*).[4]

Let us consider a simple indirect utility function for a single representative household in the economy:

$$V(p+v\cdot t, p^x, p^c, w, m) = V(\mathbf{p}, m), \tag{1}$$

where, $g = p + v\cdot t = p + tc$ denotes the generalized travel cost, p^x denotes the price (or generalized travel cost, suppressing here the time cost) of a substitute transportation mode, p^c is the price of a composite commodity, *w* denotes the wage rate, and *m* denotes income. The right-hand side of the equation provides a more compact notation. Partial differentiation with respect to time costs results in:[5]

$$\frac{\partial V(.)}{\partial tc} dtc = -[V_m \cdot z^d(.)]dtc, \tag{2}$$

where V_m denotes the marginal utility of lump-sum income, and z^d denotes the demand for trips. The change in *tc* might be due to a change in the valuation of travel time and/or a change in travel time. In the former (latter) case, $dtc = tdv$ ($dtc = vdt$) in equation (2). An increase in travel time (*t*) and/or the cost (*v*) per time unit causes a decrease in welfare. The typical transport project changes the travel time leaving *v* unchanged, i.e., corresponds to the case for which $dtc = vdt$ in equation (2).

First, consider the case in which the supply of the considered transport mode is infinitely elastic over the relevant interval so that the direct travel cost *p* is fixed. However, the price could be altered. For example, the toll for passaging a toll road might be changed. There is also a time cost per trip. Use a superscript 1 (0) to denote final

[4] In the practical evaluation of projects, it is common to disaggregate *p*, *t* and *v* in their main components. For example, for passenger-trips: egress, waiting, and in-vehicle time in the case of *t*, and the same for *v*.

[5] According to the Envelope Theorem, the *total* derivative of *V*(.) with respect to *tc* reduces to the partial one.

(initial) levels of prices and incomes. Then, equation (1) can be used to implicitly define the compensating variation associated with the shift:

$$V(p^1+tc^1,p^{x0},p^{c0},w^0,m^1-CV)=V(\mathbf{p}^0,m^0), \tag{3}$$

where CV denotes the compensating variation, and all prices but those relating to the considered transport mode are kept constant. The compensating variation is the maximal willingness-to-pay for the change in prices and income caused by the project. If negative, CV is interpreted as the smallest compensation that keeps the individual at the initial level of utility.

Utility functions are not observable or easily estimated so the question arises how to measure CV. One obvious alternative is to estimate the area to the left of a (Hicksian) demand curve and add a change in income:

$$\begin{aligned}
&CV=-\int_{g^0}^{g^1} z^{dH}(g,\ldots)dg+m^1-m^0=\\
&-\int_{p^0}^{p^1} z^{dH}(p+tc^0,\ldots)dp-\int_{tc^0}^{tc^1} z^{d}(p^1+tc,\ldots)dtc+\Delta m=\\
&-\int_{p^0}^{p^1} z^{dH}(p+tc^1,\ldots)dp-\int_{tc^0}^{tc^1} z^{d}(p^0+tc,\ldots)dtc+\Delta m\approx\\
&\frac{1}{2}(g^0-g^1)(z^0+z^1)+p^1\cdot z^1-p^0\cdot z^0-\Delta C,
\end{aligned} \tag{4}$$

where a superscript H refers to a Hicksian demand function. The first line uses the generalized travel cost to estimate the (compensated) consumer surplus change. The change in income is added (and made explicit in the final line of the equation).

The second and third lines split the surplus change between p and tc. In the second line p is changed, holding tc at its initial level. Then tc is changed, holding p at its final level. In the third line, the order of integration is reversed. This illustrates that no unique or path-independent values can be attributed to the individual changes, even though the sum of the two surpluses is unaffected by the order in which the two travel cost components are changed.

The common approach to the measurement of the user benefits of transport improvements consists in assuming a linear approximation between the initial and the final generalized price (Harberger, 1967; Neurberger, 1971; Small, 1999). The generalized price in transport includes the price (e.g. tariff, toll, fare), the time component and any other disutility element affecting the total cost of travel for the user. The reader can consider that all the users travel the same length, have the same value of time; and there are neither externalities nor any other user cost beyond the time component and the price. This is the equivalent to the model assumption of a single representative consumer.

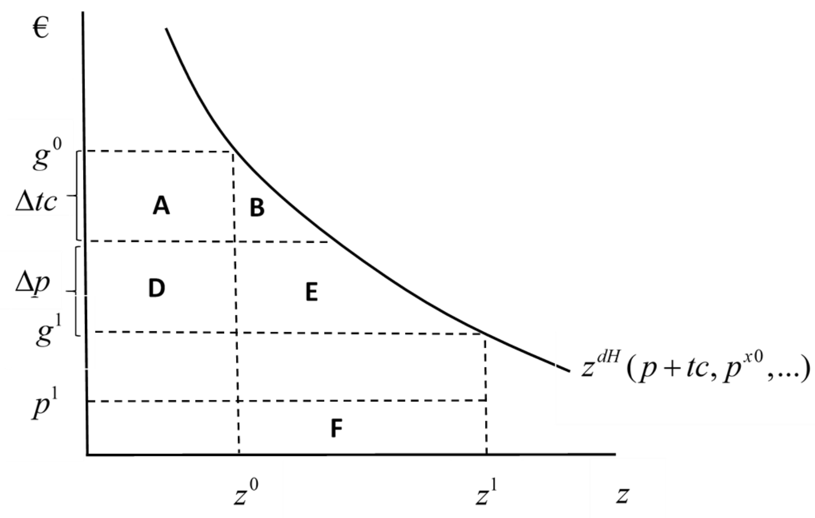

Figure 1. The reduction in the generalized price of transport

Figure 1 provides an illustration. The reduction in the time cost adds a surplus equal to area A+B. The reduction in the monetary price (e.g., ticket, fare) adds a further surplus equal to D+E. However, we could first change the monetary price and then the time cost. Then, they will be multiplied by other numbers of additional trips than in the figure. Special cases occur when Δtc=0 or Δp =0 “eliminating” either area A+B or area D+E in Figure 1.

In the final line of equation (4), the change in income Δm is replaced by any change in the firm’s revenue, i.e., $p^1 \cdot z^1 - p^0 \cdot z^0$, and in its costs, ΔC. The rule of a half is used to approximate *CV*. This is equivalent to drawing a straight line from (z^0, g^0) to (z^1, g^1) in Figure 1.

Next, evaluate the area to the left of this line, i.e., approximately area A+B+D+E. Then, add the change in producer surplus (i.e., F-D) and any change in costs (to obtain the approximation of *CV*. Note that ΔC might be different from zero even if $\Delta p = 0$, because the change in the time cost will affect the number of trips.

In Figure 1 the reduction in the generalized price of travel is due both to time savings (the value of time is also constant and a reduction in the monetary price. Area A represents the value of time savings. Area D is a transfer. Areas B+E+F represent additional willingness to pay net of user time costs. It corresponds to z_1-z_0, and includes both the benefits of new trips (new users or more trips of former users) and the benefits of users shifting from other transport modes.

The additional (induced) trips (z_1-z_0) can be completely new (generated) or deviated from other transport modes. Moreover, the induced traffic may be the result of trips changing destination or routes, as a consequence of the improvement in the considered project. The sum of all the generated and deviated trips is called induced and its heterogeneity does not imply a problem for the measurement of areas B+E+F, as the way to evaluate of the induced trips are similar (Abelson and Hensher, 2001).

The consumer surplus obtained with this derived demand (the market demand for transport) is not necessarily equal to the CV, or the EV, but if the income effect is not significant, it is well-known that under reasonable circumstances the user benefits can be approximated using this procedure. The relative error of using the change in consumer surplus instead of CV is low if the elasticity of demand with respect to income is or the proportion of the change in consumer surplus with respect to income is low enough (Willig, 1976). As an illustration, with an elasticity of demand with respect to income of 2 and a change in consumer surplus equal to 5 per cent of the individual income, the error is less or equal to 5 per cent.

Thus far it has been assumed that the supply curve is horizontal. Assume next that the supply curve is upward sloping and defined as $z = z(p,w)$. In principle, equation (4) is still applicable. However, the equilibrium price p is now endogenous and the market equilibrium condition, $z^{dH}(p+tc,\ldots)=z(p,w)$, can be used to solve p as a function of tc (and suppressed constants); for notational simplicity, labor is the sole input used by firms. Denote this equilibrium price path $p^* = f(tc)$. In equation (4) we can let $g(tc) = f(tc) + tc$. Defining $f(tc^0) = p^0$ and $f(tc^1) = p^1$, we can evaluate a change in the time cost as in equation (4).

However, another approach is possible. Consider a marginal change in the time cost. Using the price path, a simple cost-benefit rule is as follows:

$$\begin{aligned} dV/V_m &= dCV = -z^d(.)dp - z^d(.)dtc + z(.)dp = [-z^d(.) + z(.)]dp - z^d(.)dtc = \\ &-z^d(.)dtc, \end{aligned} \tag{5}$$

where dCV denotes the marginal compensating variation, and the terms within brackets in the third equality sum to zero because $f(tc)$ clears the market; compare the Envelope Theorem which stipulates that the total effect of a small parameter change can be obtained by simply taking the partial derivative of a value function (e.g. an indirect utility function) with respect to the parameter. One could add the labor market to (5) but if the wage clears the market it will vanish, just like the market for trips within brackets in the third equality of (5). Integrating equation (5) along the optimal path produces:

$$\begin{aligned} CV &= -\int_{tc^0}^{tc^1} z^{dH}(f(tc)+tc,\ldots)dtc \approx \\ &\frac{1}{2}(tc^0 - tc^1)(z^0 + z^1). \end{aligned} \tag{6}$$

The integral evaluates the change in demand along the equilibrium path for trips as a function of the exogenous time cost. In this case, the project is evaluated as an area to the left of the equilibrium demand path between initial and final time costs, as represented by areas A+B in Figure 2.

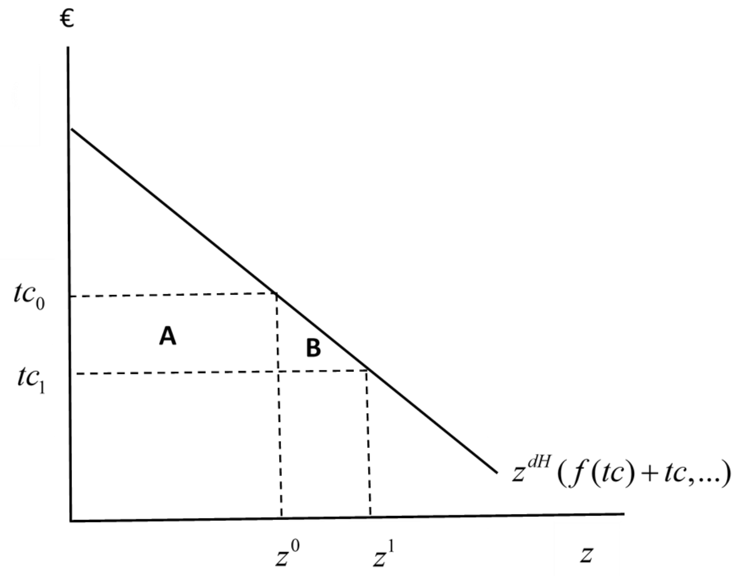

Figure 2. The reduction in the generalized price of transport when the supply curve is upward sloping.

Consider now a marginal change in *z*, keeping *tc*, constant and *z* evaluated at z^0, and supplied by a private or public firm (pofits=$p_z z$-$C(z)$).

$$dV / V_m = dCV = \left[(-z^d + z^0)dp^z + p^z dz - C_z(.)\right] = \left[p^z - C_z(.)\right]dz \tag{7}$$

For a non-marginal project.

$$CV = \int_{z^0}^{z^1} \left[f(z) - C_z(.)\right]dz \approx \frac{1}{2}(z^1 - z^0)(p^{z0} + p^{z1}) - \Delta C. \tag{8}$$

Many projects consist of an investment in additional capacity which reduces time costs and attract new demand, both increasing z and reducing time costs. This is the case of an expansion of capacity in a congested facility and requires to consider both the time savings for the existing and deviated traffic and the willingness to pay of the generated demand net of time and producer costs. Adding equations (6) and (8):

$$CV = \frac{1}{2}(tc^0 - tc^1)(z^0 + z^1) + \frac{1}{2}(z^1 - z^0)(p^{z0} + p^{z1}) - \Delta C, \tag{9}$$

which is equal to the last line of (4)

It is worth noting that equations (4) and (9) are the expression of the two common approaches to the economic evaluation of projects (de Rus, 2010): adding the change in surpluses (4) and adding the change in willingness to pay and the change in resources (9).

The substitution of $g^i = p^i + v.t^i$ (i=0,1) in the last line of (4) leads to equation (10), a different way to interpret the social benefit of the project:

$$v(t^0 - t^1)z^0 + \frac{1}{2}(z^1 - z^0)\left[(g^0 + g^1) - vt^1\right] - \Delta C \tag{10}$$

Expression (10) shows the transport benefits ignoring transfers, and measuring the social benefits through the changes in willingness to pay and resources (time is a resource). The social benefit is composed by the value of time savings for existing travellers (z^0) and the willingness to pay of generated traffic, net of time costs), plus the avoidable costs of the initial transport option minus the costs of the new transport option.

The two approaches are shown in figures (3) and (4). The case represented in these figure consists of a reduction of the generalized price with time saving and an increase in price.

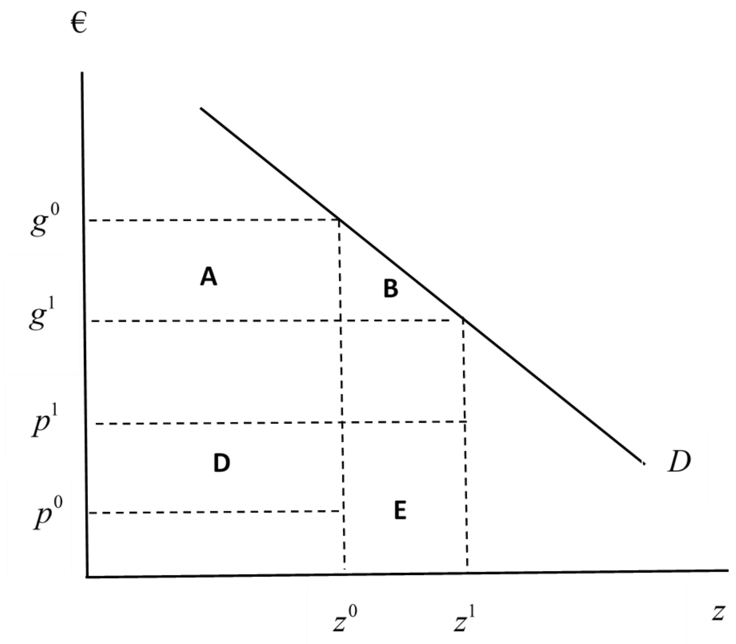

Figure 3. The benefits of a reduction in the generalized price of transport adding the change in surpluses.

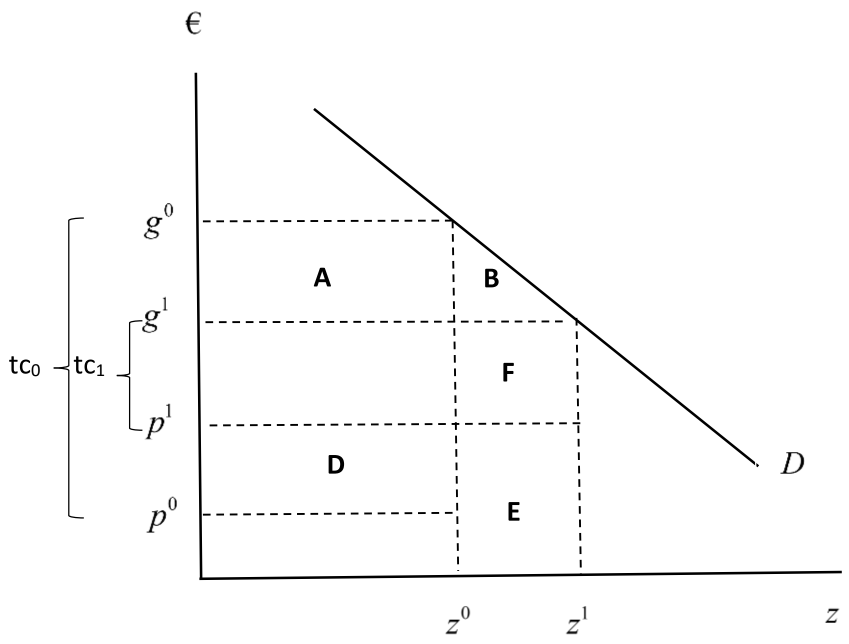

Figure 4. The benefits of a reduction in the generalized price of transport adding the change in willingness to pay and resources.

Figure (3) shows that when the generalized price goes down from g^0 to g^1 the consumer surplus increases in the amount represented by the area A+B. To this benefit, the change in producer surplus has to be added. The rise in price from p^0 to p^1 increases revenue (areas D+E). Hence, adding consumer and producer, total benefits are equal to areas A+B+D+E, net of any change in producer cost.

In Figure (4) total benefits are obtained through the change in willingness to pay and resources. When the generalized price goes down from g^0 to g^1 there is an increase in the number of trips (z^0-z^1). This generated traffic is willing to pay areas B+F+E. The existing users save time costs[6] equal to areas A+D (it is assumed that all elements others in the utility function, like quality, remains constant). The change in resources to obtain these benefits come from additional time costs (area E) and any other change in producer costs. Total benefits are equal to areas A+B+D+E, net of any change in producer cost.

Many transport projects get their benefits from time savings (up to 80 per cent in typical road projects), and usually, the analyst has information on the initial generalized price and quantity and an estimation of the new generalized price. If the generalized price change is small, the new demand quantity (z^1) can be predicted using the existing evidence on the elasticity of demand in the mode of transport being evaluated. The rule of a half plus the producer surplus in expression (4) includes the benefits to existing users and the benefits of deviated and generated demand. It includes the benefits of new trips (new users or more trips of former users) and the benefits of users shifting from other transport modes (Abelson and Hensher, 2001).

The consumer surplus obtained with this derived demand (the market demand for transport) is not necessarily equal to the CV, or the EV, but if the income effect is not significant, it is well-known that under reasonable circumstances the user benefits can be approximated using this procedure (Willig, 1976).

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[6] Alternatively, areas A+D could be considered as a change in willingness to pay instead of resource cost saving.

3. Wider economic benefits: relocation or growth?

The ex-ante estimation of the benefits of a transport improvement, with the rule of a half, may overlook the possibility of additional benefits. A warning is needed at this point because of the two potential risks in the practical evaluation of projects: double counting and the underestimation of benefits. If the measurement of users benefits has already been done using the derived transport demand, one should ignore the surpluses of the primary product markets affected directly by the improvement. These benefits, not to be forgotten, are the real benefits of transport improvements, which for convenience are measured using the allied transport market. Had the practitioner access to the information of the changes in surpluses in the primary markets, the evaluation would not require the use of the transport demand function.

The transport benefits can also be measured in the land market when this market is not affected by bubbles or any other exogenous factor, i.e., it is perfectly competitive. In conclusion, the direct user benefits of the transport investment can be measured using the derived demand for transport *or* calculating the net present value of changes in consumer and producer surplus in the primary markets *or* the change in the value of a fixed factor like land. "Failure to recognize these three approaches as alternative ways of measuring the same thing has often led to double-counting of benefits and in some cases to triple-counting!" (Harberger, 1967).

Up to this point, we have ignored the presence of market distortions. The existence of a wedge between price and marginal cost, both in primary and secondary markets, may change the value of transport impacts in any direction, though the usual criticism is that the traditional approach of measurement (rule of a half for the change in the user surplus plus changes in the producer surplus plus externalities) seriously underestimates the social benefits of transport projects.

For example, many promoters of public infrastructure investment argue that there exist other benefits[7], beyond the direct user benefits, like industry reorganization, so it is essential to avoid the potential underestimation of transport improvements including some of these alleged additional benefits.[8] Which are the candidates to add value to the direct user benefits already measured in the derived demand for transport?

Gains in productivity derived from industry reorganization are not, in principle, additional benefits. This is a well-known result in transport economics. Although it is true that transport cost reductions allow firms to reorganize plants, inventories and warehouses leading to productivity gains, these effects have already been measured with the transport demand (Mohring and Williamson, 1969). Basically what we need for the existence of additional benefits, and not merely transfers, is the presence of market distortions, a wedge between price and marginal cost, like agglomeration economies (Venables, 2007) or changes in land use in the presence of a market failure (Laird and Venables, 2017), the increase of competition or the existence of labour market imperfections.

An increase in productivity as a consequence of the increase in labour density is analysed in Venables (2007) and estimated for the UK in Graham (2007). Nevertheless, the conclusion of significant agglomeration benefits following a transport improvement is followed in Venables´paper by some qualifications: only commuting trips are considered in the model, and hence, the higher the share of leisure trips in the real world, the lower the gains in productivity; congestion and any other negative externalities are ignored; the potential reduction of productivity in those areas losing employment are also ignored.

[7] The defence of infrastructure investment for economic development based on the results of the econometric aggregate approach is a bit discredited today (Gramlich, 1994) though politicians still use the argument of infrastructure investment as a sufficient condition for economic development ignoring endogeneity, or the difficulty of disentangle relocation and growth in the estimates ("much of the estimated effect of transportation costs and infrastructure on the spatial organization of economic activity is probably due to reorganization rather than growth" Redding and Turner, 2014).

[8] Laird et al (2014) warn of the use of expenditure and costs instead of genuine benefits. They mention the recent shift by planners in the UK, using changes in gross value added, including wages as a benefit.

The improvement of infrastructure may increase competition, boosting the concentration of economic activity and, consequently, reducing monopoly power. The reduction of transportation costs between two regions can open new opportunities for trade widening the relevant market and giving the consumers the possibility of buying in the other region and hence reducing the deadweight loss of monopoly. Jara-Diaz (1986) calculates that benefits could increase 50 per cent more than those obtained with the rule of a half. Although this source of additional benefit could be locally pertinent, one could not expect, in developed economies, that the source of market power in large and dense areas is caused by the lack of efficient transport infrastructure.

Another source of wider economic benefits is the impact of the transport improvement in land use. The reduction in transport costs may boost private investment and be a cause of the redevelopment of a zone in the city. To be genuine additional benefits, and not merely double counting, a market failure is needed. In the case of a change in land use, the benefits can come from more attractiveness of the new area (increase in consumer surplus) or when the existence of market power of the developer, or a coordination failure of the firms, is removed thanks to the transport improvement (Laird and Venables, 2017). The same qualifications apply as in the case of agglomeration economies.

Finally, the impact on the labour market could be another source of wider economic benefits though the risk of double counting is high: the increase in productivity due to an increase in labour density is already measured as agglomeration economies, as well as the creation of new jobs through shadow pricing when measuring the opportunity cost of inputs.

Recent research (Holtkamp, 2018) casts some doubts on the existence of wider economic benefits, supposedly overlooked in CBA. This research on agglomeration and imperfect competition with general equilibrium models of spatial economies, in which the reduction in transport costs are achieved by means of a tax-funded scheme, does not lead to the conclusion of the existence of additional benefits as commonly argued in the defence of many large transport projects, in which the conventional CBA delivers poor results.

A transport improvement investment with imperfect competition or with agglomeration economies has the wider impacts already described in this section. What Holtkamp (2018) shows is that the sign of these effects are ambiguous. "Strictly speaking, I would even be very cautious to conjecture which sign is by and large the more probable one. Presupposing a positive sign, and maybe even a considerable scale, whether for imperfect competition or agglomeration, would constitute a considerable bias in transport appraisal. The signs of the net wider impacts are found to be highly ambiguous (…) it rather appears necessary to conduct project-based assessments, maybe as addenda to conventional cost-benefit analyses. In line with my reluctance to predict the wider impacts' potential scale, I am just as reluctant to predict whether the wider impacts are significant enough to justify their ex-ante assessment" (Holtkamp, 2018, p.103).

4. The rule of a half and the secondary markets

The considered project might also cause a significant price effect in a secondary market, here taken to be the market for *x*. One way of accounting for significant changes in a secondary market is as follows:

$$CV^M + CV^x = CV^M - \int_{p^{x0}}^{p^{x1}} x^d(g^1, p^x, \ldots)dp^x + \Delta\pi^x, \tag{11}$$

where CV^M is the previous compensating variation modified by the fact that p^1 might be different from the final price(s) in the previous equations. The sum of the change in (compensated) consumer surplus and the change in profits in the *x*-market is added to the previous surpluses.

Note that the consumer surplus in the *x*-market is evaluated conditional on the changes in the primary market. However, as underscored above, we could take any other (permitted) path and obtain the same total compensating variation. The rule of a half could be applied as before, but the equilibrium g^1 and z^1 will be different.

Finally, the approach suggested by equation (6) is still applicable. The main difference is that we now have to solve a system of equations to obtain the equilibrium paths for p as well as p^x (as is illustrated in the appendix). Therefore, the path, say, $f^M(t)$, will differ from the one employed in equation (6). Nevertheless, the rule of a half, as defined in equation (6), is still applicable. It is worth noting that rules of a half of the kind stated in equation (4) seem to draw on the assumption that any changes in other markets are evaluated along equilibrium paths in sharp contrast to how surpluses in the primary market are handled. Symmetrical handling of all markets would result in something like the approximation suggested in the final line of equation (6).

The case where the shift in time cost causes, in addition, a significant shift in the supply of labor and hence the wage rate is highlighted in the appendix of Johansson and de Rus (2018); see in particular the discussion following their equation (A.9). This latter case might be an illustration of a project that also improves the functioning of the local labor market by streamlining commuting. However, equation (6) above is still valid if all markets are competitive. It simply takes another path from initial to final prices and wages.

The description of the different types of wider economic benefits has a common characteristic: they happen in the primary markets affected by the reduction of the generalized cost of transport. To generate genuine additional benefits, the markets benefiting from the transport cost reduction require the presence of a market failure. These potential additional benefits are not captured, with the rule of a half, using the market demand for transport.

On the contrary, indirect benefits occur in secondary markets, channelled through the existence of complementarity and substitutability relationships with the goods and services of the primary markets affected directly by the transport cost reduction. They share with the wider economic benefits the circumstance of a market distortion but they are not directly affected by the transport improvement.

The indirect effects of transport projects are usually overlooked for practical reasons, though there is a theoretical justification to ignore them. In principle, when the rest of the economy is competitive and prices equal marginal costs, the indirect effect is null, as the marginal willingness to pay for the increase/decrease of the quantity in the secondary market equals its opportunity cost. This is so with and without changes in prices in secondary markets. In the context of highway investment: “To summarize, *if* marginal cost tolls are charged for trips, and *if* society attaches the same value to a dollar gained (or lost) by any of its members or by society collectively, *then* determining the net short-run benefits of improving a highway link requires only data of the use made of that link. Specifically, the benefit equals the sum of the changes in consumers‘ surplus and toll revenues on the improved link. This is true even if the improvement affects traffic conditions on other links in the system. Given marginal cost pricing an accepting the principle, `A dollar is a dollar to whomsoever it may accrue´ results in consumer benefits and toll-revenues charges on unaltered links that exactly offset each other” (Mohring, 1993 p.420).[9]

Even when there are market distortions (price and marginal cost differ in several markets) the net effect could be positive or negative. The sign of the effect depends on the complementarity and substitutability with the primary market, and the sign and size of the distortion. This for every secondary market, being the total indirect effect the sum of all of them. Difficulties getting reliable information and the belief that some of them might net out in the aggregate, induce the analysts to ignore them or concentrate in the most obvious candidates (e.g., airlines in the case of HSR).

[9] For a graphical analysis see Boardman *et al.* (2018) pp.166-168.

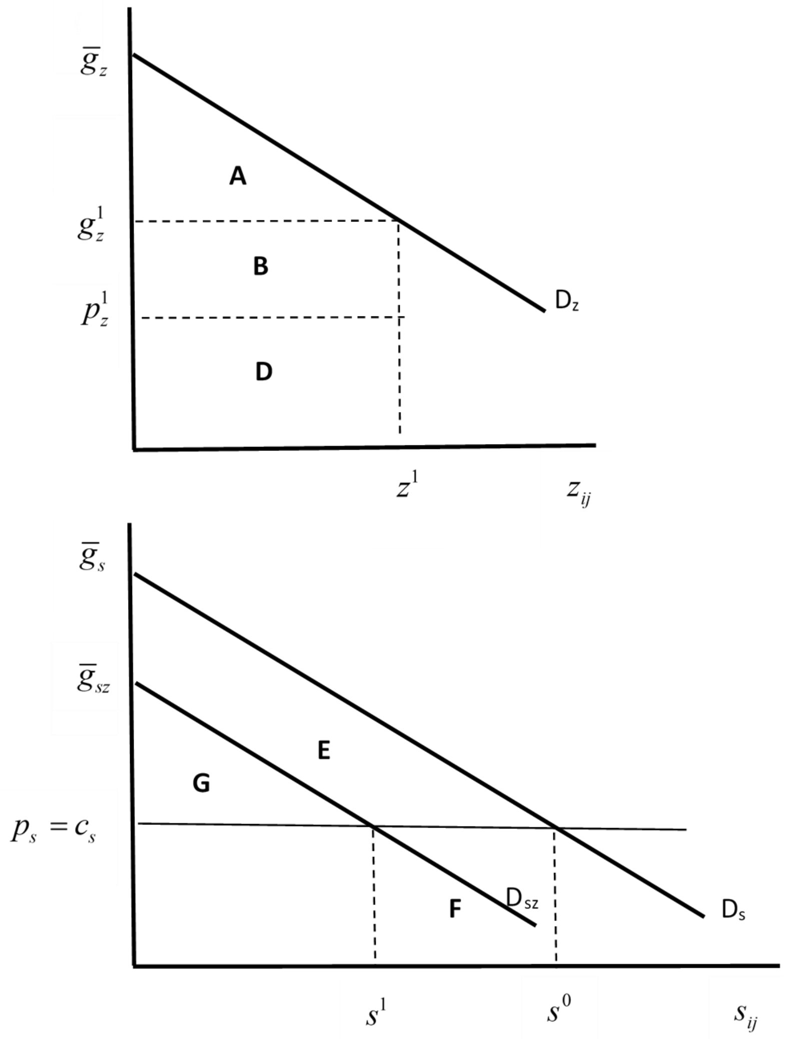

Figure 5. The benefits of the introduction of a new service in the primary and secondary market (e.g. air transport)

Let us consider the construction of a new high-speed rail infrastructure providing a transport service between *i* and *j*; and an existing substitute (air transport) provided with several airlines in perfect competition. These two options of transport differentiated exclusively in the length of travel time (all other dimensions of service quality are assumed to be identical). The upper panel of Figure 5 shows the market for the HSR service (*z*) and the lower panel represents the air transport market, the secondary market (*s*).

In the upper panel of Figure 5, when the *z* service is introduced at a generalized price of $g_z^1 = p_z^1 + vt_z$ the demand quantity is z^1. The direct benefits of the project are the consumer surplus (A) plus the producer surplus in the *z* market: area D minus the cost of *z* (C_z), not represented in the figure.

$$CS + PS = \frac{1}{2}(\bar{g}_z - g_z^1)z_{ij}^1 + p_z^1 z_{ij}^1 - C_z = A + D - C_z \qquad (12)$$

The market for air transport services between *i* and *j* is shown in the lower panel of Figure 5. Although the new service *z* affects this secondary market, shifting the demand curve to the left, nothing happens in terms of social surplus. The indirect effect in the secondary market is zero. The demand of air transport shifts to the left and reduces the quantity of air transport trips from q_s^0 to q_s^1. As the price of air transport equals marginal cost, the airlines surplus remains unchanged. Moreover, as travellers move voluntarily to the new transport mode *z*, and the generalized price remains constant, the demand shift to the left does not imply any change in utility in the air transport market.

It is worth noticing that the upper and lower panel of Figure 5 have to be compatible. For example, assuming that $p_z^1 = p_s$, the whole area A is composed of the value of time savings and revenue represented by area D is equal to the avoidable cost of the reduction in air transport services. If $p_z^1 > p_s$ a share of the time savings goes to the producer surplus, changing all the areas in the upper panel. Then, if the shift to the left of the demand curve in the air transport market does not affect the utility of consumers, what is the interpretation of the lost area E?

The social value of the air transport market before the introduction of *z* is represented by E+G and after the introduction of *z*, only by G, so E represents the loss of social value of this transport mode when the substitute *z* is introduced. An irrelevant fact for the measurement of user benefits of the introduction of the new service but relevant for other economic questions like, what is the social cost of closing the air transport service? Without *z*, that loss is G+E; and with z*,* only G.

5. Conclusions

There exists a wide variety of transport projects, from infrastructure investment in new capacity to those aimed to the increase in travel safety. All of them have in common the reduction in the generalized cost of transport. The challenge is the measurement of the impacts of transport improvements as accurately as possible, avoiding both the underestimation and the overestimation of the expected benefits.

Considering a simple utility function for a single representative household in the economy we derive "the rule of a half", commonly used in the social appraisal of transport projects as reflected in the national and supranational CBA guidelines. We have tried to show in an intuitive way how to use this measurement in different circumstances. In many transport project, the use of this rule and the estimation of the producer surplus (plus the externalities) are enough for the monetary approximation of the welfare change.

We have not analysed in this paper the equity implication of transport improvements but the practitioner should not be tempted to conclude that the users and producers primarily affected by a project are the final beneficiaries, particularly when a fixed factor (land) is present and its demand is affected by the transport improvement. Moreover, the risk of double counting should also be avoided.

A discussion of the indirect effects and the so-called wider economic impacts is also included in this paper. The evidence of their existence is clear but the magnitude, or even the sign, is not conclusive and call for a prudent view on how significant these effects can be in different contexts.

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