Transtools III: development of a new transport model for Europe – preliminary work on non-linearities and value of time inputs

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1. INTRODUCTION

Europe, in its broadest geographic definition, covers an area of over ten million square kilometres, comprises around fifty countries, and with a population of almost eight hundred million people. In terms of income, the area exceeds the GDP of North America. An understanding of current transport patterns and the ability to forecast changes therein are both crucial with a view to delivering efficient transport policy for the European Union as well as the wider area of Europe and neighbouring countries in Africa and Asia.

Transtools is a model developed for the European Commission which aims to provide users with a flexible tool for studying both passenger and freight movements in Europe, and in particular forecasting changes as a result of policy and infrastructure changes. In 2011, a consortium led by the Danish Technical University and with major contributions from the Royal Institute of Technology (Stockholm) and the Institute for Transport Studies (Leeds University) was tasked with the development of the next generation of this model.

The present paper presents an overview of two current pieces of research that feed into the development of the model, related to the treatment of non-linearities and the value of time inputs for the passenger model.

2. TREATMENT OF NON-LINEARITIES

A non-linear treatment of core attributes such as cost and travel time adds an important degree of flexibility to the modelling of passenger choices. A common approach is to use a Box-Cox transform. This however can lead to numerical issues and slow estimation in large-scale models. This section explores the equivalence between Box-Cox and 'Gamma' functions and their use in choice modelling.

Basic equations

Box-Cox is defined as usual by

$$x^{(\alpha)} = \frac{x^{\alpha} - 1}{\alpha}, \quad when \quad \alpha \neq 0$$
$$x^{(\alpha)} = \log(x), \quad when \quad \alpha = 0$$

Inspired by old-fashioned transport planning jargon, we use the 'Gamma' label to apply to functions defined by[i]

$$x^{[\alpha]} = \alpha\, x + (1-\alpha) log(x) - \alpha$$

Note that when x=1, both transformations take the value 0, whatever the value of α. Moreover, if we differentiate

$$x^{(\propto)'} = x^{\propto-1}$$

$$x^{[\propto]'} = \propto + (1-\propto)x^{-1}$$

both of which are equal to 1 at *x*=1, whatever the value of α. Finally, when we differentiate a second time, we obtain

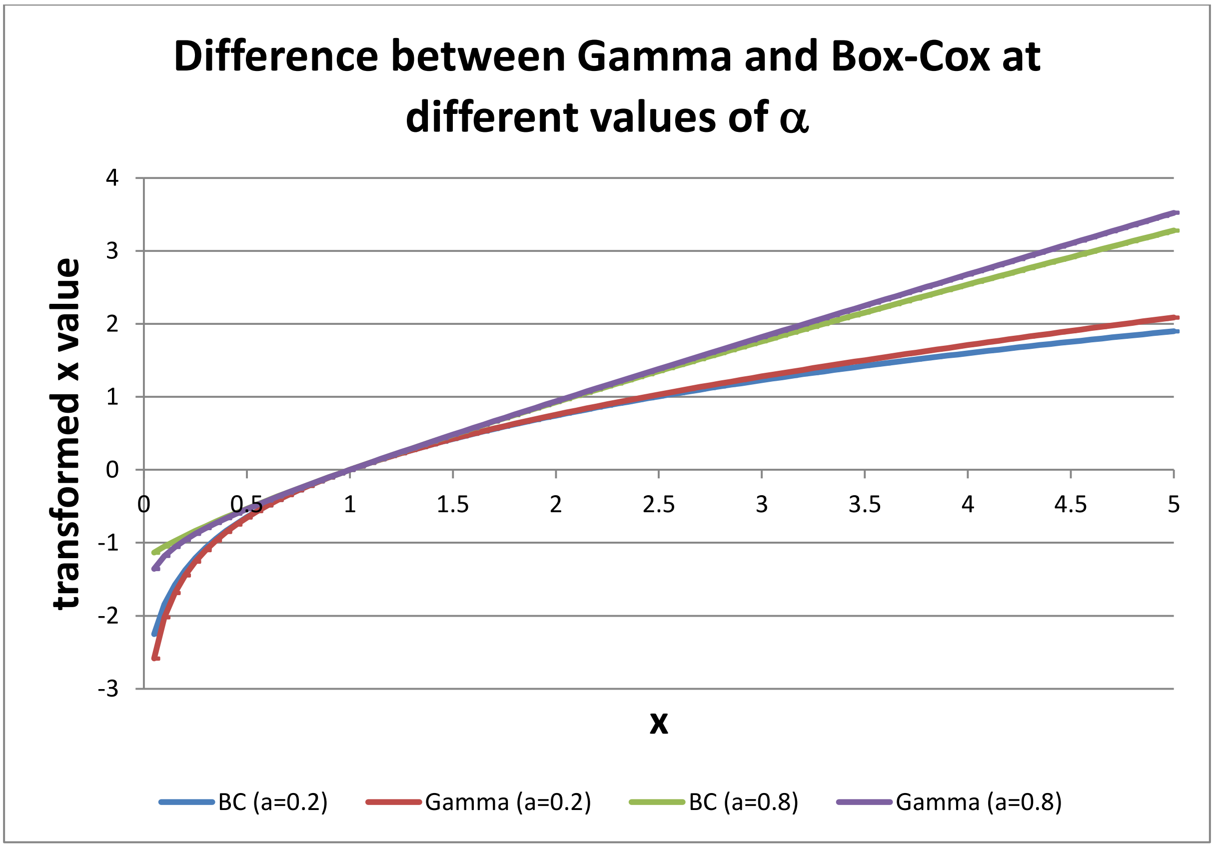
$$x^{(\propto)''} = (\propto - 1)x^{\propto-2}$$

$$x^{[\propto]'\prime} = -(1-\propto)x^{-2}$$

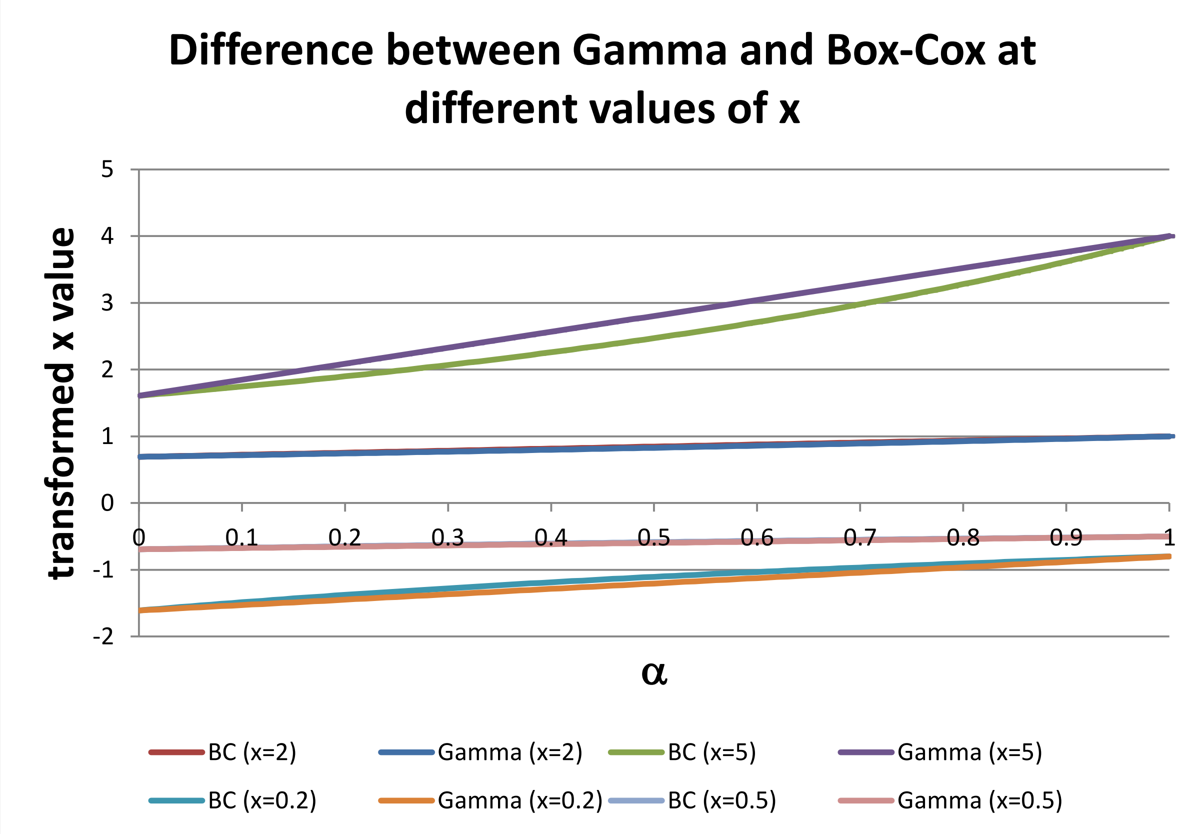
both of which are equal to (α-1) at *x*=1.

So at this specific value of *x*, the functions are equal and have the same slope and curvature. It also seems that the dependence of the function on α is the same in each case.

However, the question is what happens when we move away from *x*=1. Clearly this depends on the value of α: this is explored in the following graphs, which show first the transformed values for α=0.2 and α=0.8 for values of *x* from close to 0 to 5; then the transformed values for *x*=0.2, *x*=0.5, *x*=2 and *x*=5 for the full range of α values between 0 and 1[ii]. Looking first at the curves for fixed α, we see that for high and low values there is some difference, but for a substantial range around 1 the curves are very close.



Looking at the curves for fixed x, we note that for α=0 and α=1 the functions are identical, so it is only for intermediate values that there is a difference. For *x*=2 the maximum difference occurs at *x*=0.52 and is about 2%, too small to be clear on the graph. For *x*=5, the maximum difference is also at *x*=0.52 and is about 13%. For *x*=0.5 we have a maximum difference less than 2%, but for *x*=0.2 the difference is as much as 8%. Again, for *x* close to 1 the differences are small, but for large and small values larger differences occur but with the range of a factor of 5 larger or smaller the differences are not large.



We conclude that for values of *x* close to 1 these transformations are performing the same function and are closely equal. Further from 1 the differences are not so small, but they are still not large. Moreover, simply by using the same parameter values (noting the subtraction of α from the Gamma formulation) we can get exact equality when *x*=1 and when α=0 or α=1. The parameter α has essentially the same meaning in the two functions.

In choice modelling using RUM the Gamma formulation is much easier to use than Box-Cox as we can set it up as a linear-in-parameters model of utility

$$V = \cdots + \beta_1 x + \beta_2 log(x)$$

with $\propto = \beta_1/(\beta_1 + \beta_2)$. To maintain the range of α in [0, 1] we need not to have β parameters with opposite signs, which is necessary in any case to fit with the logic of utility functions. The popular ALOGIT software which is commonly used for large-scale analyses is not able to estimate directly models that are not linear in parameters in this way; while Biogeme can do this, it tends to be very slow in converging for such models, so in this case also the Gamma formulation is preferable.

We showed close equivalence between Gamma and Box-Cox for values of *x* close to 1. In practice closeness to 1 can be achieved by using a value in the modelling **divided by the mean**, so that a clustering of values close to 1 would be expected and values such as 5 might be unusual.

It would be interesting to make some estimations of Gamma models and then to repeat the runs using Box-Cox with the same formulation to see how similar the results appeared to be.

In conclusion, the Box-Cox and 'Gamma' transformations give very similar results when the same transformation parameter is used. There is no reason to regard one of these functions as having higher status than the other, so that we may use whichever is more convenient. For choice model estimation this is the gamma function.

3. VALUE OF TIME INPUTS

The TransTools3 project requires an update of the Value of Time (VOT) table, used as input for the passenger demand modelling. Specifically, country-specific VOT estimates need to be obtained (or updated) and where needed disaggregated by travel purpose, mode and possibly distance. The purpose of this section is to describe the considerations that need to be made in updating the VOT input table.

The VOT measures the monetary benefit of reductions in travel time. For example, in Cost-Benefit-Analysis and other methods of project appraisal, VOT estimates are needed to convert the expected benefits of a particular infrastructural project, such as travel time savings, into monetary equivalents (De Jong et al., 2004). Besides serving as an important input for policy appraisal, the VOT is also frequently used to represent the sensitivity of demand to changes in travel time and associated travel costs with a particular trip. These behaviourally focussed VOT estimates are more suited to predict travel demand (i.e. forecasting), which is the main aim of the passenger model in the TransTools 3 (TT3) project. Obviously, the two types of VOT estimates are closely related but differences may arise.[iii]

Differences may occur, for example, for the following reasons.

- Because of non-linearities in the behavioural values that are omitted from the social values. Non-linear VOT estimates may generate significant complexities for appraisal procedures.
- Because of segmentation by mode in behavioural values, perhaps associated with travel comfort, while governments often require equal VOT estimates across the modes.
- Because of the need to take account of productivity issues and marginal taxation in the social evaluation of (business) travel time, whereas behavioural values primarily account for traveller preferences.

VOT estimates applied in TransTools2.0 and 2.5 rely on the values and recommendations made by the HEATCO project. HEATCO provided a set of social VOT values for the EU-25 countries and Switzerland (in 2002 € factor prices) and derived a set of recommendations to obtain these values for policy appraisal. Moreover, it also provided a guideline for adjusting VOT values over time (inter-temporal elasticity of 0.7 with GDP per capita growth as the default).

Policy appraisal frequently uses the wage rate to monetise savings in travel time for business trips based on the simple conjecture that reductions in travel time imply an increase in productive time (Gunn, 2000). Hensher (1977) establishes a slightly more sophisticated relationship between the value of time and wage rate, which recognises that only part of the travel time saved from work-related trips is transferred into productive time, while travel time can itself be productive. Reductions in travel time thereby generate benefits to both the employer and the employee. In the UK, the following approach to evaluate changes in productivity in the social values for business trips is taken (WebTAG 3.5.6, 2011):

" *1.2.4 Working time values apply only to journeys made in the course of work. This excludes commuting journeys. The perceived value of working time is the value as perceived by the employer. Businesses perceive costs in the factor cost unit of account and therefore the perceived cost and the resource cost are the same for values of working time. The resource cost is calculated as being equal to the gross wage rate plus non-wage labour costs such as national insurance, pensions and other costs which vary with worker hours. The 24.1% mark-up for non-wage labour costs used in the March 2001 edition of TEN has been revised down to 21.2%, a figure derived using more recent data from the 2000 Labour Cost Survey.*"

HEATCO proposes the 'Hensher-approach' as the best method to obtain a harmonized value of travel time savings for work related passenger trips in an international context. The recommendation was, however, made with the purpose of using of VOT measures in project appraisal, not demand forecasting. The present task of the TT3 project focusses on demand forecasting and an alternative approach may therefore be desirable.

Behavioural models of VOT rely on actual and/or stated travel behaviour by people and data is collected by, for example, interviews and surveys, covering both work-related and other travel. In these studies, trade-offs between trip length and trip costs are compared to derive a measure of willingness-to-pay for travel time savings. Frequently, the derived values of time are applied in transport models in predicting individual decisions with respect to a particular mode of transport or route choice. This is also the case in the TT3 project, which aims at predicting passenger travel patterns in an international context.

Distinct behavioural VOT measures can be derived for alternative modes of transport and alternative trip purposes, possibly varying by journey distance. Differences in level of comfort, and the possibilities for engaging in other activities during the trip may result in different cost and time sensitivities across modes of transport. Moreover, the fact that business trips are usually paid by the employer, the employee is likely to be cost sensitive and therefore exhibit a higher VOT estimate, while the VOT for commuters also tends to be higher than for leisure trips. A further common finding is that the VOT increases with the distance of the journey which reflects the discomfort of longer journeys and the larger opportunity cost of time spent travelling (Wardman et al. 2012); possibly there is also a self-selection of higher income travellers to longer trips. HEATCO argues that such disaggregated values should at least comprise VOT estimates for passenger-work, passenger-non-work and commercial goods traffic. Since we only focus on the passenger side, the VOT for commercial goods traffic is not covered by this section.

The potential for estimating disaggregate VOT values depends on the quality of the available data and underlying study design. When there is insufficient information in the data, the VOT estimates obtained may be biased as the impact of the underlying modes and purposes cannot be separated from each other. In those cases, generic (or non-disaggregated) VOT estimates may be more reliable. We return to this issue below.

One of the core recommendations from the HEATCO project is that: *"…local values should be used whenever possible, provided that they have been developed using an appropriate methodology. If no such values exist then 'default' or 'fall-back' values derived from international meta-analyses of value of time studies should be used".* While it is intuitively correct to use the local VOT values for applications in a national settings or for national policy appraisal, their application in an international model exercise are not straightforward. Local values have been developed for national purposes and fit to national circumstances, but those values are not necessarily consistent across countries. Moreover, they may provide strange results when applied to cross-border long-distance travel applications. Under these circumstances, the use of robust and more consistent VOT estimates seems more sensible and may prevent unexpected distortion of travel patterns across countries.

International meta-analyses smooth these national estimates and come up with a more consistent prediction of the VOT by mode and purpose across countries. As such, individual studies are less likely to influence variation in the VOT across countries. This solves the potential problem of data inconsistency highlighted earlier. Additionally, TransTools3 will provide a passenger demand model for all 49 countries in Europe. It is not likely that small countries like Moldova will have conducted its own local VOT study. As such, benefits transfer methods need to be applied to expand the geographical coverage of the HEATCO (and other) values. In these cases, the estimated functional form from international meta-analyses can be applied to predict these missing VOT values. Returning to the previous point, meta-analyses can also be used to derive more accurate disaggregate VOT estimates by smoothing the results from a wide range of studies.

We recommend the use of behavioural VOT values predicted (and the functional form estimated) by international meta-analyses for the purpose of the TT3 project. In line with the focus on predicting travel patterns of passengers in the TT3 project, meta-analyses allow for the construction of a set of robust and consistent VOT estimates across countries, which is less likely to result in distortions in cross-border long-distance travel patterns. The ability to predict VOT robust estimates for countries where national values are missing, and to obtain disaggregate VOT estimates per mode, purpose and/or distance provides a strong case for the use of meta-analysis in the TT3 project. The meta-analysis by Wardman et al. (2012) appears a good basis, as it includes the HEATCO values, takes account of preceding RAND Europe work and provides up to date VOT estimates for the relevant segments.

4. CONCLUSIONS

This paper has discussed two important inputs into the Transtools3 model. The paper has illustrated how similar results can be obtained when replacing the Box-Cox transform with the gamma specification, leading to very substantial gains in efficiency as the model can then be estimated in ALogit. Secondly, the paper has discussed how the value of time inputs for the model should come from meta-analysis values rather than country-specific values obtained from individual studies.

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[i] More standard mathematical nomenclature is to define the gamma function as the integral of the exponential of this function (see http://en.wikipedia.org/wiki/Gamma_function). The subtraction of α in this formula makes the functions equal at x=1.

[ii] Values of α outside this range are not compatible with the framework of the problem; see Daly, A. (2008) The relationship of cost sensitivity and trip length, http://www.dft.gov.uk/pgr/economics/rdg/costdamping/pdf/costdamping.pdf.

[iii] For simplicity we refer to the VOT estimates used for policy appraisal as 'social values' and to the VOT estimates related to demand sensitivity as 'behavioural values'.