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Attitudes to Distance, Time and Cost in Logit Transport Choice Models

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Abstract

During the last 20 years, a distance variable has sometimes been added to specifications of Logit utility functions that already included travel time and cost variables long assumed in theory and practice to embody the impeding effect of distance on transport demand. We briefly recall some milestones of this seemingly superfluous enrichment of modeling practice and propose to understand it as allowing for the expression of an "Attitude to Distance" (or DA) distinct from the "Attitude to Time or Cost" level of service outcomes.

The framework adopted to document this split role of distance, a duality not entirely absent from common language, is the Multinomial Box-Cox Logit model where, in the hope of improving estimates of Values of Travel Time Savings, distance raised to a simple power has recently often been introduced in interactions with the time and cost terms. Under the DA interpretation, the new power parameters of distance reveal an optimistic, pessimistic or neutral behavior towards distance distinct from any attitudes to the level of service variables themselves. In alternate specifications of utility functions based from the start on price, speed and distance variables, the self-standing distance term can also be re-interpreted as comprising a "Distance Attitude" component in addition to an impedance effect.

Key words: multinomial logit, attitude to outcome, attitude to distance, DA, power functions, Box-Cox transformations, value of travel time savings, marginal disutility of time and cost.

JEL codes: C35, C53, D12, R41

1 The absence of distance from transport mode and itinerary choice models.

The workhorse of transport demand analysis has long been the Logit model. Ever since early Binomial applications 55 years ago, for instance as an itinerary choice model to produce road traffic forecasts for the Channel Tunnel (Setec, 1959) or as an urban mode choice model (Warner, 1962), it was implicitly assumed that key level of service (LOS) variables, primarily travel time and travel cost, duly incorporated the role of distance. Other variables potentially missing from the V_i utility functions defined by alternative $i = 1, \cdots, M$, such as comfort or even risk and uncertainty, were often seen as inherent qualities of the alternatives reflected in the constant (intercept), other specific coefficients, or orthogonal error terms. In practice, a distance term was deemed unnecessary, even as potential stand-in for the missing variables.

What about theory? The first proper deductions of the Probit and Linear Probability model types from utility functions defined by a combination of systematic and random terms (of Normal and Uniform distributions) were based only on the time and cost determinants of systematic utility and on their errors (Abraham, 1961)[1]. And later derivations of the Logit and Arctan model types, based on Weibull and Cauchy distributions (CRA, 1972) of the random terms, did not break step on this point. Until Ramjerdi (1993), distance was always absent from the systematic utility components of Logit models of any character – Multinomial or Nested (*e.g.* McFadden, 1978); with fixed or random regression coefficients (*e.g.* Hensher and Johnson, 1979; Johnson, 1979) – containing time and cost.

Although we limit our discussion to the Logit model type, which rapidly displaced its early Random Utility Maximization (RUM) competitors, such as the Probit favored in some urban modal choice problems (*e.g.* Barbier, 1966), from the mainstream of theoretical and applied transport demand work, minority streams did not differ from the dominant Logit stream in this respect: they did not use distance as an explanatory variable in addi-

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[1]The author even associated pairs of time and cost specific errors to road itineraries in California.

tion to the LOS variables themselves.

But minority stream Probit models, by contrast with majority stream Logit models, were for many years seldom estimated with non linear forms of their time and cost variables because of the numerical difficulty of the task[2]. Consequently, to the extent that firstly used interactions between distance and LOS variables aimed precisely at modifying the constant values of travel time savings (VTTS) implied by linear LOS specifications, it was easier to introduce them, and to further question those linear restriction as well, in Logit models. The framework of the Box-Cox Logit specification is then very fitting for us to present both a brief history of the introduction of distance over the last 20 years and our interpretation of its role. Similarly, we adopt the available general terminology of rank dependent utility even if distance is not here shown to act as a rough measure of risk[3] and if LOS outcomes are assumed certain. This avoids inventing a new expression for the interpretation proposed.

That interpretation, as the expression of an "attitude to distance" distinct from the "attitude to time or to cost", with parameters perhaps jointly estimated by co-monotonic non linear transformations of distance and LOS variables (assumed known with certainty), has implications for other transport demand contexts, such as trip distribution and destination choice. We do not discuss those here but simply adopt the language of mode (and itinerary) choice applications, where the role of distance was first introduced with increasing success, as our chronological focus briefly documents.

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[2]Bolduc (1999), for instance, stated that: "to implement a Box-Cox technique within a MNP setting represents a too formidable task".

[3]The present authors first derived the «Attitude to Distance» interpretation in April 2010 as a device to classify some of the 50 models reported in a survey of Box-Cox Logit mode choice models (Gaudry, 2010, Section 5) that notably included a prospect theory path choice application (Lapparent, 2005) contextualized within a classification of rank dependent utility specifications. Here, we draw extensively upon this Section 5, without further due reference.

2 Some occurrences of the introduction of distance in Logit utility functions.

We are principally interested in how the contents of typical random utility functions (RUF) progressively changed from $V_i = f_i (Time_i, Cost_i, etc.)$ to $V_i = f_i (Time_i, Cost_i, Distance_i, etc.)$, but we shall also briefly discuss implications of this development for the understanding of the less frequently found RUF that had included distance from the start, *e.g.* $V_i = f_i (Price_i, Speed_i, Distance_i, etc.)$. For any origin to destination (O-D) pair, RUF belonging to the latter class are written directly in terms of rates and distance, rather than in terms of time and money expenditures, of the modes.

We discuss neither cases of "universal" or "mother" utility functions (i.e. unconstrained Marshallian ones), where the service characteristics of one mode might also appear in the utility functions of other modes (McFadden, 1975), nor cases of random coefficients associated to variables, would these pertain to weights or to nonlinear parametric transformations. For the sake of clarity, we also neglect all O-D and observational subscripts and will not directly report in our table on the t-statistics (or on the Likelihood ratio tests) associated with selected parameter results because these statistics are not always available from the referenced papers.

2.1 Econometric framework: the Box-Cox MNL and its derived values of time savings.

In the Standard Box-Cox MNL, the choice probabilities for the ith mode are assumed given by

$$p(i) = \frac{\exp(V_i)}{\sum_{j=1}^{M} \exp(V_j)}, \forall i = 1, \cdots, M, \tag{1}$$

$$V_i = \beta_{i,0} + \sum_{k}^{K} \beta_{i,k} X_{i,k}^{(\lambda_k)}, \forall i = 1, \cdots, M \tag{2}$$

$$X_{i,k}^{(\lambda_k)} = \begin{cases} \frac{X_{i,k}^{\lambda_k}-1}{\lambda_k} & \lambda_k \neq 0 \\ \ln(X_{i,k}) & \lambda_k = 0 \end{cases}, \forall i = 1, \cdots, M, k = 1, \cdots, K, X_{i,k} \in \mathbb{R}_{\star}^{+} \tag{3}$$

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where the Box-Cox transformation (BCT; Box and Cox, 1964) defined in (3) without Tukey's shift parameter is for simplicity assumed to be generic and applicable only to strictly positive valued variables $X_{i,k}$. It is a particularly convenient way[4] to tests consumers' responsiveness to these characteristics, linearity implying constant marginal utility.

A key statistic derived from such models is the marginal rate of substitution (MRS) between time (T) and cost (C), or Value of Travel Time Savings (VTTS), defined[5] for instance for an alternative i as:

$$\mathrm{VTTS}_i \equiv \frac{\partial V_i / \partial T_i}{\partial V_i / \partial C_i} = \frac{\beta_{i,\mathrm{Time}} T_i^{\lambda_{\mathrm{Time}}-1}}{\beta_{i,\mathrm{Cost}} C_i^{\lambda_{\mathrm{Cost}}-1}}, \tag{4}$$

which may also be rewritten in terms of the implicit price (P), speed (S) and distance (D) terms, presuming $C_i = P_i D_i$ and $T_i = S_i^{-1} D_i$, as:

$$\mathrm{VTTS}_i = \frac{\beta_{i,\mathrm{Time}} S_i^{1-\lambda_{\mathrm{Time}}}}{\beta_{i,\mathrm{Cost}} P_i^{\lambda_{\mathrm{Cost}}-1}} D_i^{\lambda_{\mathrm{Time}}-\lambda_{\mathrm{Cost}}} \tag{5}$$

where $\lambda_{\mathrm{Time}} - \lambda_{\mathrm{Cost}} > 0$ is a necessary and sufficient condition for the VTTS to increase with distance, traditionally interpreted as impeding spatial interaction.

If one allows in (2) for interactions between distance raised to a simple power γ and LOS variables, namely for new $D_{\mathrm{rail}}^{\gamma_{\mathrm{Time}}}$ and $D_{\mathrm{rail}}^{\gamma_{\mathrm{Cost}}}$ terms, the corresponding expression for the VTTS becomes:

$$\mathrm{VTTS}_i = \frac{\beta_{i,\mathrm{Time}} S_i^{1-\lambda_{\mathrm{Time}}}}{\beta_{i,\mathrm{Cost}} P_i^{\lambda_{\mathrm{Cost}}-1}} D_i^{\gamma_{\mathrm{Time}}-\gamma_{\mathrm{Cost}}} D_i^{\lambda_{\mathrm{Time}}-\lambda_{\mathrm{Cost}}}, \tag{6}$$

where a new identifiable role appears for distance, apparently independent from its previous impedance role. Summing the simple and BCT powers $\gamma_{\mathrm{Time}} - \gamma_{\mathrm{Cost}} + \lambda_{\mathrm{Time}} - \lambda_{\mathrm{Cost}}$ then yields the direction of the total effect of distance on the VTTS.

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[4]There exist several ways to test for non-linearities such as, to cite a few, piecewise linear formulations, power series expansions or ad hoc mixtures of pre-determined non-linear forms, but there is no parametric function combining flexibility and parcimony like the BCT. Non-parametric formulations of the problem often amount to "super-parametric" ones!

[5]In models with non separable "Marshallian" utility, the derivative with respect to the choice probability differs from the derivative with respect to the utility because any given modal time of cost variable may appear in many utility functions.

2.2 The intuitive introduction of interactions between distance and LOS variables.

For the VTTS to increase with distance in this last sum if $\gamma_{\text{Cost}} = 0$ and the BCT are set to 1, it suffices that $\gamma_{\text{Time}} > 0$. This is precisely the unconsciously seminal specification used by Ramjerdi (1993), with the following unique interaction with time:

$$g_i\left(D_i, T_i\right) = \beta_T D_i^{\gamma_T} T_i \qquad (7)$$

which yielded the positive value 0.40 reported in table 1. This simple interaction was introduced on an intuitive basis at the end[6] of an extensive study of intercity travel patterns and related VTTS in Norway, but its significance was not immediately realized and nothing is made of it in the finalized text (Ramjerdi et al., 1997).

Many researchers, typically using linear specifications of logit utility functions and models laboriously estimated over distinct cost and time ranges (*e.g.* low, medium, high) had of course long noticed that the coefficient of travel time varied across the slices : examples, which include many generations of national models, are legion, but a representative example could be Johansson et al. (2003) who use 3 "time distance" ranges for commuting trips. Estimates of truly non linear relationships by piecewise linear approximations are notoriously hard to interpret and to "connect" consistently. More generally, both time and cost coefficient estimates by ranges often showed a pattern that appeared related to distance, even though distance (excluded in theory) was naturally not used as regressor.

A prevailing general impression that this is often the case and numerous other indications that distance somehow mattered to estimates, despite the dearth of studies using continuous non linear functions of cost and time whereby this hypothesis can be explored with ease, led five experienced researchers (Mackie et al., 2003) to perform an extensive meta-analysis of the link between implicit distance[7] and VTTS estimates. It showed that:

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[6]It does not appear in the first part of her study (Ramjerdi and Rand, 1992).

[7]Distance was not observed, but its role was estimated from the reported cost of the journey.

1. relatively to cost, the value of in-vehicle time systematically increased with implicit distance, but more for car users than for users of public transport modes (train and bus). This property of models estimates is called "cost damping" by the UK Department for Transport (DfT) which later had it studied systematically by Daly (2008, 2009);

2. relatively to in-vehicle time, the value of walking and waiting times systematically decreased with implicit distance while that of vehicle headway increased, again more for car users than for users of public modes.

These authors' conclusive results and correspondingly strong recommendations stimulated many to introduce interactions between actual distance and LOS variables. Notably, a group of six co-authors (Axhausen et al., 2008) extended interactions with implicit distance and income (I), used in Mackie et al. (2003) but related only to the cost variable, to both LOS variables to obtain for Switzerland VTTS that varied continuously with both actual distance and income. Their specification for time, similar to that adopted for cost (not replicated here for simplicity), remained linear in the LOS variables, *e.g.*:

$$g_i\left(D_i, I, T_i\right) = \beta_T D_i^{\gamma_T} I^{\rho_T} T_i \tag{8}$$

and their paper title made it clear that interactions with distance were now part of the state-of-the art, a point of practice confirmed also by Hess et al. (2008) with 4 distinct data sets considered separately and jointly.

State-of-the art formulations, specified for instance as:

$$g_i\left(D_i, I, T_i\right) = \beta_T D_i^{\gamma_T} I^{\rho_T} T_i^{(\lambda_T)} \tag{9}$$

were recently estimated for the first time (Lapparent et al., 2009), and continue to be estimated (*e.g.* Lapparent, 2014), despite their technical difficulty[8]. The negative tally of -0.42 obtained for $\gamma_{\text{Time}} - \gamma_{\text{Cost}} + \lambda_{\text{Time}} -$

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[8]For reasons that remain unclear, here thinking about strictly numerical challenges that still need to be overcome despite the availability of computational power, products of BCT are notably more difficult to estimate that products of simple and BCT powers, or products of simple powers.

λ_{Cost}, as reported in bold in column 9 of table 1, may be due to the very unusual nature of the sample pertaining to "occasional" trips because such a tally is usually positive.

Table 1 here

In the first three intercity models (A, B[9], and C) presented in table 1, the justification for the use of distance remains intuitive, by contrast with the justification for the inclusion of income, which has a long micro-economic history almost requiring its presence in some form or other (Train and McFadden, 1978). For consumer surplus calculations, the simplest form for the inclusion of income is linearity, lest "the calculation of the log-sum be perturbed" (McFadden, 1998).

Unfortunately, linearity in income is no more generally tenable empirically than the assumption that the marginal utilities of time and cost are constant in (9). This points to the existence of a major scientific gap still to be filled, at least in transport models, between the search for a parcimonious and a parametrized non-linear form of some utility functions determined by the data and a more general cost-benefit approach.

3   A survey of Box-Cox Logit models and the multiple roles of distance.

As part of the examination of "cost damping" for the DfT referred to above, Daly (2008, 2009) asked in particular whether damping claims were consistent with evidence provided by the class of Box-Cox Logit models, thereby prompting the survey of such models mentioned above (Gaudry, 2010).

On the basis of a sample of about 50 models where distinct BCT had been estimated for time and cost in 10 countries, it was found in intercity freight[10] and in intercity or urban passenger models that :

1. as expected, in the overwhelming majority of cases, $\lambda_{\text{Time}} - \lambda_{\text{Cost}} > 0$;

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[9]In table 1, -0.26 is the mean of the 8 estimates (between -0.13 and -0.37) for the 4 trip purposes and the two modes.

[10]The sample contained no urban freight model.

2. simultaneously, $\lambda_{Time} > 1$ in urban markets and $\lambda_{Time} < 1$ in intercity markets.

This empirical finding of an apparent structural difference in consumer preferences with respect to LOS between urban and intercity markets whereby, given $\hat{\beta}_k < 0$, utility appeared to fall more than proportionally with distance in urban markets and less than proportionately in intercity markets[11], made it imperative to make sense of the new role of distance interaction terms. This additional role, emerging perhaps in competition with that of distance already built into time and cost terms, gives rise to an enriched applied calculus of component parameters such as $\gamma_{Time} - \gamma_{Cost} + \lambda_{Time} - \lambda_{Cost}$ in (6).

Interestingly, none of the studies making use of powers of variables, whether simple or Box-Cox, have tested differences between men and women despite a long tradition of findings, based on linearly specified variables, establishing that commuting distance (*e.g.* White, 1977, 1986), or travel time (*e.g.* Picard et al., 2013; Raveau et al., 2014), are much more unpleasant for women than for men.

3.1 Defining the Distance Attitude (DA).

In the survey, the present authors had noted that, as in columns 1, 4 and 7 of table 1, estimated powers of distance associated with time or cost and their differences were always smaller than unity, which implied a "contraction" of actual distances. In these conditions, perhaps might distance, as revealed in everyday language, have a role in consumer utility functions independently from that of its implicit presence in LOS variables.

Using rank dependent utility terminology, this split was implemented by distinguishing formally between the attitude to LOS outcome and the attitude to distance, per force linked in (2-B). The adopted mechanism was that of a product of functions which assumed that LOS service variables

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[11]In accordance with $\partial V_i / \partial X_{i,k} = \beta_k X_{i,k}^{\lambda_k - 1}$, the first derivative of utility function (2).

(the network) are provided under certainty and taken as given[12] by the traveller. In say (9)[13], the Distance Attitude (DA) power parameter γ is then readily interpreted: convexity ($\gamma < 1$) contracts objective distance, indicating optimism; concavity ($\gamma > 1$) amplifies it, indicating pessimism; and a neutral pivot ($\gamma = 1$) designates "untwisted" neutrality.

Estimates found in table 1 all show optimism, including the most recent ones based on (3-A) to explore a huge sample of intercity trips in France (L'Hour et al., 2013).

3.2   The changed meaning of rate-specified RUF

If RUF are of exactly logarithmic form, the specification $V_i = f_i\left(Time_i, Cost_i, \text{etc.}\right)$ is indistinguishable from the alternate $V_i = f_i\left(Price_i, Speed_i, Distance_i, \text{etc.}\right)$; but, as this form restriction almost never holds in reality, the latter perfectly distinct and identified variant is sometimes preferred to the former because of reduced collinearity and better fit.

But rate-specified RUF that include distance from the start can also be reinterpreted under DA because the new term need not appear as an interaction with LOS variables but can stand alone: the self-standing distance term will then fulfill two roles, that of pure impedance and that of revelator of the DA, but some effort will be required to distinguish them.

If M mode-specific pairs of parameters by alternative $\left(\beta_{i,D}, \lambda_{i,D}, \forall i = 1, \cdots, M\right)$ are estimated, they will reflect both DA and pure impedance roles and effects. To remove the DA effect and be left only with the impedance component, it is necessary to assume that the impedance role is common to all alternatives. This implies the estimation of a generic effect with a reference variable D_r common to all modes; but, as only $M - 1$ of

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[12]We therefore excluded from the "Distance Attitude" formulation both LOS uncertainty and any potential endogeneity resulting, at least in aggregate models, from equilibration between demand and supply, but we did not exclude the possibility that distance be observed with error, notably of the Berksonian kind (Berkson, 1950) where the true value X_{true} is distributed around observed values X_{obs}, so that $X_{true} = X_{obs} + u$. In the classical case, the measured value is distributed around the true value and the observed value is equal to the true value plus an error ($X_{obs} = X_{true} + u$).

[13]Instead of making the weights functions of distance, one might make the BCT of time or cost functions of distance, but this has not been tried to this day.

the coefficients of any variable common to all alternatives are then identified, estimation of M generic coefficients and powers (β_D, λ_D) requires roundabout methods[14].

Existing models with $M - 1$ pairs of generic or specific parameters therefore provide an implicit and constrained measurement of both effects. For instance, the very strongly negative generic coefficient estimates of $(\beta_i - \beta_r) D^{(\lambda_D)}$ obtained for the classic and container rail modes (as opposed to the trucking mode used as reference) in Gaudry et al. (2008) combine pure impedance and DA effects that reveal strongly negative attitudes towards classical and container rail freight distances, relative to road freight distance, in France.

4   Conclusion

If the "Distance Attitude" (DA) interpretation makes good sense of the new functional roles of distance that are progressively emerging, and if distance-enriched practice continues to receive successful confirmation in empirical work, the question of distance as a stand-in for missing variables may need to be explored further and the dual roles of distance, built into time or cost factors but also used alongside these LOS variables, accepted in both RUM and other types of transport models.

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[14]For an example of such methods based on Inverse-Power Transformation capture, see Gaudry and Tran (2012)

Table 1: Estimates of simple powers of distance (γ) and of Box-Cox powers (λ) of time or cost

Intercity models				Power parameter estimates						Differences			Mean distance (km)	Sample size
				TIME			COST			VALUE OF TIME				
Study	Market	Modes	Purpose	T	T	F	F	F	F	T-F	T-F	T-F		
A. Ramjerdi (1993), T.9.5.28	Norway	5 modes	Work	0.40	1.00	1.40	0.00	1.00	1.00	0.40	0.00	0.40	180.79	5824
B. Axhausen et al. (2008), T.4	Switzerland	4 modes	All	-0.26	1.00	0.74	-0.60	1.00	0.40	0.34	0.00	0.34	42.89	15870
C. Lapparent et al. (2009), T.6	Czech Rep.	5 modes	Occasional	-0.66	0.74	0.08	0.21	0.29	0.50	-0.87	0.47	**-0.42**	145.47	2044
D. L'Hour et al. (2013), p.30	France	3 modes	All	-0.44	1.00	0.56	-0.92	1.00	0.08	0.48	0.00	0.48	n.a.	18039
=Attitude towards distance		Optimism	< 1	Yes			Yes			Yes				
		Pessimism	> 1	No			No			No				
			Column	1	2	3	4	5	6	7	8	9		

Legend
Fixed value

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