Transport and Land Use Benefits under Location Externalities

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ABSTRACT

Transport projects are economically assessed partly through estimating users’ benefits in the transport system and ignoring impacts on land use under the argument that these benefits are already incorporated into transport users’ benefits. In this paper we discuss this argument under two main viewpoints: the level of percolation of transport benefits into land values and the presence of external economies in urban systems. We first propose and discuss measures of benefits in the transport and in the land use system. Then we analyse to what extent transport users’ benefits percolate into land rents, showing empirical evidence that it may be limited. The paper then focuses on the less studied effect of three types of technological externalities: direct effects associated with traffic nuisance; location externalities, associated with economies of agglomeration of households and firms, which in some cities may be a dominant location choice factor; and land use-transport interaction. We conclude by specifying in more detail the conditions under which the classical argument and current project appraisal methods are valid.
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1. Introduction

In theory, the benefits generated in the activity system as a result of a transport project should be observed and properly measured in the transport system, as a direct consequence of the argument that travel demand is derived from individuals’ demand for performing activities. This is the well known Mohring’s (1961, 1976) classical argument on the relationship between transport and land use benefits, which is based on Alonso’s (1964) urban location approach where the land market operates as a bid-auction process. Mohring studied the highway impact on land values and concluded that “changes in land values as may result from transportation improvements involve transfer of income among members of the population, not additional benefits (or losses) that must in some fashion be added to those arising directly from the improvement” (Mohring, 1976, pp. 119). As this is only a distributive effect it is irrelevant in social evaluation as long as the relative importance of all the agents’ welfare is the same or, alternatively, a compensation tax system operates cancelling the losses of some with the gains of the others.

Wheaton (1977) studied the same issue for the urban area considering the residential market. His basic assumption is that competitive land bidding insures that landlords will eventually extract savings.
that consumers may enjoy. He defines a measure of location benefit as the exogenous income necessary to compensate the change in transport costs (the compensating variation). As this measure only depends on the aggregated travel demand, he concludes that all the changes in the location market associated with an investment in transport could be completely ignored in the calculation of benefits if travel demand is adequately forecast. Sasaki and Kaiyama (1990) extend this result incorporating the behaviour of firms. It is important to mention that Wheaton acknowledges that his result is valid if the transport investment generates only indirect (or pecuniary) effects on land and housing, such as those altering some other market prices (e.g. transport market). According to Wheaton the existence of direct effects (which we understand as technological externalities) would invalidate this classical result. Here we shall analyse these arguments incorporating common technological effects in the urban context, namely traffic nuisance, location externalities and land use-transport interaction, concluding with the conditions for classical arguments to apply.

Of particular interest is to analyse current practice in transport project appraisals. The calculation of transport benefits is based on the estimate of resource savings and transport users’ benefits (Williams and Lam, 1991a, b), and applies Mohring’s and Wheaton’s argument to ignore any land value benefit. However, these methods use travel demand models that ignore land use effects on the transport project: land values and location impacts, because they are limited to partial transport equilibrium analysis.

Our research builds upon Jara-Díaz and Martínez (1999) derivation of the theoretical indirect utility and the willingness to pay functions for residential location. This framework relaxes Alonso’s restrictive assumption (also made by Mohring and Wheaton) that location utility is only associated with land space, trip costs and a composite good. Indeed, we assume that residents obtain utility from the set of **activities performed**, considering the available time constraint (hence the value of time). This microeconomic approach justifies the role of location externalities in residents and firms location, which is associated with the existence of agglomeration economies; it also clearly justifies the
role of access (accessibility and attractiveness) in locators’ behaviour. As access measures coincide with the trips benefit, associated with trips made by locators (Martínez, 1995), the connection between transport and land rent becomes explicit and consistent.

This theoretical framework has been successfully applied in the Santiago City land use model MUSSA, which is used here to make empirical calculations of transport users’ benefits and economic assessments of impacts on the urban land market.

In the following section we present measures of transport users benefits (TUB) used in some advanced transport project appraisal methods. In section three, land use benefits (LUB) are derived based on the urban economic theory and their variations from changes in accessibility are defined. The link between TUB and LUB is established by means of accessibility measures, which allow us to analyse the theoretical relationship between TUB and LUB in the fourth section. The application of this analysis using the land use model MUSSA provides the empirical evidence presented in section five, followed by a summary of main practical conclusions in the final section.

2. Transport Users’ Benefits

The benefit to users derived from transport projects, either infrastructure investment or operational policies, are obtained from consumers’ surplus (CS) measures, which are derived directly from trip utility functions or from trip demand models. Let us consider, as an example, the well-known and widely applied doubly constrained spatial interaction model for trip distribution to represent travel demand between zones:
\[ T_y = A_i O_i B_j D_j \exp(-\beta c_{ij}) \]
\[ \sum_j T_y = O_i \]
\[ \sum_i T_y = D_j \]  
which distributes trips exogenously generated at each zone \( O_i \) to all destinations, subject to comply with the also exogenously given total trips at each destinations \( D_j \). The fulfilment of these constraints is assured by parameters \( A_i \) and \( B_j \), known as balancing factors. These constraints introduce a context where the land use system is exogenous to the transport system, which we call the short run context. The response of travel demand to the transport cost measure \( c_{ij} \) is captured by the users’ sensitivity parameter \( \beta \).

Williams (1976) proposed a measure of the Marshallian consumers’ surplus associated with this model, which estimates the aggregated transport users’ benefit (TUB) variation due to a change in transport costs. Since the travel demand model assumes land use as exogenous and fixed, these are short run benefits (TUB\(_{SR}\)) useful for comparing two situations: with (1) and without (0) a project. These are:

\[ \Delta TUB_{SR} = \frac{1}{\beta} \left[ \sum_i O_i \ln \left( \frac{A_i^0}{A_i^1} \right) + \sum_j D_j \ln \left( \frac{B_j^0}{B_j^1} \right) \right] \]  

According to Williams and Senior (1978), each term in equation (2) represents either transport users’ benefits or land rents, depending on whether the traveller is assumed to be a job seeker (with fixed residence) or home seeker (with fixed job). This interpretation is asymmetrical and subject to the assumption that the traveller is seeking either job or residence. Martínez (1995) argues that the first terms (with factors \( A_i \)) are associated with accessibility from the trip origin, or the benefit of making
trips, and the second ones (with factors $B_j$) are associated with attractiveness at the trip destination, or the benefit of receiving trips. Additionally, Martínez argues that the transformation of these benefits into land rents is symmetrical but can only be identified in the land use system.

The condition that land use is fixed was recently relaxed by the authors (Martínez and Araya, 1999) obtaining an expression for the long run ($TUB^{LR}$), where $O_i$ and $D_j$ change between situations 0 and 1. This measure is:

$$\Delta TUB^{LR} = \frac{1}{\beta} \left[ \sum_i \frac{(O^0_i + O^1_i)}{2} \ln \left( \frac{A^0_i}{A^1_i} \right) + \sum_j \frac{(D^0_j + D^1_j)}{2} \ln \left( \frac{B^0_j}{B^1_j} \right) + (T^0 - T^1) \right]$$

(3)

where the first two terms can be interpreted as representing a pseudo-rule-of-a-half of transport benefits and the last term $\beta^{-1}(T^0 - T^1)$ represents the benefit associated with total trip generation. The difference with the original rule-of-a-half is that this pseudo rule does not assume a linear approximation of the trip demand function.

Following Martínez (1995), accessibility ($Q^{acc}$) and attractiveness ($Q^{att}$) may be defined as:

$$Q^{acc}_i = -\frac{1}{\beta} \ln(A_i) \quad Q^{att}_j = -\frac{1}{\beta} \ln(B_j)$$

(4)

which represent the expected benefits per trip generated and attracted respectively, considering the distribution of trip destination, mode and route choices. Note that $A_i$ and $B_j$ are relative terms, i.e. they can only be identified up to an unknown multiplicative constant, then $Q^{acc}_i$ and $Q^{att}_j$ are also relative measures.
Additionally, in Martínez and Araya (1999) we have extended the analysis deriving trip associated measures of access and proposed the following disaggregated accessibility expression, which is the expected household transport benefit strictly associated with the trip pattern:

\[ hc - acc_i^n = - \sum_{i=k}^{1} \beta_{ij} T_{ij} \ln \left( A_i^m B_j^n \right) \]

where \( hc - acc_i^n \) measures the total benefit associated to the trips pattern \( K^n \) of a given household \( n \) from a given location zone \( i ; k \) is the index for individual trips ; \( R0_k \) is the trip purpose and \( j_k \) is the zone trip destination index.

In line with Jara-Díaz and Martínez (1999), these expressions can be used as accessibility attributes in households’ willingness to pay for residential location. Therefore, they directly integrate the behavioral function of location models associated with Alonso’s bid-rent framework. This approach guaranties that the interaction between transport and land use is performed, through accessibility, in a consistent microeconomic procedure. Note that these access measures do represent transport users’ benefits, thus their explicit role into location choices provide the consistent linkage between transport benefits, location choices and the impacts on land rents, as we discuss below.

### 3. Benefit From Land Use

It is now necessary to derive and analyze appropriate measures of benefits associated with impacts in the land use system generated by investment or policy changes in transport. For this purpose, an economic model to describe the urban system performance is required. The classical microeconomic paradigm proposes that the consumer maximizes his/her utility subject to income and time constraints. From this utility maximizing problem, Alonso (1964) derived functions for the individual’s willingness
to pay for land that enabled him to introduce the classic bid-rent model, which assumes that land lots are acquired by the highest bidder.

3.1 The basic model
Let us first consider a basic model of consumers’ behaviour in location choices. Rosen (1974), who assumes that consumers maximise their utility that depends on the residential location, provides a detailed derivation of Alonsos’s willingness to pay functions. Utility is obtained by the consumption of a composite good $x$ and the location choice described by a vector of attributes $z$. Assuming an exogenous income constraint, the consumer $h$ optimal behaviour is given by the solution of:

$$\begin{align*}
\max_{x, j} U_h(x, z_j) \\
\text{subject to} \quad Px + p(z_j) = I_h
\end{align*}$$

(6)

where $P$ is the price of the composite good and $p(z_j)$ is the hedonic price of land located in zone $j$, which is assumed dependent on location attributes ($z_j$); $I_h$ is the fixed income of the individual $h$. Optimising, we obtain the conditional demand function for the composite good, $x^*$, which is then replaced in the direct utility to obtain the indirect utility function conditional in the location choice $j$:

$$U_h(x^*(P, I_h - p(z_j)), z_j) = V(P, I_h - p(z_j), z_j)$$

(7)

Fixing the utility level at $U_h^*$ and inverting in $p(z)$, we obtain the willingness to pay function:

$$WP_{hj} = I_h - V^{-1}(P, z_j, U_h^*)$$

(8)
which represents the consumer’s maximum value that consumer \( h \) is willing to pay for a location with characteristics \( z_j \), in order to obtain a level of utility \( U^*_h \) and subject to the exogenous values \( P \) and \( I_h \). This function represents the inverse of the Hicksian compensated demand for land with characteristic \( z_j \).

This basic model allows us to derive measures of the consumer’ surplus associated with a change in land attributes. For that purpose, it is worth noting that the expression \( V^{-1}(P, z_j, U^*_h) \) is the minimum expenditure \( e \) in all goods other than land required to reach the level of utility \( U^*_h \); therefore \( WP_{hj} \) represents the maximum that the consumer is willing to pay for that location. We postulate the following theorem:

**Theorem:** The location benefit or consumer surplus \( (CS_{hj}) \), measured by the compensating variation obtained by a consumer \( h \) at location \( j \), is well defined (in a microeconomic sense) by the difference between the willingness to pay (or real location value for the consumer) and what he/she actually pays for that location \( (p_j) \):

\[
CS_{hj} = WP_{hj}(U^*_h) - p_j
\]  
(9)

with \( U^*_h \) a reference utility level.

**Proof:** By definition, the compensating variation \( CV \) is the income changes necessary to compensate for a price change to maintain utility; it is measured by the difference in the expenditure function calculated after the price change. Consider two cases: the consumer change his/her location and, second, the set of location attributes and price change, without relocation. Assume the change is from
(z, p) to (z, p). The income compensation or compensating variation for these changes is given by the expenditure differential to obtain the reference utility level $U^*$. Then
\[ CV_h = e_h(z, P, U^*_h) + p_i - e_h(z, P, U^*_h) - p_j \]
or, introducing equation (8), we obtain:
\[ CV_h = WP_h(z, I_h, P, U^*_h) - p_j - (WP_h(z, I_h, P, U^*_h) - p_j) = \Delta CS_h \]

Therefore, a well defined measure of the consumer’ surplus is
\[ CS_{hj} = WP_h(z, I_h, P, U^*_h) - p_j \]
which proofs the theorem.

On the supply side, a change in the land prices (or rents) is capitalized by landowners and represents the variation of the producers’ surplus ($\Delta PS$). Then, assuming that location $j$ is occupied by household $h$ before and after the change in one or more attributes, the total variation in land use benefits ($LUB_{hj}$) is given by:
\[ \Delta LUB_{hj} = \Delta CS_{hj} + \Delta PS_j = \Delta WP_{hj} - \Delta p_j + \Delta p_j = \Delta WP_{hj} \] (10)

which turns out to be identical to the variation of the locator’s change of the willingness to pay for that location. Considering relocations, total benefits are calculated adding consumers’ surplus at location before (0) and after (1) the project, plus the producers’ surplus:
\[ \Delta LUB = \sum_{l \in H} (WP_{hi}^{(1)} - p_i - (WP_{hi}^{(0)} - p_i)) + \sum_{s \in \Omega} \Delta p_s = \sum_{l \in H} (WP_{hi}^{(1)} - WP_{hi}^{(0)}) \] (11)

where $H$ is the set of locators and $\Omega$ the set of location options in the city. Note that this calculation of $\Delta LUB$ requires identifying the location of each consumer before and after the project, that is, all relocation caused by the project should be estimated. Second, remind that in equations (10) and (11)
willingness-to-pay should be calculated holding the utility level constant, which makes the variation in land use benefits different to the variation of the expected location prices in the city.

With regards to transport impacts, it is also worth noting that variations in willingness to pay and rents are generated by an original variation of location attributes (contained in vector $z$) which include accessibility and attractiveness. This implies that a change in any attribute $z_k$ will induce an impact on land use benefits according to two conditions: the sensitivity of the household to that attribute, which produce changes in willingness to pay values (the behavioural response), and the effect of this change in the land use market equilibrium.

### 3.2 A marginal deterministic analysis

In order to focus on the role accessibility plays in land use benefits, let us consider the microeconomic residential location model of Jara-Díaz and Martínez (1999). They analysed the consumer utility regarding residential location constrained by time and income, and the available distribution of land use in the city that defines location attributes. From this framework the individual willingness to pay for alternative locations is derived as an explicit function of the consumer’s perception of transport benefits, interpreted by the authors as a measure of accessibility according to Martínez (1995). The proposed $WP$ function is:

$$WP_i = C + I + \alpha T + \gamma \sum_k f_k \delta_{kil} acc_{kil}$$  \hspace{1cm} (12)$$

where $i$ denotes the residential location, $I$ the household income and $T$ the total available time. $acc_{kil}$ is the net trip benefit (benefit minus cost) or relative accessibility generated by performing activity $k$ in zone $l$ while located in zone $i$; $f_k$ is the activity frequency; $\delta_{kil}$ is a dummy variable that takes the value 1 if the $k^{th}$ activity is carried out in zone $l$ and 0 if not (it represents a trip destination choice model). $\alpha$
and $\gamma$ are parameters and $C$ is an individual specific constant. Relative accessibility is expressed as the difference between the benefit obtained by performing an activity at some destination minus the transport cost involved in reaching that destination from the residential location:

$$acc_{kil} = U_k(z_l) - TGC_{kil}(tv_{il}, c_{il})$$

where $U_k(z_l)$ is the monetary utility obtained from carrying out activity $k$ in zone $l$, which depends on the set of attributes $z_l$ at the destination zone. $TGC_{kil}(tv_{il}, c_{kil})$ is the transport-generalised cost from $i$ to $l$, including fare ($c_{il}$) and travel time ($tv_{il}$). Notice that accessibility combines land use attributes, expressed by $z$, and transport costs, which explicitly states that trip benefits integrate consumer’s behaviour in location (equation 12) and transport choices in a consistent way.

A variety of effects of transport projects in location behaviour can be identified from equations (12) and (13). If the transport cost decreases in one OD pair, both the origin and destination zones become more attractive locations and $WP$ functions change for all potential bidders (due to the last term in equation 12). This modifies location attributes ($z_i$) and willingness to pay and represents the access effects on land use, through transport and time costs, which are what Wheaton calls indirect or pecuniary externalities. Direct or technological effects, as pollution, traffic noise and accidents may also affect location choices, which may be referred to as nuisance externalities. In this case transport variables other than access should be represented in $z$ in order to affect $WP$ functions directly.

A third and highly relevant effect is generated by location attributes endogenous to the location process. Indeed, $WP$ depends on environmental attributes $z_l$ (equation 13 first term), including land use attributes (e.g. location of activities in zone $l$), which makes the location choice dependant on the
land use pattern, that is dependent on the location choice of all other locators. Therefore, further location and accessibility changes are expected to follow after any location change, which is also a type of technological externality called \textit{location externality}, which is directly associated with \textit{agglomeration economies} in urban economics, although here we refer not only to location of firms but also residences.

The impact of transport changes on the \textit{LUB} (equation 11) may be analysed differentiating the willingness to pay function (equations 12 and 13) with respect to a given trip benefit:

\[
\frac{\partial WP_{hi}}{\partial acc_{mij}} = \sum_{kl} f_k \delta_{dil} \left[ \frac{\partial U_{hk} (z_i)}{\partial z_i} \frac{\partial z_i}{\partial acc_{mij}} - \frac{\partial TGC_{kil}}{\partial acc_{mij}} \right]
\]  

(14)

These terms describe the transference of transport benefits (\textit{acc}) into location willingness to pay, hence into the land use market. The first term represents all technological externalities. It is composed by the dependence of each activity’s utility with the local environment where the activity is performed (\( \partial U_{hk} / \partial z_i \)), the inter-dependence of local environments or the internal dependence of land use pattern (\( \partial z_i / \partial z_j \)), and the dependence of the local environment on the accessibility to activity \textit{m} in zone \textit{j} (\( \partial z_j / \partial acc_{mij} \)). The second term represents the access effect, which includes all interactions between \textit{TGC} and \textit{acc} at the level of trips generation, destination choices, transport mode choices and road congestion.

Observe that equations (12) to (14) may be extended to include not only outward trips from zone \textit{i}, associated with accessibility, but also inward trips in order to include attractiveness effects; such extension to the above analysis would provide analogous effects related to attractiveness.
3.3 Towards an operational approach: the stochastic model

Several models of urban location are based on stochastic versions of Alonso’s bid-rent economic theory (Hayashi and Doi, 1989; Miyamoto and Kitazume, 1993), including the bid-choice theory (Martínez, 1992) applied in the Santiago land use model MUSSA (Martínez and Donoso, 1996). The bid-choice theory assumes that bids for a location \( B \), defined as willingness to pay minus a speculation factor \( w \), are stochastic variables, which make these models operational and more realistic. Assume bids given by:

\[
B_{hi} = W_{hi} - w_{hi} + \varepsilon_{hi}
\]  

with \( W_{hi} \) the systematic term and \( \varepsilon_{hi} \) a random term to be distributed, in this example model, identical and independent Gumbel. The rent for a given location \( i \) is directly obtained by the expected value of the maximum bid, then:

\[
r_i = E\left[ \text{Max} \left( W_{hi} - w_{hi} + \varepsilon_{hi} \right) \right] = \frac{1}{\mu} \ln \sum_{h \in H} \exp \left[ \mu \left( W_{hi} - w_{hi} \right) \right] + \frac{\gamma}{\mu}
\]  

with \( \mu \) the scale parameter of the Gumbel distribution and \( \gamma \) is the Euler’s constant (aprox. 0.577); \( H \) is the set of individual bidders at a given time. Additionally, according to the rule of the highest bidder the probability that an individual \( h \) will locate his residence in a given place \( i \) is:

\[
P_{h/i} = \frac{\exp \mu(W_{hi} - w_{hi})}{\sum_{h \in H} \exp \mu(W_{hi} - w_{hi} - r + \gamma)} = \exp \mu(W_{hi} - w_{hi} - r + \gamma)
\]  

13
According to the bid-choice theory and under Walras’ type of equilibrium (no excess of demand), the best bidder clearing rule is equivalent to the choice rule where each locator maximises her/his consumer’s surplus (Martínez, 1992). Thus, for any forecasting year, the expected consumer’s surplus value obtained by a locator type h facing an exogenous rent \( r \) is:

\[
E(\text{CS}_h) = \frac{1}{\mu} \ln \sum_{i \in \Omega} \exp\left(\mu (WP_{hi} - r_i)\right)
\]

with \( \Omega \) the set of available locations. This equation is a direct result of the assumed Gumbel distribution and the assumption that consumers behave as price takers. Additionally, the expected surplus for the landlord of an elementary lot is equal to the expected rent given by equation (16).

Assume consumers categorised, with \( N_h \) consumers in category \( h \), and supply grouped into zones, with \( N_i \) locations in zone \( i \). The expected total change in \( LUB \), obtained by adding benefits of all consumers and producers between situations \( t=0 \) and \( t=1 \), is:

\[
E(\Delta LUB) = \left[ \sum_{h \in H} N_h E(\text{CS}_h(U^*)) + \sum_{i \in \Omega} N'_i r'_i \right]_{t=1} - \left[ \sum_{h \in H} N_h E(\text{CS}_h(U^*)) + \sum_{i \in \Omega} N'_i r'_i \right]_{t=0}
\]

Observe that \( \Delta LUB \) depends on the exogenous variation of population \( (H) \) and the variation of supply options \( (\Omega') \), which is endogenously defined in MUSSA model, both affecting the land market equilibrium defined by \( WP, w \) and \( r \) (Martínez and Donoso, 1995). Also observe that the consumer surplus should be calculated for a fixed utility level.
Analogously to the deterministic case, the variation of location benefits should be analysed noting that the location willingness to pay is a function of the access attributes (accessibility and/or attractiveness, depending on the activity been located). The expected marginal variation on $LUB$ with respect to a generic attribute $z_{hi}$ of the willingness to pay function is:

$$
\frac{\partial E(LUB)}{\partial z_{hi}} = \sum_{h \in H} \sum_{i \in \Omega} N_i \left( \frac{\partial WP_{hi}}{\partial z_{hi}} p_{hi} + \frac{\partial r}{\partial z_{hi}} (1 - p_{hi}) \right) dz_{hi}
$$

with

$$
\frac{\partial r}{\partial z_{hi}} = P_{hi} \left( \frac{\partial WP_{hi}}{\partial z_{hi}} - \frac{\partial \gamma_{hi}}{\partial z_{hi}} \right)
$$

These equations assume that the Walras equilibrium condition holds in the urban market; if this is not the case, the bid-choice equivalence does not hold and these equations are slightly more complex because some terms do not cancel out.

It can be observed that the effect on $LUB$ associated with rent variations depends upon the highest bidder probability ($P_{hi}$). Consider the extreme case where it is equal to one, which can only happen if $B_{hi}=r_g$ (see equation 17), to see that the rent effect vanishes (assuming speculation constant) yielding the variation on the expected $LUB$ value equal to the expected variation in willingness to pay, which is the result obtained for the deterministic case (equation 11). In all others cases, there is a combination of willingness to pay and rent effects. This shows that, in line with to the deterministic case, the variation of rents does not correctly represent land use benefits.

4. Transport and Land Use Relationship
In the analysis of the relationship between location benefits \((LUB)\) and transport benefits \((TUB)\), the values of the derivatives \(\partial WP_{hi}/\partial acc_{hi}\) and \(\partial WP_{hi}/\partial att_{hi}\) are decisive in defining the degree of similarity between these measures. For example, consider \(WP\) being a lineal function of access, that is:

\[
\frac{\partial WP_{hi}}{\partial acc_{hi}} = \xi_h \quad \text{and} \quad \frac{\partial WP_{hi}}{\partial att_{hi}} = \chi_h \quad \forall \ i \tag{22}
\]

then (assuming the bidders’ speculation independent of access), expression (21) reduces to:

\[
dE(LUB) = \frac{1}{\mu} \sum_{n \in \Omega} N_i \sum_{h \in H} \left( P_{h,i} + P_{h,i} (1 - P_{h,i}) \right) (\xi_h acc_{hi} + \chi_h att_{hi}) + \Lambda \tag{23}
\]

where \(\Lambda\) represents technological externalities, including direct and endogenous location effects.

Reminding that the total variation in accessibility and attractiveness directly represents the total transport benefit \((TUB)\), then equation (23) establishes a direct relationship between \(LUB\) and \(TUB\).

It shows that the set of values for \(\xi, \chi\) and \(\Lambda\) defines whether \(TUB\) could over or under estimate \(LUB\). It is enlightening to note that complete equivalence between \(TUB\) and \(LUB\) only occurs if \(\xi = 1, \chi = 1, \Lambda = 0\). We conclude then that these parameters define the degree to which travellers retain benefits and the degree of percolation of these benefits into land rents. A second conclusion is that the temptation to take changes in land rents as a good estimate of a transport project benefits is generally incorrect.
Let us consider the relationship between $TUB$ and $LUB$, concentrating only on the more known effect of access, i.e. ignoring $\Lambda$ for the moment. The degree of the access effect depends on parameters $\xi$ and $\chi$ of the $WP$ functions, which define the locators’ trade off between access (to activities other than residence) and other location amenities. Hence they are associated with household utility functions and are expected to be specific to socio-economic and cultural characteristics. Indeed, one can think of two cities of different cultures: one with a transport minded population, where household and firms locate themselves so as to minimise transport costs, and a second one where locations are mainly decided with regards to social ties (family or culture background). In the first city one should expect that $TUB$ will be fully transferred into land values and is similar to (the access effect of) $LUB$. Conversely, in the city where people are less sensitive to transport costs, transport benefits will produce a low impact in the land use system, particularly on land rents, hence transport user benefits will be considerably greater than the land use benefits. The obvious conclusion is that total benefits derived from a transport project should be assessed in the transport system; since $LUB$ would underestimate benefits in this case. On the other hand, in a highly sensitive city $LUB$ is expected to be a close estimate of $TUB$, although $TUB$ is still the correct estimation of total benefits on the assumption of no technological effects.

Consider now technological effects only. As for nuisance externalities of transport (pollution, noise, etc.), the analysis is similar to the access effect because the relevant transport variables explicitly appear in location $WP$ functions, but the conclusion is different. Indeed, in this case nuisance disbenefits can only be properly determined in the land use system since it affects located activities (non-users) and not travellers, hence it should be measured as part of the $LUB$. With regards to location externalities, they are definitively not observable in the transport system and may be better analysed in a quasi-dynamic framework: direct transport impacts generate relocation of activities, which induce further relocation due to location dependency. Additionally, relocation also generates changes in trip patterns, which in turn has a feedback into more location changes, describing a
cyclical interaction that only settles if the global land use-transport system attains equilibrium. Theoretically, at the global equilibrium, all transport and land use variables achieve a static equilibrium and every technological effect vanishes in the next iteration between transport and land use. However, at a disequilibrium stage, the technological effect may induce important relocation impacts with relevant benefits in addition to those calculated by $TUB$ with a partial equilibrium transport demand model.

It is clear that available travel demand models do not forecast global equilibrium, but the partial equilibrium conditional on the location of activities. Hence under current modelling practice, technological externalities are neglected and total transport benefits are biased in at least two ways. First, it is reasonable to expect the bias to be an underestimation of total benefits since relocation will attempt to maximise locators utility under an improvement in access conditions (other things ceteris paribus), which should lead to an equilibrium with total benefits equal or greater than before the access change. Secondly, all relocations are neglected in the travel demand model, therefore $TUB$ measures are biased but it is not possible to anticipate the sign of this bias.

Additionally, combining access and technological relocation effects, it is worth noting that the higher the sensitivity to access, the more direct effects are expected, since more relocation adjustments should occur. Hence, the closer $LUB$ is to the measure $TUB$ on access effects, the larger the expected bias due to technological effects. Therefore, allowing for technological effects to be counted for, the more sensitive to transport is the city population the poor the estimation of total benefit made by $TUB$ obtained from partial transport equilibrium.

This lead us to the following conclusions:
1) Total benefits generated by a transport project will be correctly estimated by transport users’ benefits (TUB) only if the travel demand model properly forecasts the combined land use-transport system equilibrium, i.e. the travel demand model incorporates all technological and access effects.

However, this is far from current practice.

2) Total benefits calculated by TUB obtained from partial transport equilibrium are expected to be biased by two ways: they neglect relevant technological effects as transport nuisance and location externalities, and ignore land use-transport feedback (e.g. congestion and environmental effects). The more sensitive the city population is to access, the larger the bias; the sign cannot be anticipated.

This imposes a difficult condition on the correct calculation of the TUB, namely that it should be done using a travel demand model able to anticipate all land use externalities; on applied grounds it requires the use of a land use-transport integrated model based in a consistent microeconomic equilibrium framework. Additionally,

3) Benefits measured in the urban land market (LUB) would normally underestimate total benefits because they ignore benefits retained by transport users; the less sensitive to access the population is, the larger the bias.

This last argument invalidates the use of land value capture as land rent changes to assess a transport projects benefits.
The diagram on Figure 1 summarises graphically our conclusions on the general relationship between benefits measured by using partial equilibrium models of transport and land use and total benefits obtained by general equilibrium. Note, however, the diagram may be misleading since total benefits might be bigger or smaller than those calculated from partial equilibrium. The diagram does not display explicitly land-use transport feedback effects.

5. Empirical Analysis

In this section we present some calculations made to assess the difference between $TUB$ and $LUB$. The purpose of this experiment is to replicate the usual calculation of $TUB$ made by partial transport equilibrium models and compare it with the $LUB$ associated with access and location effects.
Calculations of benefits were carried out using the land use-transport interaction model of the city of Santiago (4.5 million inhabitants), called MUSSA-ESTRAUS (Martínez, 1996; Martínez and Donoso, 1996), which is consistent with the basic theoretical and empirical approach discussed above. Population is disaggregated into 65 household categories (regarding income, car ownership and household size) and 5 firm types describe economic activity. The urban area is divided into 264 homogeneous zones and residential supply is segmented into 10 types (regarding land lot size and differentiating houses and flats). The land use model, MUSSA, finds the market equilibrium for households and firms locations in the urban area for a given pattern of accessibility. The transport market equilibrium is modelled by ESTRAUS for the 264 origin and destination zones and 11 transport modes, including public and private transport, operating in a network subject to congestion. Although MUSSA-ESTRAUS feedback is a normal procedure, this was not performed in this test to as to approximate results to current practice. Access variables are calculated from ESTRAUS outputs using equation (4).

We considered two hypothetical examples depicted in Table 1. In the first case we compared the long run (time series) values of $\Delta LUB$ (equation 19) and $\Delta TUB$ (from equation 3) taking two years (1991-1997) for a given transport system, where the main change is the population growth (from 4.7 to 5.2 million of inhabitants). Because total population changes, total trips also change between these two years and $\Delta TUB$ should be calculated with the long run formulae of equation (3). Here the calculation of transport benefits is performed using the set of balancing factors associated with the corresponding trip demand model of each year, with exogenous calculations of total trip origins and destinations. In the second case of Table 1, population is fixed representing the year 2005, where measures of benefits for situations with and without an investment plan are compared; the plan includes road and public transport infrastructure investments. In this case benefits were calculated using, again, equation (19) for $\Delta LUB$ and equation (2) for $\Delta TUB$, which is appropriate when total trips remain fixed while their distribution across destinations changes due to the investment plan.
Transport benefits are obtained using balancing factors of the corresponding demand model with and without the plan.

Table 1: Comparison of land use and transport benefits (million US$)

<table>
<thead>
<tr>
<th>CASE</th>
<th>ΔTUB</th>
<th>ΔLUB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-1997</td>
<td>-787</td>
<td>891</td>
</tr>
<tr>
<td>2005wp-np</td>
<td>1.957</td>
<td>419</td>
</tr>
</tbody>
</table>

The negative value of \( TUB \) for the time series 91-97 reflects the impact of the population increase and the consequently increase in congestion, without mediating any capacity adjustment. The land use measure, on the other hand, reveals the development impelled by the population increase and the economic growth, generating higher rents and higher households’ income. Hence, the \( \Delta LUB \) index is confounded by the capitalisation of the city economic growth into urban development, in the form of land rents, despite the reduction on access due to higher congestion. This example clearly shows that \( LUB \) is a misleading indicator of \( TUB \) despite similarities in some circumstances.

In order to isolate the impacts of transport projects from changes in population, a fair comparison between \( LUB \) and \( TUB \) is obtained for the year 2005 with and without investments, with population held constant. Notice that \( LUB \) incorporates access and technological externalities. Table 1 (bottom) shows that benefits measured in the transport system (\( TUB \)) are 4.6 times those in the activity system (\( LUB \)). This lower \( LUB \) is consistent with the low locutors’ sensitivity to access observed by the estimated parameters of \( acc \) and \( att \) in the MUSSA willingness to pay functions. This is important
empirical evidence that transport users retain most of transport benefits in Santiago, with only a fraction percolating into land rents.

6. Conclusions

Current methods for evaluation of urban transport projects rely on calculated benefits to users \((TUB)\) based on the absence of equilibrium in the land use-transport system. A first contribution in this work is the extension of theoretical measures of transport benefits to cope with inelastic demand, able to calculate valid measures in the case of significant changes in total trips, called the long-term case. Secondly, measures for land use benefits \((LUB)\) have been specified, differentiated by consumers and producers benefits and analysed for a stochastic location model.

Previous studies (Mohring 1961, 1976; Wheaton 1977 and Sasaki and Kaiyama 1990) had demonstrated that total benefits generated by projects in the transport system are correctly measured by the users’ benefit. The assumption that allows them to reach this conclusion is implicit in their analysis, namely that locators behaviour is well described by the maximisation of accessibility and attractiveness; a second assumption, explicitly stated by Wheaton, is the absence of “direct” or technological externalities, including transport nuisance, location externalities and land use-transport feedback. In the urban context this assumption is highly restrictive since externalities are widely recognised as a variety of agglomeration economies. In this work we have generalised the locator’s utility function allowing explicit consideration of these effects.

We have reaffirmed that, indeed, total benefit can be correctly measured by transport users’ benefits if global transport and land use equilibrium is achieved and well described by the travel demand function (or that all technological externalities can be neglected). This extends Mohring-Wheaton previous result to the case with technological externalities, retaining the assumptions that general land use transport equilibrium is attained and everything else remains ceteris paribus. Additionally, we
have concluded that the assumption that locators behave as access maximizers (or even more restrictive as transport cost minimizers), which implies full capitalisation of transport users’ benefits into land rents, is not supported by the evidence. This extremely simple assumption is unlikely to occur and it depends on the relevance of other location attributes affecting consumers’ location choices, i.e. it depends upon the level of population sensitivity to access. Hence, under global equilibrium, we expect that a significant part of transport users’ benefits are retained by transport users and the rest percolate into land rents.

A widespread practice is the use of partial transport equilibrium models for transport project assessments, which, by ignoring technological externalities, implies that the resultant measures of TUB underestimate total benefits. A less common practice, but one still mentioned in planning studies, is to assess transport project benefits measuring the expected change in land rents, which is expected to underestimate total benefits, especially if sensitivity to access is not the dominant factor for activities location. Moreover indexes of LUB can be severely confounded by the impact of population and economic growth on rents and relocation. In some cases underestimation of benefits is considered a weak problem, assuming that higher benefits will only improve the possibilities of the project to be developed, but this should be taken carefully as it is not clear to what extent this underestimation would favour some type of projects systematically. For example, it may bias results persistently towards some specific transport modes or population categories.

The main recommendations arising from these conclusions is that practice in transport project appraisals should move towards land use-transport integrated models to assure global equilibrium conditions, which incorporates all access and technological location externalities.

References


