Transportation (2017) 44:977–997
DOI 10.1007/s11116-016-9689-3

Mode-valued differences of in-vehicle travel time Savings

C. Angelo Guevara[1]

Published online: 2 March 2016

Abstract The value of in-vehicle travel time savings (*VT*) estimated from mode-choice models has been sometimes found to be higher for private car than for public transportation. This mode-valued variation may seem paradoxical, if public transportation (especially the bus) is perceived as less pleasant than the private car, and because mode-valued differences in the *VT* cannot be attributed to self-selection. This article describes two alternative microeconomic explanations for this empirical finding. The first follows from noticing that the marginal consumption of goods may depend on travel time, but differently for each mode. A marginal reduction in travel time induces marginal savings in the consumption of goods like fuel or oil, but those marginal savings are perceived by the user only when conditioning on the use of the car. This effect can be explicitly accounted with the inclusion of technical constraints relating goods consumption and time assignment in the microeconomic framework of the *VT*. The second explanation follows from noticing that the activity schedule does not need to be the same conditional on the use of each mode. Since the car is usually faster and more accessible, a schedule constructed conditional on the use of the car could be more complex, justifying higher values of time as a resource for that mode. The article finishes illustrating the proposed explanations with an example and then summarizing the contributions of this research and proposing lines for further investigation.

Keywords Value of time · Mode choice · Microeconomics · Activity schedule · Discrete-continuous

✉ C. Angelo Guevara
crguevar@ing.uchile.cl

1 Civil Engineering Department, Universidad de Chile, Blanco Encalada, 2002 Santiago, Chile

Introduction

The subjective valuation of travel time savings (*VT*) corresponds to individual's willingness to pay for a marginal reduction of travel time. Reductions in travel time account for about 60 % of the total benefits of transportation projects (Hensher 2001). Therefore, disentangling the components and determinants of *VT* plays a crucial role in transportation economics.

VT needs not to be the same between modes. Wardman (2004) distinguishes two types of differences in the *VT* by mode: *user type* and *mode-valued* differences. *User type* differences are explained by the differences in the characteristics of the individuals that choose each mode. For example, people with higher income will have a higher *VT*, and will choose the car more often since it is usually faster and more expensive. Consequently, *VT* for people that choose the car is likely to be found higher than the *VT* of bus riders. Instead, *mode-valued* differences correspond to variations in the in-vehicle *VT*, for the same individual, depending on the mode where this time is spent. This research is concerned with the latter type of between-modes differences in the *VT*.

Countless studies have estimated *VT*, but only a few have made a distinction of it between modes. Wardman (2004) points out that this occurs because most studies focus only on the chosen mode (as in, e.g. Gunn et. al 1999; Kouwenhoven et al. 2014), or consider mode-choice models with generic coefficients, forcing the *VT* to be the same between modes (as in, e.g. Gaudry et. al. 1989). Wardman (1997) identified 20 mode-choice studies that considered mode specific coefficients, finding for 6 of them that mode-valued *VT* for car was higher than for public transportation. Axhausen et al. (2004) and Gutierrez and Cantillo (2012) are two additional examples of articles that report mode-valued *VT* that are higher for the car than for public transportation. Shires and De Jong (2009) investigated this issue in a meta-analysis study, but without reaching conclusive results because of lack of sufficient observations. More recently, the meta-analysis of UK *VT* studies developed by Wardman et al. (2012) and Abrantes and Wardman (2011) showed mode-valued *VT*s that were statistically equal between the bus and the car, and higher for the car than for the train.

The finding of higher mode-valued in-vehicle *VT* for car could be explained from a microeconomic viewpoint if one is willing to accept, e.g., that travel time by public transportation is more pleasant or productive. This is likely true for the train, but may become highly questionable, e.g., for urban buses. Often, public transportation is perceived as less comfortable than the car, and also less reliable in terms of travel time. Therefore, individuals should be willing to pay relatively more, instead of less, for saving a marginal unit of time spent on public transportation, especially for the bus. This statement is analyzed further in "Classical microeconomic explanations for mode-valued differences in the value of time" section, after a detailed review of the classical microeconomic framework of the *VT*.

Although Wardman (1997) found higher mode-valued in-vehicle *VT* in only 30% of comparable cases, the real share of this phenomenon could be much higher. It is likely that many experiments that used generic *VT*, could have reported higher *VT* for private transportation, if mode-specific parameters would have been considered. To illustrate this statement, this section revisits an urban mode-choice model that was estimated with generic coefficients in previous studies, and results in higher *VT* for private modes when considering mode-specific time coefficients. The results are summarized in Table 1.

Table 1 Logit mode choice model from "Las Condes-Centro" database with and without mode specific in-vehicle (IV) travel time coefficients

	Model I generic IV time coefficient		Model II mode specific IV time coeff.	
Coefficients	$\hat{\beta}^G$	s.e	$\hat{\beta}^S$	s.e.
1. Walking time	−0.161	0.0193	−0.165	0.0195
2. Waiting time	−0.236	0.116	−0.255	0.118
3. IV time private	−0.0824	0.0174	−0.138	0.0299
4. IV time public			−0.0818	0.0174
5. Cost/Income	−0.0245	0.00877	−0.0211	0.00875
6. Female	−0.295	0.215	−0.295	0.215
7. Licenses	2.36	0.422	2.36	0.420
Final log-likelihood	−949.135		−946.397	
Adjusted rho-square	0.224		0.225	
N	697		697	

Alternative specific constants by mode omitted from this summarized report

IV time In-vehicle travel time, *Private* car and carpool, *Public* bus, metro, shared-taxi and combinations, *Source of data* Ortuzar and Donoso (1983). Generic specification replicates Munizaga and Daziano (2002)

The database used for this example is known as "Las Condes-Centro" (Ortuzar and Donoso 1983). This revealed preference database consists of 697 individuals from different areas of Santiago de Chile, who have 9 modes on their choice-sets, including public transportation (bus, metro, shared-taxi and combinations) and private modes (car and carpool). This database has been used before by several researchers (see, e.g. Gaudry et al. 1989; Munizaga and Daziano 2002; Amador et al. 2008) all of whom considered generic coefficients for the car and public transportation, forcing the *VT* to be the same by mode.

Model I, at the left of Table 1, was obtained replicating the specification used by Munizaga and Daziano (2002). The level of service includes in-vehicle travel time (IV time), walking and waiting time, and cost divided by income. Besides, this model includes the variable Licenses for the car-driver mode, which corresponds to the number of cars divided by the number of licenses in the household. Finally, gender (1 if it is female) is included for carpool and shared-taxi modes.

As it is going to be shown in "Classical microeconomic explanations for mode-valued differences in the value of time" section, the VT could be obtained from this choice model as the ratio of the coefficients of time and cost. Since in this specification the cost was divided by person's income, the in-vehicle VT for the generic model $\left(V\hat{T}^G\right)$ can be calculated as

$$V\hat{T}^G = \frac{\hat{\beta}_3^G}{\hat{\beta}_5^G} * Income = \frac{\hat{\beta}_4^G}{\hat{\beta}_5^G} * Income = 3.36 * Income.$$

Model II, in the right column of Table 1, considers the same specification of Munizaga and Daziano (2002) but with specific coefficients for IV time for public and private modes.[1] Therefore, In this case, a *VT* for each mode type can be calculated, resulting that

[1] The model still considers the same coefficient of travel cost for both modes. This implicitly assumes that income effect is negligible and that the money has the same value, regardless of how it is spent. The former assumption would be broken if transportation expenditure is a large share of total income. The latter

the in-vehicle *VT* for the private modes $V\hat{T}^S_{\text{Private}}$ is higher than for public modes $V\hat{T}^S_{\text{Public}}$ for the same individual, that is, even after controlling by income or any other characteristic of the individual.

$$V\hat{T}^S_{\text{Private}} = 6.54 * Income = \frac{\hat{\beta}^S_3}{\hat{\beta}^S_5} * Income > \frac{\hat{\beta}^S_4}{\hat{\beta}^S_5} * Income = 3.88 * Income = V\hat{T}^S_{\text{Public}}.$$

Thus, in this example, when the time coefficients are not forced to be generic, the mode-valued in-vehicle *VT* for private transportation becomes almost twice as the in-vehicle *VT* for public transportation. Applying a likelihood ratio test, it can be shown that this difference is statistically significant. This suggests that the real share of cases in which in-vehicle *VT* is higher for private transportation, may be much larger than the 30 % found by Wardman (1997).

This article proposes two alternative microeconomic explanations that may justify this seemingly contradictory result. The first explanation is that the marginal consumption of some goods, like oil or fuel, depends on travel time, but differently by mode. Only in the case of the car, where the user is also the operator, this indirect effect is likely to have an impact in the *VT*. The second explanation follows from noticing that the activity schedule does not need to be the same when using each mode. Since the car is faster and more accessible, the activity schedule that is performed when using the car, will be often more complex, resulting in a higher value of the time as a resource.

The article is structured as follows. After this introduction, "Classical microeconomic explanations for mode-valued differences in the value of time" section provides a review of the classical microeconomic theory for analyzing the *VT* and its application for the analysis of mode-valued differences in the *VT*. Then, "Alternative explanation I: differences in technological constraints by mode" section presents the first alternative microeconomic explanation that is proposed in this article. This explanation follows from accounting for the differences in technological constraints by mode. "Alternative explanation II: differences in activity schedules by mode" section presents the second alternative explanation, which follows from accounting for activity schedule differences between modes. "Numerical example of proposed and classical explanations" section illustrates the proposed alternative explanations with a numerical example. Finally, "Conclusion" section summarizes the contributions of the paper, and identifies future lines of research in this area.

Classical microeconomic explanations for mode-valued differences in the value of time

This section describes the classical microeconomic framework of the *VT* that was proposed by DeSerpa (1971). Besides, it reviews the extension of DeSerpa's (1971) framework to discrete choice modeling, which allows the estimation of the *VT* from observed modal choices.

Footnote 1 continued
assumption would no longer hold if the mental account of expenses (see, e.g. Bao et al. 2015) differs between public and private transportation.

DeSerpa (1971) considers that individuals determine their daily activities and goods consumption by maximizing a utility function U that depends on time T and goods X, subject to three types of constraints, as shown in Eq. (1). There is first a monetary budget constraint, with Lagrange multiplier λ, which indicates that individuals use all their income I in consuming the goods X_i with prices P_i. There is also a time budget constraint, with Lagrange multiplier μ, which states that the sum of the time assigned to all activities T_i should be equal to the total time available τ. Finally, there is a technological constraint associated to each activity i, with Lagrange multiplier K_i, which states that the time assigned to activity i should be enough to consume the goods X_i associated to it. Note that DeSerpa's (1971) framework considers that goods X_i are specific to activities T_i.

$$\begin{aligned}
&Max_{X,T} U(X_1, \ldots, X_n, T_1, \ldots, T_n) \\
&s.t \quad \sum_{i=1}^{n} P_i X_i = I \qquad [\lambda] \\
&\sum_{i=1}^{n} T_i = \tau \qquad [\mu] \\
&T_i \geq a_i X_i \qquad [K_i] \quad \forall i = 1, \ldots n \\
&X_i \geq 0; T_i \geq 0 \qquad \forall i = 1, \ldots, n
\end{aligned} \tag{1}$$

The optimal utility level U^* attained by resolving the problem shown in Eq. (1) is called the indirect utility. This utility depends on the exogenous variables I, τ and the prices. If this optimization problem is non-degenerate (see, e.g. Luenberger 2003), the Lagrange multipliers at the optimal point will correspond to the marginal impact in the indirect utility of relaxing each constraint. Consequently, λ is the shadow price of income or the marginal (indirect) utility of income ($\partial U^*/\partial I$); μ is the marginal (indirect) utility of time as a resource ($\partial U^*/\partial \tau$); and K_i is the marginal (indirect) utility of reducing the minimum time required to be assigned to activity i. Therefore, K_i/λ corresponds to the willingness to pay for a reduction in the minimum time required to perform activity i. If $T_i* > a_i X_i*$, then K_i will be equal to zero and if $T_i* = a_i X_i*$, then K_i will be positive.

For discrete choices, such as the selection of a transportation mode, the behavioral model implied by Eq. (1) has to be slightly modified. Adapting from McFadden (1981) and Jara-Díaz (2007; Sect. 2.2.2), consider the model depicted in Eq. (2), which can be seen as a conceptualization of the discrete continuous consumption problem (Dubin and McFadden 1984) that allows a formal microeconomic interpretation of the value of travel time savings.

Consider that traveling is a particular activity that can be performed by different modes, e.g., car and bus, with respective travel times t_{car}, t_{bus} and travel costs c_{car}, c_{bus}, which are exogenous. To decide between car and bus, the individual determines the set of consumption levels of X and T for all other activities that maximizes his/her utility. The maximum level of utility attained, conditional on the use of each mode j, is known as the conditional indirect utility U_j^*. The behavioral assumption is that the individual chooses the alternative j with the largest U_j^*. This problem is summarized in Eq. (2), where M is the set of available modes.

$$
\begin{aligned}
& Max_{j \in M} Max_{X,T} U(X_1, \ldots, X_n, T_1, \ldots, T_n | j) \\
& s.t \quad \sum_{i=1}^{n} P_i X_i + c_j = I \quad [\lambda] \\
& \sum_{i=1}^{n} T_i = \tau \quad [\mu] \\
& T_i \geq a_i X_i \quad [K_i] \quad \forall i = 1, \ldots, n; i \neq travel \\
& T_{travel} \geq t_j \quad [K_{travel}] \\
& X_i \geq 0; T_i \geq 0 \quad \forall i = 1, \ldots, n
\end{aligned}
\tag{2}
$$

Solving the first-order conditions of Eq. (2), conditional on mode j, it can be shown that $K_i = \mu - \partial U / \partial T_i$. Consequently, considering that activity $i = Travel$ corresponds to be travelling on a given mode, the following three definitions of the *VT* can be postulated:

- $VTR = \frac{\mu}{\lambda}$ is the *Value of Time as a Resource*, which corresponds to the opportunity cost of time, the money equivalence for the change of indirect utility that would be attained if τ is marginally extended.
- $VTA_{Travel} = \frac{\partial U / \partial T_{Travel}}{\lambda}$ is the *Value of Time Assigned to Travel*, the money equivalence for the marginal *direct* utility of assigning time to travel.
- $VT = \frac{K_{Travel}}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U / \partial T_{Travel}}{\lambda} = VTR - VTA_{Travel}$ is the *Value of Travel Time Savings*, the money equivalence for the marginal indirect utility of saving travel time. This is the *VT* used for the assessment of transportation projects and the one obtained from mode-choice models.

The model in Eq. (2) assumes that working time, and thus income, is fixed. If this framework is extended to assume an amount of variable work T_W at a given wage rate w, it could be shown that the expression for *VTR* could be rewritten as follows (Jara-Díaz 2007, Sect. 2.3.1)

$$VTR = \frac{\mu}{\lambda} = w + \frac{\partial U / \partial T_W}{\lambda}$$

Since that extension is not essential for the problem under study in this research, for the rest of the article it is going to be assumed that income is fixed, as shown in Eq. (2).

The implementation of this behavioral model into a method that allows the estimation of the *VT* from observed modal choices, follows from considering what is known as the Random Utility Model (*RUM*). The first step is to recognize that the researcher can measure only a part of the conditional indirect utility. The measureable part is called the systematic utility V_j^* and what remains is an error term ε_j. Then, the probability that individual n would choose, e.g. the bus, will correspond to

$$
\begin{aligned}
P_n(bus) &= P_n\left(U^*_{bus,n} \geq U^*_{car,n}\right) = P_n\left(\varepsilon_{car,n} - \varepsilon_{bus,n} \leq V^*_{bus,n} - V^*_{car,n}\right) \\
&= F_{\varepsilon_n}\left(V^*_{bus,n} - V^*_{car,n}\right),
\end{aligned}
$$

where F_{ε_n} is the cumulative distribution function of $\varepsilon_n = \varepsilon_{car,n} - \varepsilon_{bus,n}$.

To estimate the model, what remains to be determined is a specification of the systematic utility V_j^*. Consider, for example, that V_j^* is linear in c_j and t_j with a coefficient β_c generic for travel cost; coefficients β_{tj} specific by mode for travel time; and alternative specific constants β_j. If ε_j follows an Extreme Value I distribution (0, μ), the choice probability will correspond to the following Logit model

$$P_n(bus) = \frac{e^{\mu V_{bus}}}{e^{\mu V_{bus}} + e^{\mu V_{car}}} = \frac{e^{\mu\left(\beta_{bus}+\beta_{t_{bus}}t_{bus}+\beta_c c_{bus}\right)}}{e^{\mu\left(\beta_{bus}+\beta_{t_{bus}}t_{bus}+\beta_t c_{bus}\right)} + e^{\mu\left(\beta_{car}+\beta_{tcar}t_{car}+\beta_c c_{car}\right)}}. \quad (3)$$

The scale μ of the Extreme Value I distribution cannot be identified and is usually normalized to 1. Similarly, one of the alternative specific constants has to be fixed to zero for identification. The other model coefficients β can be estimated, e.g., maximizing the likelihood of observed choices using Eq. (3).

The link between coefficients β of the choice model in Eq. (3) and the *VT* can be established in two steps. Note first that from the model shown in Eq. (2) $\partial U^*/\partial I = -\partial U^*\big/\partial c_j = \lambda$. Assuming that the traveler selects the shortest path and there is no uncertainty, the actual time spent travelling T_{travel} would be equal to the minimum possible t_j, which is exogenous. This would imply that travelling is not a leisure activity, that the *VT* is not equal to zero, and that $-\partial U^*\big/\partial t_j = K_{Travel\_j}$.

The next step is to consider that the model does not suffer of endogeneity, that is, that the error terms ε_j are independent from t_j, and c_j. This assumption is crucial for discrete choice model estimation (Guevara 2015; Guevara and Ben-Akiva 2006, 2012), and also has a critical implication in establishing the link between mode choice models and DeSerpás (1971) model. Without endogeneity, it can be affirmed that $\partial U^*\big/\partial c_j = \partial V^*\big/\partial c_j = \beta_c$ and $\partial U^*\big/\partial t_j = \partial V^*\big/\partial t_j = \beta_{t_j}$, which allows the estimation of

$$V\hat{T}_j = \frac{\hat{\beta}_{t_j}}{\hat{\beta}_c} = \frac{K_{Travel\_j}}{\lambda}$$

in the binary choice model example shown in Eq. (3). Thus, different *VT* by mode can be obtained by considering coefficients β that are not generic by mode. That was the approach used to estimate the *VT* from the estimators reported in Table 1. The estimation of the components of *VT* is possible but more complex. Jara-Díaz and Guevara (2003) developed a method to achieve that goal by jointly estimating a mode choice model and a time assignment model.

Under the classical microeconomic framework $VT = VTR - VTA_{Travel}$, seemingly leaving VTA_{Travel} as the only possible source for differences in the *VT* by mode. Therefore, the finding of a higher *VT* for car for the same individual would occur only if the VTA_{Travel} is more negative for car than for public transportation. This would occur if the marginal utility of travel time is more negative when driving a car than when riding a bus. Previous research has suggested four possible explanations for this to occur.

The first source of modal differences in VTA_{Travel} could be productivity. Compared to the time spent in a car, travel time in public transportation vehicle may not be completely wasted, but instead used to perform certain activities. This assumption is likely to hold, especially for the train, where passengers may be able to read, work or just relax having a coffee or even watching a movie. In the case of the bus, this assumption is less likely to hold. Lyons and Urry (2005) state that travel time productivity depends on many modal attributes and individual characteristics such as crowding, noise, temperature, availability of seating, age, and personal equipment. Consequently, travel time by car may end up being as or even more productive than travel time by public transportation, especially for the bus in an urban context. Lyons and Urry (2005; Fig. 1) suggests that, although there is a

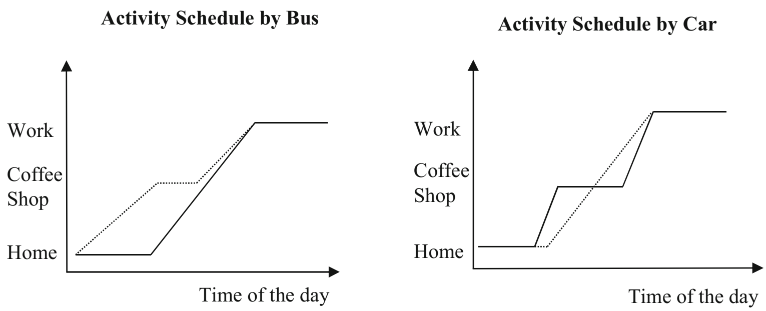

Fig. 1 Different activity schedules conditional on the modal usage

range in which travel time by bus may be more productive than by car, the opposite is instead more likely to occur, thanks in part to what Mokhtarian and Salomon (2001) define as "carcooning".

A second attribute that may turn VTA_{Travel} into a less negative variable for public transportation, could be the aversion to the risk of being involved in accidents, a variable that Elias and Shiftan (2012) found to be a potentially relevant source of mode shift. However, it is unclear that the risk of accidents when using public transportation modes would really be smaller than the risks that are faced when driving a car. While risk aversion to accidents may be a source for differences in the VTA_{Travel} by mode, the net effect will depend on the particular conditions of the transportation system under analysis.

A third attribute that may make VTA_{Travel} less negative for public transportation than for the car, might be the differences in the cognitive solicitation, which corresponds to the mental workload involved in making the trip. Steimetz (2008) report a case study in which 42 % of the *VT* for car could be explained by the combination of the risk and the cognitive effort of driving a car in congested conditions. However, on the side of public transportation, one would also need to account for the cognitive effort and other psychological effects experienced by the passengers in crowded vehicles. For example, from a cognitive point of view, public transportation users have to find out how to move quickly through a dense group of people, stand in a vehicle that is in motion and find out and be aware of where to descend or to transfer. Tirachini et al. (2013) found that, depending of the load factor, a large percentage the value of travel time by bus can be explained by accounting for crowding conditions. A similar result is reported by OECD/ITF (2014). Hence, the net between-modes effect of the risk and the cognitive effort in VTA_{Travel} seems to be unclear.

A fourth possible explanation for having a more negative VTA_{Travel} for car than for public transportation, results from the concavity of the utility function (see, e.g. Jara-Díaz 2007). Since travel time by car is usually shorter than by bus, the concavity may make the marginal effect of the former to be higher than for the latter; even if the direct utility coefficient implies that the person dislikes more the time spent in public transportation than in the car. This explanation is further illustrated with an example in "Numerical example of proposed and classical explanations" section.

Nonetheless, even if VTA_{Travel} does not differ by mode under the classical framework, there are two additional sources that can explain differences in the *VT* by mode.[2] The first source corresponds to modal differences in the marginal utility of income, λ in Eq. (2). Since λ decreases with income (see, e.g. Jara-Díaz 2007), conditional on the use of a more

[2] Section 4 will add a third element to this list.

expensive mode, the individual will be relatively poorer and his/her λ will be higher, causing a reduction of the *VT*. Since the car is usually more expensive than the bus, this effect would imply smaller *VT* for car. This effect is usually negligible, but may become relevant if transportation costs are a large share of the available income.

A final source for differences in the *VT*, even if VTA_{Travel} does not differ by mode, is self-selection. This problem is analyzed, e.g. by Fosgerau et al (2010), Mabit and Fosgerau (2008), Mackie et al. (2001) and Mackie et al. (2003). For example, Fosgerau et al. (2010) developed an experiment in which interviewees were asked first about their *VT* in a given observed trip, and then they were questioned again about their *VT*, but assuming they have to make that particular trip in a different mode. The authors found, for example, that bus users have smaller *VT* in bus, compared to car users that are asked to assume that they travel by bus. The authors interpret this as the result of self-selection, in the sense that it would show that people with higher *VT* tend to choose car and, in the experiment, they "carry" their *VT* with them to the other mode. As it was stated in the introduction, this source of differences in the *VT*, corresponds to what Wardman (2004) defined as *user type* differences, which is not the focus of this article, but is described in general in this section for the sake of completeness.

Summarizing, the empirical finding of higher mode-valued in-vehicle *VT* for car than for bus may seem counterintuitive. It cannot be explained by self-selection and the net effect of previous explanations, elaborated under the classical micro-economic framework, seems inconclusive. This research proposes two alternative microeconomic explanations that provide additional evidence to justify this empirical result.

Alternative explanation I: differences in technological constraints by mode

The first alternative microeconomic explanation for finding higher *VT* conditional on the use of the car, results from a re-interpretation of a result on the *VT* that was attained by Guevara (1999) and Jara-Díaz (2003).

Building on Evans (1972), Jara-Díaz (2003) extended DeSerpás (1971) framework by allowing goods k to not be directly linked to a unique activity i and by replacing the restriction $T_i \geq a_i X_i$ in Eq. (2) by the following two inequalities:

$$\begin{aligned} X_k &\geq g_k(T) \quad [\psi_k] \quad \forall k \in \textit{set of goods} \\ T_i &\geq f_i(X) \quad [K_i] \quad \forall i \in \textit{set of activities} \end{aligned}. \tag{4}$$

The first constraint in Eq. (4) states that there is a minimum amount of goods required to perform an activity. For example, travelling by car implies consuming a minimum amount of fuel. Likewise, chatting with a friend at a coffee shop implies buying a minimum amount of coffee and pastries. This is captured by the function $g_k(T)$ for each good k, a function that depends, in general, on the full vector T of time assigned to activities. ψ_k is the Lagrange multiplier of this constraint. It will be positive if the constraint is binding, and zero otherwise. For goods that the individual enjoys (like chocolate) ψ_k is likely to be zero. For goods that the individual dislikes but have to consume (like fuel) ψ_k is likely to be positive.

The second constraint in Eq. (4) is a generalization of DeSerpa's (1971) technological constraint. It states that, in some cases, there is a minimum amount of time required to consume goods. For example, it may not be possible (or reasonable, or healthy) to eat a meal in less than a given time. Likewise, it might be impossible to perform a trip in less than a given time. This is captured by the function $g_i(X)$ for each activity i, which is a function of the vector X of all goods. K_i is the Lagrange multiplier of this constraint. It will be positive if the constraint is binding and zero otherwise. For activities that the individual enjoys, like chatting with a friend, K_i is likely to be zero. For activities that the individual dislikes, but have to perform (like travel), K_i is likely to be larger than zero.

The value of saving travel time, estimated from choice models like Eq. (3), corresponds to a measure of the trade-off between marginal changes in travel cost and travel time, evaluated at the conditional indirect utilities and satisfying all constraints. Guevara (1999) and Jara-Díaz (2003) showed that, when considering the set of technological constraints shown in Eq. (4), the *VT* has the form shown in Eq. (5).

$$VT = \frac{K_{\text{travel}}}{\lambda} = \frac{\mu}{\lambda} - \frac{\partial U/\partial T_{Travel}}{\lambda} + \sum_k \frac{\psi_k}{\lambda}\frac{\partial g_k}{\partial T_{travel}} \tag{5}$$

The first two terms Eq. (5) are, respectively, the Value of Time as a Resource (*VTR*) and the Value of Time Assigned to Travel (VTA_{Travel}) described by DeSerpa (1971). The third term

$$VCT = \sum_k \frac{\psi_k}{\lambda}\frac{\partial g_k}{\partial T_{travel}} \tag{6}$$

can be interpreted as the subjective Value of saving Consumption of undesired goods when Travel time is reduced (*VCT*).

Whenever $VCT \neq 0$, neglecting the technical relationship between the goods and time assigned to activities would result in an erroneous account of the *VT*. This indirect effect cannot be accounted by the inclusion of the goods consumed in the income constraint, but only by acknowledging the technical relations between goods and time.

For each good k, *VCT* has two components. The first component is $\frac{\partial g_k}{\partial T_{travel}}$, which corresponds to the marginal impact on the consumption of good k of increasing travel time. For example, as travel time grows, it is likely that the individual will be forced to increase the minimum amount of fuel, oil and car maintenance, what implies that $\frac{\partial g_k}{\partial T_{travel}} > 0$ for those goods.

The degree in which the variation of travel time will result in additional goods consumption $\frac{\partial g_k}{\partial T_{travel}} > 0$ will depend on the nature of the time change. For example, if travel time grows as the result of using a route that is longer, the $\frac{\partial g_k}{\partial T_{travel}}$ resulting from it will likely be higher than when such a variation is only due to an increase in the level of congestion on the same route. This impact will also be different depending on a variety of other aspects, such as road roughness and steepness, the driving behavior and the type of vehicle (see, e.g. Chatti and Zaabar 2012).

The second component of the *VCT* is $\frac{\psi_k}{\lambda}$. It can be interpreted as the subjective value of saving consumption of good k, or the willingness to pay for a marginal reduction in the required consumption of k. $\frac{\psi_k}{\lambda}$ will be positive if the constraint for consuming the good k is binding, meaning that the individual would like to consume less of that good. If the constraint is not binding, $\frac{\psi_k}{\lambda}$ will be zero. In the case of fuel, oil, and maintenance, $\frac{\psi_k}{\lambda}$ is likely to be positive.

Resolving the first-order conditions of the behavioral model, it can be shown that $\frac{\psi_k}{\lambda}$ takes the following form:

$$\frac{\psi_k}{\lambda} = P_k - \frac{\partial U/\partial X_k}{\lambda} + \sum_i \frac{K_i}{\lambda} \frac{\partial f_i(X)}{\partial X_k}, \tag{7}$$

where P_k corresponds to the price of the good k, $\frac{\partial U/\partial X_k}{\lambda}$ accounts for the pleasure or displeasure associated with the consumption of good k, and $\sum_i \frac{K_i}{\lambda} \frac{\partial f_i(X)}{\partial X_k}$ corresponds to the impact of increasing the consumption of good k on the time assigned to non-leisure activities.

For example, if the good k is car fuel, P_k would be the fuel market price, the term $\frac{\partial U/\partial X_k}{\lambda}$ will be negative if the individual is concerned about the environmental impact of using fossil fuels. For the same example, $\frac{\partial f_i}{\partial X_k}$ will be positive if consuming fuel implies longer stays at gas stations, an activity that is likely to have a positive $\frac{K_i}{\lambda}$.

Guevara (1999) and Jara-Díaz (2003) analyzed the components of *VCT*, but implicitly considering only the chosen mode. In what follows, the analysis is extended to the comparison of the conditional indirect utilities of chosen and non-chosen modes. This allows formulating an alternative explanation for the finding of higher *VT* conditional on the use of the car.

When the user is not the operator, as e.g. in the bus, the consumption of goods such as fuel, oil and maintenance will enter the individual's behavioral model through the fare. But fare is marginally exogenous from the point of view of the user because it is unlikely that a marginal bus delay for a particular user would translate into a fare increase. In other words, it is unlikely that a bus passenger would perceive any indirect benefit, in terms of fuel, oil or maintenance savings, due to in-vehicle *VT* in the bus, at least not in the short term.

In turn, when the user is also the operator, as e.g. in the car, such indirect marginal effect of in–vehicle *VT* in goods consumption is likely to exist. In this case, fuel, oil and car maintenance is a decision of the individual, and he/she is likely to choose to consume the minimum possible amount of them. If travel time decreases, those minimum required amounts will also decrease, producing an indirect additional benefit from the reduction of travel time, a benefit that will reflect in the *VT*. Such effect cannot be captured unless the technological constraints in Eq. (4) are added to the microeconomic framework.

Thus, under the framework summarized by Eq. (5), a higher *mode-valued VT* for car can be explained in part by the marginal additional consumption of, for example, fuel, oil, or maintenance, goods that are not marginally accounted when traveling by bus. Assuming that those goods are consumed to their minimum required levels, the respective term ψ_k/λ will be positive, and then the positive sign of $\partial g_k/\partial T_{travel}$ will trigger a higher *VT* for car. On the contrary, this effect will not be present when travelling by public transportation because, in that case, the passenger is not the operator.

It is worth noting that, although including the impact that traveling has in the consumption of goods allows justifying higher *VT* for car, so far it is unclear how to disentangle this effect from others. Guevara (1999; Sect. 4.2.5) suggested a method to measure the term *VCT*, which involves a set of additional assumptions and the estimation of a discrete choice model for restricted goods consumption. Further analysis is required to determine the feasibility of implementing such a procedure in practice.

Alternative explanation II: differences in activity schedules by mode

The second alternative explanation for finding a higher *VT* conditional on the use of car than on the use of public transportation, results from a re-interpretation of DeSerpa's (1971) microeconomic framework.

The random utility model, under which the *VT* is estimated from observed choices, considers that users compare optimal arrangements of activities and goods consumption, conditional on a given mode. The conditionality of the modal utility is usually stated as the result of optimizing over continuous goods, given that certain mode is used. However, the maximum level of utility attainable by an individual also depends on the activity schedule he/she performs during the day, which may vary significantly between modes because of their different features. This means that the activity schedule and the overall consumption need not to be the same conditional on each mode.

For example, since the car is faster, it may allow visiting a larger number of places and, therefore, performing a more complex schedule. Complexity of the feasible schedule may also be larger for the car, because the car is more accessible, and its network is often much larger and denser than the public transportation network, allowing the visit of a larger number of places. Likewise, the feasible schedule of car may be more complex because the car allows (or makes easier) to carry goods that are required to perform certain activities, such as groceries, sport clothes, or tools. Guevara et al. (2015) found evidence, using real data from Santiago de Chile, which seems to confirm that the use of the car induces the performance of more complex schedules.

If the activity schedules differ by mode, the *VTR* might also differ by mode. For example, consider that commuting by car makes optimal to stop at a coffee shop, but the contrary occurs when commuting by public transportation. Time assignments and goods consumptions for the unconstrained activities (leisure) of "being at home" and "being at the coffee shop" will not be the same conditional on the use of the car or public transportation. Equivalently, the marginal utility of the time assigned to these leisure activities does not need to be the same, what implies that the *VTR* will generally differ by mode. For example, the time assigned to the activity "being at home", conditional on using the car, could be shorter than the time assigned to that activity when conditioning on the use of public transportation. In such a case, the *VTR*, and therefore the *VT*, will be higher for the car because of the concavity of the direct utility function.

The impact of mode usage on the *VTR* can be described by the example shown in Fig. 1. The left plot in Fig. 1 describes the feasible activity schedules that the individual can perform, conditional on the use of bus. In this case, it is optimal to go straight to work (continuous lines). Instead, visiting the coffee shop (dashed lines in the left plot) is not convenient because the bus speed is not enough to perform such activity between "being at home" and "being at work" within a reasonable amount of time. The right plot of Fig. 1 describes the feasible schedules conditional on the use of car. In this case it becomes optimal to visit the coffee shop (continuous lines), rather than go straight to work (dashed lines in the right plot).

Since in this example the individual leaves home a little earlier when using the car than when using the bus, because of the concavity of the utility function, the marginal direct utility of being at home (leisure) should be higher conditional on the use of car than of bus. In other words, for this example, the *VTR* will be higher conditional on the use of car than on the use of bus. This effect is further illustrated in the example presented in "Numerical example of proposed and classical explanations" section.

Formally, the behavioral assumption is that the individual chooses the alternative with the largest indirect utility, conditional on the mode $j \in M$ and schedule $s \in S$. This problem is summarized in Eq. (8), which is an extension of Eq. (2) that considers optimization over modes and discrete scheduling alternatives in the set S.

$$
\begin{aligned}
& Max_{s \in S} Max_{j \in M} Max_{X,T} U(X_1, \ldots, X_n, T_1, \ldots, T_n | j, s) \\
& \quad s.t \quad \sum_{i \in s} P_i X_i + c_{js} = I \quad [\lambda] \\
& \qquad \sum_{i \in s} T_i = \tau \quad [\mu] \\
& T_i \geq a_i X_i \quad [K_i] \quad \forall i \in s, i \neq travel \\
& T_i = 0 \quad [K_i] \quad \forall i \notin s, i \neq travel \\
& \qquad T_{travel} \geq t_{js} \quad [K_{travel}] \\
& \qquad X_i \geq 0; T_i \geq 0 \quad \forall i = 1, \ldots, n
\end{aligned}
\tag{8}
$$

In the next section, this model will be further extended to include the technological constraints described in "Alternative explanation I: differences in technological constraints by mode" section, and will be used to develop a comprehensive numerical example to illustrate the different sources for mode-valued variations in the VT.

But before that, it is worth noting that the model depicted in Eq. (8) could be used to justify not only different VT by mode, but also different VT along the day. The key resides in the consideration of a time constraint that does not sum over all possible activities, but only over the subset S. This feature can used to account for the fact that re-assignments of marginal savings of travel time are only possible among those activities that are within the relevant chain of activities to which the trip belongs. Then, time saved from midday and commuting trips could only be re-assigned to different sets of leisure activities, resulting in differences in the VTR across the day. This method, which study is left for further research, could be useful to complement the approaches and applications of Tseng and Verhoef (2008), Ozbay' and Yanmaz-Tuzel (2008) and Palety et al. (2015).

Numerical example of proposed and classical explanations

This section provides a numerical example to illustrate the classical and the two alternative explanations proposed in this paper as potential sources for finding higher values of time for car than for bus in mode choice models.

Consider that the person has the possibility to visit a coffee shop between home and work, but with a small modification of his/her commuting route. The mode and schedule options faced by the person are described in Fig. 2, where the numbers on the arrows are the respective in-vehicle travel time in minutes, which are assumed to be fixed.

In this example, travel time by car is always shorter than by bus. If the person does not visit the coffee shop, it takes him/her 40 min to go to work by bus and 20 min by car. If the person does stop at the coffee shop, it takes him/her 30 min in total to go by car and 60 min by bus. For simplicity, it is assumed that there is neither access nor waiting time associated to the bus mode. This assumption is not essential and can be generalized.

In this case, the choice of commuting mode is not only about the choice of a mode, but also the choice of a schedule. For each combination of mode and schedule, the person will determine his/her indirect demand for time assignment, which is the optimal amount of

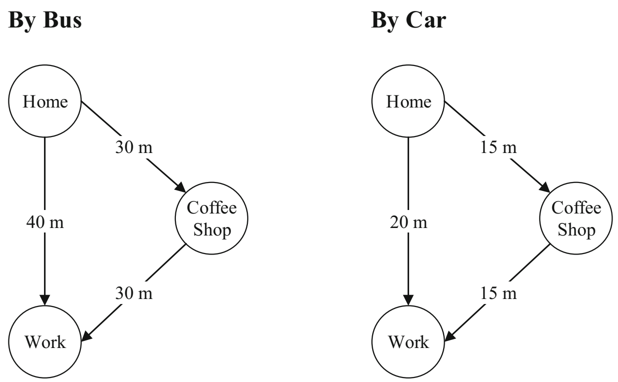

Fig. 2 Example of commuting options of mode and activity schedules

time he/she would like to assign to each activity. The conditional indirect utility for each combination of mode and schedule will be equal to the utility evaluated at the respective indirect demands for time assignment. The conditional modal utilities for the mode choice model shown in Eq. (3) will correspond to the conditional indirect utilities attained with the optimal schedule for each mode.

This choice process could be represented by the overall optimization model described in Eq. (8), but with the addition of the technical constraint of minimum consumption defined in Eq. (4). By this, both proposed alternative explanations for finding higher mode-valued *VT* for car can be handled with a single comprehensive model. Conditioning on each mode and schedule, the overall problem could be transformed into four linear sub-problems that are easier to solve. From left to right in Fig. 2, these models are: Model I, direct trip by bus; Model II: trip by bus that stops at the coffee shop; Model III: direct trip by car; and Model IV: trip by car that stops at the coffee shop.

For example, *conditional on the use of the car and visiting the coffee shop* (Model IV), the person's behavior may be represented by the following optimization problem

$$\begin{aligned}
&Max_{T_i,G} U = K + \alpha_G G^\rho + \alpha_F F^\rho + \alpha_H T_{Home}^\rho + \alpha_{CS} T_{CS}^\rho + \alpha_{TC} T_{TravelC}^\rho \\
&s.t. \\
&T_{Home} + T_{CS} + T_{TravelC} = \tau - \bar{\tau} \quad [\mu] \\
&G + P_F F + c_{IV} + c_{CS} = I - \bar{G} \quad [\lambda] \\
&T_{TravelC} \geq t_{IV} \quad [K] \\
&F \geq \gamma T_{TravelC} \quad [\psi] \\
&T_i, G, F \geq 0
\end{aligned} \quad , \tag{9}$$

where the vector α and the power ρ, are the parameters of a utility function with constant elasticity of substitution, assuming that $0 < \rho < 1$.

The individual perceives direct utility from the time assigned to activities (T), from the amount of money G available for variable consumption and from the consumption of fuel F. The relevant chain of activities for this mode choice problem involves only leisure time at home T_{Home} (Gronau 1986); the time spent traveling by car $T_{TravelC}$ and the time spent at the coffee shop T_{CS}. Time assigned to other activities is considered to be fixed, entering the direct utility in the constant K. This would be the case if, for example, starting time at work and non-leisure time at home are both fixed.

For the numerical example it is going to be assumed that $\rho = 0.5$, $\alpha_G = 1$, $\alpha_F = -0.01$, $\alpha_H = 2$, $\alpha_{CS} = 1$,$\alpha_{TC} = -1$ and $\alpha_{TB} = -1.1$. This implies that the person likes having money available for variable consumption ($\alpha_G > 0$), dislikes consuming fuel ($\alpha_F < 0$), likes being at home ($\alpha_H > 0$) and being at the coffee shop ($\alpha_{CS} > 0$), but dislikes traveling, especially if doing it by bus ($|\alpha_{TB}| > |\alpha_{TC}|$).

μ, λ and κ are the Lagrange multipliers of time, income and travel time constraints, respectively. ψ is the Lagrange multiplier for the restriction for the minimum amount of fuel needed as a function of the travel time by car, and γ is the respective linear parameter. This constraint is not present when travelling by bus, and thus the amount of fuel consumed in that case would be zero. τ is the total available time during the day and $\bar{\tau}$ is the sum of the time assigned to other activities that are considered to be fixed for the relevant chain of activities under analysis. t_{IV} is the exogenous minimum travel time by car when the coffee shop is visited, which for the case described in Fig. 2 is equal to $30 = 15 + 15$.

I is the total income of the individual, $\bar{G}$ are the expenses that are exogenous or fixed, c_{CS} is a fixed cost associated with the visit to the coffee shop (e.g. cost of buffet breakfast). c_{IV} is the fixed travel cost of the schedule that includes visiting the coffee shop by car, which may correspond to travel costs associated with distance. Finally, P_F corresponds to the market price of fuel.

The overall optimization model (Eq. (8) plus Eq. (4)) can be resolved by complete enumeration of all the combinations of modes and schedules. This is done in two stages. First, one has to solve the problem conditional on each combination of mode and schedule. This is, e.g., the problem depicted in Eq. (9) for the case of visiting the coffee shop by car. Then, the global solution results from comparing the indirect utility attained, conditional on each combination of mode and schedule. For the first stage, the problem reduces to a continuous optimization problem as the one shown in Eq. (9).

For Model IV, which involves visiting the coffee shop and using the car (Eq. 9), the Lagrangian ℓ would be the following:

$$\ell = U + \mu\left(\tau - \bar{\tau} - \sum_i T_i\right) + \lambda(I - \bar{G} - P_F F - c_{IV} - c_{cs} - G) + \kappa(T_{TravelC} - t_{IV}) + \psi(F - \gamma T_{TravelC}). \tag{10}$$

Considering that travel time by car $T_{TravelC}$ and fuel consumption F are equal to their minimum allowed values, the person would only have the freedom to decide the optimal time spent at home T_{Home} and the time spent at the coffee shop T_{CS}. It can be shown[3] that, in such a case, the maximization of Eq. (10), implies that the optimal assignment of time is

$$T_{Home} = \frac{\tau - \bar{\tau} - t_{IV}}{1 + \left(\frac{\alpha_H}{\alpha_{CS}}\right)^{\frac{1}{\rho-1}}};\ T_{CS} = \frac{\tau - \bar{\tau} - t_{IV}}{1 + \left(\frac{\alpha_{CS}}{\alpha_H}\right)^{\frac{1}{\rho-1}}}. \tag{11}$$

Besides, μ, $\partial U/\partial T_{TravelC}$, F, G, ψ, λ and κ can be shown to be equal to

[3] See Appendix.

$$
\begin{aligned}
\mu &= \alpha_H \rho T_{Home}^{\rho-1}, \\
\frac{\partial U}{\partial T_{TravelC}} &= \alpha_{TC} \rho T_{TravelC}^{\rho-1}, \\
F &= \gamma T_{TravelC}, \\
G &= I - \bar{G} - P_F F - c_{IV} - c_{CS}, \\
\psi &= \lambda P_F - \alpha_F \rho F^{\rho-1}, \\
\lambda &= \alpha_G \rho G^{\rho-1}, \\
\kappa &= \mu - \frac{\partial U}{\partial T_{TravelC}} + \gamma \psi.
\end{aligned} \tag{12}
$$

Table 2 shows the results of solving the optimization problem for each mode-schedule sub-problem, together with the respective conditional indirect utility attained in each case. It is assumed that $\tau - \bar{\tau} = 150$, $I - \bar{G} = 1000$, $c_{IV} = 11.25$, $c_{III} = 7.5$, $c_I = c_{II} = 5$, $c_{CS} = 5$ and $\gamma = 0.5$.

Conditional on the use of the car (two last columns in Table 2), the person will choose to visit the coffee shop, since it will allow him/her attaining a higher utility of 50.3, instead of 49.8. In turn, conditional on the use of the bus (first two columns in Table 2), the person will choose not to visit the coffee shop, since that will allow him/her attaining a higher utility of 45.6, instead of 44.2. When comparing car and bus in the choice model, the person in this example will consider attending the coffee shop in the former case, and going straight to work in the latter. The modal utility in a mode choice model, like the one described in Eq. (3), will be the largest conditional indirect utility attainable among the

Table 2 Summary of optimal assignment for each mode and schedule combination

Model Mode/schedule	Model I Bus/coffee S.	Model II Bus/direct	Model III Car/coffee S.	Model IV Car/direct
G	990	995	980	990
F	0	0	15.0	10.0
T^*_{Travel}	60.0	40.0	30.0	20.0
T^*_{CS}	18.0	0.0	24.0	0.0
T^*_{Home}	72.0	110.0	96.0	130.0
μ	0.118	0.095	0.102	0.088
κ	0.189	0.182	0.205	0.209
ψ	0	0	0.0234	0.0198
$\partial U/\partial T_{Travel}$	−0.0710	−0.0870	−0.0913	−0.112
λ	0.0159	0.0159	0.0160	0.0159
$VT = \kappa/\lambda$	11.9	11.5	12.8	13.2
$VTR = \mu/\lambda$	7.42	6.02	6.39	5.52
$VTA_{Travel} = [\partial U/\partial T_{Travel}]/\lambda$	−4.47	−5.49	−5.72	−7.04
$VCT = \gamma[\psi/\lambda]$	0	0	0.731	0.622
U^*	44.2	45.6	50.3	49.8
Modal Utility		U^*_{bus}	U^*_{car}	
Choice			X	

alternative schedules for a given mode. This implies that, in this example, $U^{*}_{car} = 50.3$ and $U^{*}_{bus} = 45.6$ and, therefore, the individual would choose the car and visit the coffee shop.

Since in this example the differences in travel cost by mode and the cost of attending to the coffee shop are both negligible compared to $I - \bar{G} = 1000$, λ is almost the same until the third significant digit for all modes and schedules. It can be seen that λ is slightly higher for the alternative that involves a higher cost, which in this case is visiting the coffee shop by car. The usual assumption in mode choice models is to ignore this effect but, if it is relevant, if would result in a slight reduction of *VT* for car, relative to that of the bus.

The subjective value of in-vehicle *VT* for car (and visiting the coffee shop) is 12.8 and for bus (and going straight to work) is 11.5. Besides the negligible modal difference in λ, this gap of 1.3 favoring caŕs mode-valued *VT* can be attributed to three sources, all pointing, in this example, toward the same direction.

The first source of differences in mode-valued *VT* can be attributed to differences in the Value of saving Consumption of undesired goods when Travel time is reduced (*VCT*), as it was described in "Alternative explanation I: differences in technological constraints by mode" section. *VCT* in this example is 0.731 for car and 0 for bus. This component of VT is related with the consumption of fuel that is induced by the travel time, and is only present when travelling by car. Following Eqs. (6) and (7), the VCT effect can be further divided into the effect of fueĺs price ($\gamma P_F = 0.125$) and the effect of the dislike for fuel $\left(\gamma \frac{\partial U/\partial F}{\lambda} = 0.606\right)$.

The second source of differences in mode-valued *VT* can be attributed to differences in the *VTR*, as it was suggested in "Alternative explanation II: differences in activity schedules by mode" section. *VTR* is 6.39 for car and 6.02 for bus. This is explained by the tighter optimal schedule attained with the car. Since when using the car it is optimal to visit the coffee shop, the person would leave home earlier and μ would be higher, with the consequent effect in *VTR*.

The third source of differences corresponds to a gap in the VTA_{Travel} between modes. This explanation is a direct application of classical De Serpás (1972) framework for the value of travel time savings. Note that, despite in this example travel time by car is relatively more pleasant than travel time by bus in the utility ($\alpha_{TC} = -1, \alpha_{TB} = -1.1$), VTA_{Travel} is higher for the former. This occurs because, in this example, travel time by car is shorter and, since utility is concave, a shorter travel time implies a more negative direct marginal utility of travel time $\partial U/\partial T_{Travel}$, an effect that more than compensates the more negative utility coefficient of travel time by bus in this example.

Summarizing, this example illustrates various sources for potential differences in mode-valued *VT*, some of which may often result in higher values for the car than for the bus. It should be kept in mind however that the numbers deployed are arbitrary and thus the relative impact of each effect does not need to be close to the levels shown in this example. New estimation methodologies would have to be developed to be able to disentangle each component of the *VT* described in this example. Some insights of the nature of the potential methods needed are given in the Conclusion section.

Conclusion

Travel time savings account for about 60 % of total benefits of transportation projects (Hensher 2001). Therefore disentangling the components and determinants of *VT* play a crucial role in transportation economics. In-vehicle *VT* obtained from mode choice models is sometimes found to be higher, conditional on the use of car than conditional on the use of public transportation, what may seem counterintuitive from a classical microeconomic perspective. This article describes two plausible alternative microeconomic explanations for this empirical finding.

The first microeconomic explanation is that the marginal consumption of goods when travelling by car depends on travel time, whereas that does not occur when travelling by public transportation. The differences arise because the user is the operator in the case of the car, but not in the case of public transportation. Thus, a marginal delay in car will result in additional expenses in oil, fuel or maintenance, whereas such effect will not be present for public transportation.

The second explanation follows from noticing that the *VT* is not only a characteristic of the individual, but a combination of individual's characteristics and the set of constraints faced. Modal utility in a mode choice model is the maximum conditional indirect utility that can be attained, given certain mode is used. For this, the maximization of utility does not only include optimization over continuous goods and time, but also, among many other things, including activity schedules. This implies that the *VTR* may vary across modes. Given that the car is usually faster and more accessible, conditioning on car would allow performing tighter schedules, resulting in higher values of time as a resource.

The classical and the two proposed alternative explanations for finding higher mode-valued *VT* for car suggest that this phenomenon exists and that it may play a relevant role in mode choice modeling. In practice, this implies that researchers should always explore the hypothesis of mode-specific coefficients for in-vehicle travel time and, upon confirmation, maintain it both for forecasting and economic appraisal (see, e.g. Flügel 2014). Neglecting this effect may have a significant impact in the consistency of the model parameters, as it is illustrated in the example shown in Table 1. Forecasting and project evaluation will be utterly wrong if they are performed using inconsistent estimators (see e.g. Guevara and Thomas 2007).

The question of what is the balance between the two extensions proposed in this article and the classical explanations for mode-value differences in *VT* cannot be responded with the tools that are currently available. Therefore, a natural extension for this research would be to develop methods to measure and to distinguish each of the potential sources for mode-valued differences in the *VT*.

A method for measuring the impact of the productivity of time by mode could consist in surveying the use of time by mode and applying stated preference surveys that inquire explicitly for the valuation of the time assigned to travel by different modes. The idea would be to develop a quantitative counterpart for the qualitative approach used by Lyons and Urry (2005). To measure the impact of risk and effort, the method proposed by Steimetz (2008) could be applied both to private and public modes. Regarding the measurement of the impact of goods consumption by mode on the *VT*, besides the method suggested by Guevara (1999), one alternative could be to measure differentiated income effects by mode using, e.g, the method proposed by Jara-Díaz and Videla (1989). Finally, to measure the impact of schedule's complexity by mode in the *VTR*, it would be possible to explore the possibility of applying the method proposed by Jara-Díaz and Guevara (2003), which is briefly described in "Classical microeconomic explanations for mode-valued differences in the value of time" section, but differentiated by mode.

Acknowledgments I would like to acknowledge the valuable comments provided by two anonymous referees and by the attendants of the conferences WCTR2013, PANAMXVII and TUO III, where preliminary ideas developed further in this paper were presented. Of course, all potential errors remain mine. This publication was funded in part by CONICYT, FONDECYT 1150590 and the Complex Engineering Systems Institute, Chile (Grants ICM P-05-004-F, CONICYT FBO16). The final version of this article was prepared when I was a Visiting Research Fellow at the Choice Modelling Centre of the Institute for Transport Studies of the University of Leeds, UK, with partial funding provided by a Leverhulme's Visiting Professorship.

Appendix: derivation of Eqs. (11) and (12)

Deriving the lagrangian ℓ in Eq. (10) with respect to the leisure activities "being at home" and "being at the coffee shop"

$$\frac{\partial \ell}{\partial T_{Home}} = \alpha_H \rho T_{Home}^{\rho-1} - \mu = 0 \Rightarrow \alpha_H \rho T_{Home}^{\rho-1} = \mu$$

$$\frac{\partial \ell}{\partial T_{CS}} = \alpha_{CS} \rho T_{CS}^{\rho-1} - \mu = 0 \Rightarrow \alpha_{CS} \rho T_{CS}^{\rho-1} = \mu$$

and thus

$$\alpha_{CS} \rho T_{CS}^{\rho-1} = \alpha_H \rho T_{Home}^{\rho-1} \Rightarrow T_{CS}^{\rho-1} = \frac{\alpha_H}{\alpha_{CS}} T_{Home}^{\rho-1} \Rightarrow T_{CS} = \left(\frac{\alpha_H}{\alpha_{CS}}\right)^{\frac{1}{\rho-1}} T_{Home}.$$

Then, considering that $T_{TravelC} = t_{IV}$ and that $T_{Home} + T_{CS} + T_{TravelC} = \tau - \bar{\tau}$, it results that $\tau - \bar{\tau} - t_{IV} = T_{Home} + \left(\frac{\alpha_H}{\alpha_{CS}}\right)^{\frac{1}{\rho-1}} T_{Home}$, arriving at Eq. (11)

$$T_{Home} = \frac{\tau - \bar{\tau} - t_{IV}}{1 + \left(\frac{\alpha_H}{\alpha_{CS}}\right)^{\frac{1}{\rho-1}}}; \; T_{CS} = \frac{\tau - \bar{\tau} - t_{IV}}{1 + \left(\frac{\alpha_{CS}}{\alpha_H}\right)^{\frac{1}{\rho-1}}}$$

from which T_{Home} and T_{CS} can be calculated given that $\tau - \bar{\tau}, t_{IV}, \alpha_{CS}, \alpha_H, \rho$ are known.

Regarding, Eq. (12) first, as it was shown before, $\mu = \alpha_H \rho T_{Home}^{\rho-1}$ is obtained by deriving ℓ with respect to T_{Home}. $\frac{\partial U}{\partial T_{TravelC}} = \alpha_{TC} \rho T_{TravelC}^{\rho-1}$ is obtained deriving the utility by $T_{TravelC}$. $F = \gamma T_{TravelC}$ is assumed to hold. $G = I - \bar{G} - P_F F - c_{IV} - c_{CS}$ is obtained re-arranging terms of the budget constraint. $\psi = \lambda P_F - \alpha_F \rho F^{\rho-1}$ is obtained by deriving ℓ with respect to F. $\lambda = \alpha_G \rho G^{\rho-1}$ is obtained by deriving ℓ with respect to G. Finally, $\kappa = \mu - \frac{\partial U}{\partial T_{TravelC}} + \gamma\psi$ is obtained deriving ℓ with respect to $T_{TravelC}$.

References

Abrantes, P.A., Wardman, M.R.: Meta-analysis of UK values of travel time: an update. Transp. Res. Part A. **45**(1), 1–17 (2011)

Amador, F.J., González, R.M., de Dios Ortúzar, J.: On confounding preference heterogeneity and income effect in discrete choice models. Network. Spatial. Econ. **8**(2–3), 97–108 (2008)

Axhausen, K., A. König, G. Abay, J. Bates, and M. Bierlaire (2004) Swiss value of travel time savings, European Transport Conference 2004

Bao, Y., Gao, Z., Xu, M., Sun, H., Yang, H.: Travel mental budgeting under road toll: an investigation based on user equilibrium. Transport. Res. Part A **73**, 1–17 (2015)

Chatti, K., and Zaabar, I. (2012). Estimating the effects of pavement condition on vehicle operating costs. National Cooperative Highway Research Program Report No. 720. Transportation Research Board

DeSerpa, A.: A theory of the economics of time. Econ. J. **81**, 828–846 (1971)

Dubin, J. A., and McFadden, D. L. (1984). An econometric analysis of residential electric appliance holdings and consumption. Econometrica: J. Econ. Soc. 345–362

Elias, W., Yoram, S.: The influence of individual's risk perception and attitudes on travel behavior. Transp. Res. Part A **46**, 1241–1251 (2012)

Evans, A.W.: On the theory of the valuation and allocation of time*. Scottish Journal of Political Economy **19**(1), 1–17 (1972)

Fosgerau, M., Hjorth, K., Lyk-Jensen, S.: Between-mode-differences in the value of travel time: self-selection or strategic behaviour? Transp. Res. Part D **15**, 370–381 (2010)

Flügel, S.: Accounting for user type and mode effects on the value of travel time savings in project appraisal: opportunities and challenges. Res. Transport. Econ. **47**, 50–60 (2014)

Gaudry, M.J., Jara-Diaz, S.R., de Dios Ortuzar, J.: Value of time sensitivity to model specification. Transp. Res. Part B Methodol. **23**(2), 151-158 (1989)

Guevara, C.A.: "Critical Assessment of Five Methods to Correct for Endogeneity In Discrete-Choice Models. Transportation Research Part A Policy and Practice **82**, 240–354 (2015a)

Guevara, C.A.: Valor Subjetivo del Tiempo Individual Considerando las Relaciones entre Bienes y Tiempo Asignado a Actividades. Civil Engineering Department, Universidad de Chile, Master Thesis (1999)

Guevara, C.A., Ben-Akiva, M.: Change of Scale and Forecasting with the Control-Function Method in Logit Models. Transport. Sci. **46**(3), 425–437 (2012)

Guevara, C.A., Ben-Akiva, M.: Endogeneity in residential location choice models. Transport. Res. Record **1977**, 60–66 (2006)

Guevara, C.A., C. Cartes and J. Cadena (2015) Determinants of the Complexity of the Agenda of Activities. Working paper, Universidad de los Andes

Guevara, C.A., Thomas, A.: Multiple classification analysis in trip production models. Transp. Policy **14**(6), 514–522 (2007)

Gunn, H.F., Tuinenga, J.G., Cheung, Y.H.F., Kleijn, H.J.: Value of dutch travel time savings in 1997. In: Meersman, H., Van de Voorde, E., Winkelmans, W. (eds.) Proceedings of the Eighth World Conference on Transport Research Transport Modelling/Assessment, pp. 513–526. Pergamon, Amsterdam (1999)

Gutierrez, M. and V. Cantillo (2012) Estimación del Valor Subjetivo del Tiempo en un Contexto Urbano: Nuevas Evidencias. Proceedings XVII Panamerican Conference in Transportation Traffic and Logistics, Universidad de los Andes, Chile

Hensher, D.A.: Measurement of the valuation of travel time savings. J. Transport. Econ. Policy **35**(1), 71–98 (2001)

Jara-Diaz, S., (2007) Transport Economic Theory, Emerald Group

Jara-Díaz, S.: On the goods-activities technical relations in the time allocation theory. Transportation **30**(245), 260 (2003)

Jara-Díaz, S., Videla, J.: Detection of income effect in mode choice: theory and application. Transp. Res. B **23**, 393–400 (1989)

Jara-Díaz, S.R., Guevara, C.A.: Behind the subjective value of travel time savings: the perception of work, leisure and travel from a joint mode choice-activity model. J. Transport. Econ. Policy **37**, 29–46 (2003)

Kouwenhoven, M., de Jong, G.C., Koster, P., van den Berg, V.A.C., Verhoef, E.T., Bates, J.J., Warffemius, P.: New values of time and reliability in passenger transport in The Netherlands. Res. Transport. Econ. **47**, 37–49 (2014)

Luenberger, D.: Linear and Nonlinear Programming, 2nd edn. Kluwer Academic Publishers, The Netherlands (2003)

Lyons, G., Urry, J.: Travel Time use in the Information Age. Transp. Res. Part A **39**, 257–276 (2005)

Mabit, S. and M. Fosgerau (2008) Self-selection and the value of travel time, European Transport Conference, Leeuwenhorst, Netherlands

Mackie, P.J., Jara-Díaz, S., Fowles, A.: The value of travel time savings in evaluation. Transp. Res. Part E **37**(2), 91–106 (2001)

Mackie, P. J.,Wardman, M., Fowles, A. S.,Whelan, G., Nellthorp, J. & Bates, J. (2003) Value of travel time savings in UK, Institute of Transport Studies, University of Leeds, Working paper 567

McFadden, D.: Econometric models of probabilistic choice. In: Manski, C., McFadden, D. (eds.) Structural Analysis of Discrete Data with Economics Applications. MIT press, Cambridge (1981)

Mokhtarian, P.L., Salomon, I.: How derived is the demand for travel? Some conceptual and measurement considerations. Transport. Res. A **35**, 695–719 (2001)

Munizaga, M. and R. Daziano (2002) Evaluation of Mixed Logit as a practical modelling alternative. Proceedings European Transport Conference, Cambridge

OECD/ITF (2014) Valuing convenience in public transport, ITF Round Tables, No. 156, OECD Publishing, http://dx.doi.org/10.1787/9789282107683-en

Ortúzar, J de D y Donoso, P. C. F. (1983) Survey design, implementation, data coding and evaluation for the estimation of disaggregate choice models in Santiago, Chile. 2nd International Conference on Survey Methods in Transport, Septiembre, Hungerford Hill Village
Ozbay, K., Yanmaz-Tuzel, O.: Valuation of travel time and departure time choice in the presence of time-of-day pricing". Transp. Res. Part A **42**, 577–590 (2008)
Paleti, R., Vovsha, P., Givon, D., Birotker, Y.: Impact of Individual Daily Travel Pattern on Value of Time. Transportation **42**(6), 1003–1017 (2015)
Shires, J.D., De Jong, G.C.: An international meta-analysis of values of travel time savings. Evalu. Program Plan. **32**(4), 315–325 (2009)
Steimetz, S.: Defensive driving and the external costs of accidents and travel delays. Transp. Res. Part B **42**, 703–724 (2008)
Tirachini, A., Hensher, D.A., Rose, J.M.: Crowding in public transport systems: effects on users, operation and implications for the estimation of demand. Transport. Res. Part A **53**, 36–52 (2013)
Tseng, Y., Verhoef, E.: "Value of time by time of day: a stated-preference study. Transp. Res. Part B **42**, 607–618 (2008)
Wardman, M. (1997) A review of evidence on the value of travel time in Great Britain. Working Paper 495, Institute for Transport Studies, University of Leeds, Leeds
Wardman, M.: Public Transport Values of Time. Transp. Policy **11**, 363–377 (2004)
Wardman, M., Chintakayala, P., de Jong, G.C., Ferrer, D.: European wide meta-analysis of values of travel time. ITS, University of Leeds, Paper prepared for EIB (2012)

C. Angelo Guevara is associate professor at Universidad de Chile, research affiliate of the ITS Lab at the Massachusetts Institute of Technology (MIT) and external affiliate of the CMC at the University of Leeds. He holds an MSc in transportation from Universidad de Chile, as well as an MSc and a PhD in the same area from MIT.