



FORECASTING TRAVEL DEMAND USING LARGE-SCALE MODELS

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OBJECTIVE

- to make forecasts in support of transport policy
 - this is applied science, not basic research
- policy drives the whole process

BUT WE HAVE DUTIES HERE TOO

- always need to be rigorous
 - statistical tests, objective results
 - wide search for model specifications (e.g. non-linearities)
 - multiple criteria for model quality
- need to keep saying our forecasts are inaccurate
 - hopefully with error margins, reasonably estimated
- sometimes need to resist client pressure

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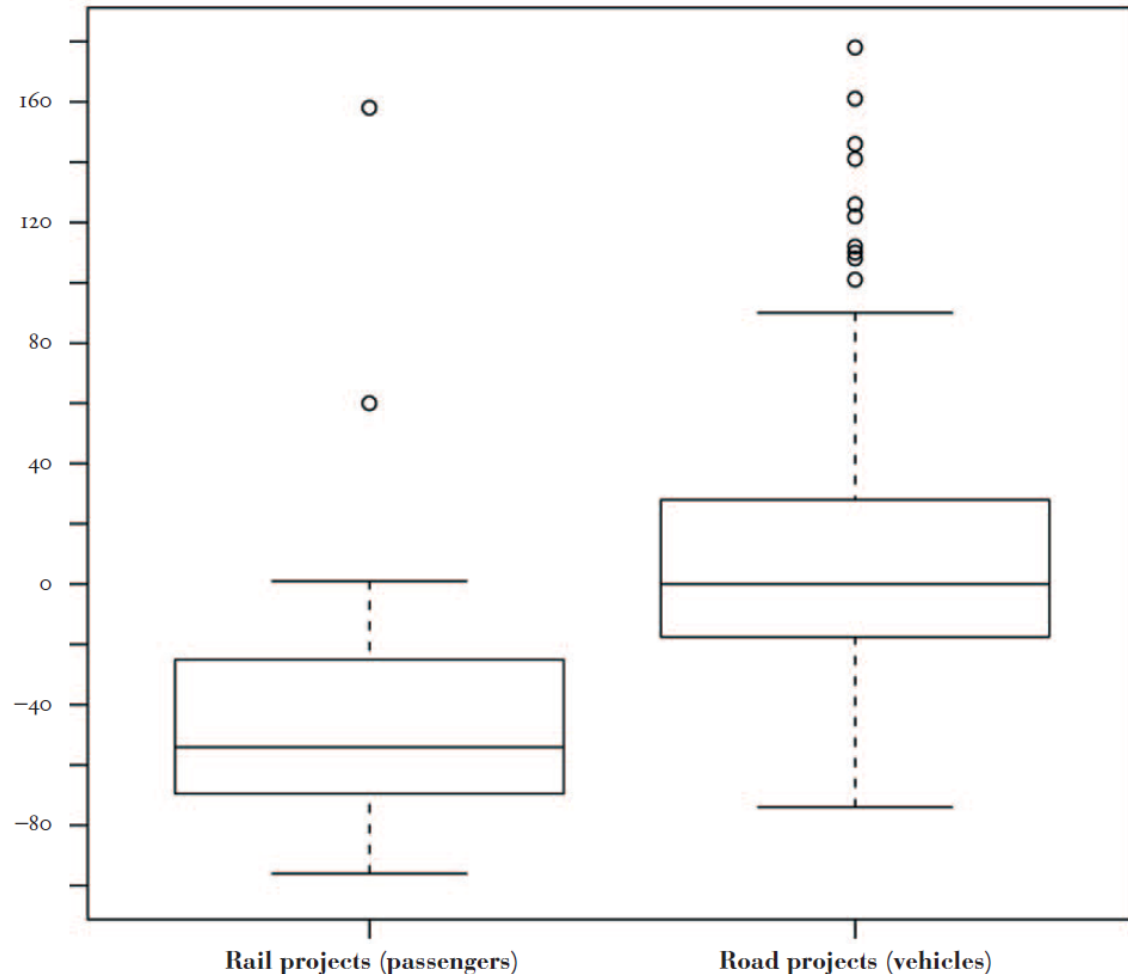
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Inaccuracy (%)



OVERVIEW OF PRESENTATION

- model scope and horizons
- review
- model specification
 - structure
 - data and estimation
 - validation
- application
 - population forecasting
 - expected and simulated demand
 - congestion and convergence
- adaptation

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THE POLICY SETS THE HORIZON

- **short-term forecasts** will usually suffice for management policies
 - e.g. cycle priorities, tolling variants, information provision, fare changes...
 - because policy can be changed
- **longer-term forecasts** are needed for infrastructure
 - e.g. roads, bridges, HSR, airports...
 - which have to pay back over long period
- UK requires 60 years but this is silly as long-term rate changes dominate the calculation

THE HORIZON SETS THE MODEL SCOPE

- **short term**, maybe up to 5 years
 - current population
 - if changes are small, may avoid modelling congestion
- **medium/long term**, 5-30 years
 - population changes
 - inevitable that congestion will change
- but of course there are overlaps and many variations
- need models of both freight and passenger movements, but talk here only about passengers



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TRAVEL DEMAND FORECASTING HAS A LONG HISTORY

- early traffic analyses were based primarily on OD surveys without modelling
- analytical conurbation study in Detroit from 1953
 - trip generation, distribution and assignment
 - not much behavioural content!
- Wardrop (1952) gives behavioural basis for assignment with congestion
- **car was king:**
 - *predict and provide*
- i.e. modelling behaviour was not very important (except for assignment)

EUROPE HAS PUBLIC TRANSPORT!

- *Traffic in Towns*, Buchanan 1963, recognised the damage done by unrestricted growth in car use
 - modelling needed to look at much more varied set of policy options
- systematic modelling of distribution and mode choice in UK from 1960s
 - books on entropy maximisation by Wilson and collaborators
 - sophisticated and complete, e.g. very early use of logsum formula for composite cost

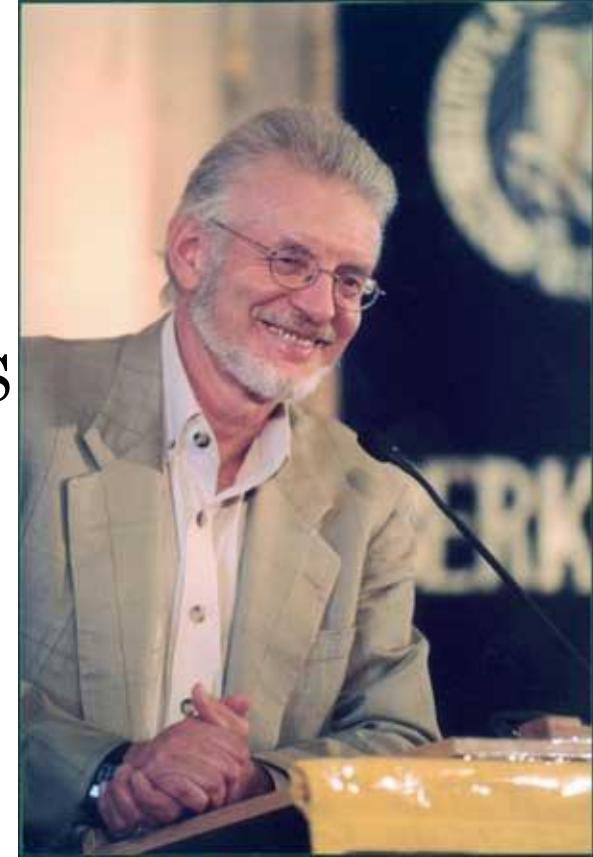


ENTROPY WAS NOT CONVINCING

- reliance on physical analogy was viewed negatively
 - by economists, psychologists, (some) geographers ...
- sophisticated mathematical models appealed strongly to a small minority
 - and further discouraged the majority
- work of Miyagi and of Anas showed the duality of entropy and utility theory
- but utility appeals to a larger audience
 - particularly, of course, economists
- and ultimately seems to be more flexible
 - and consistent with policy appraisal systems

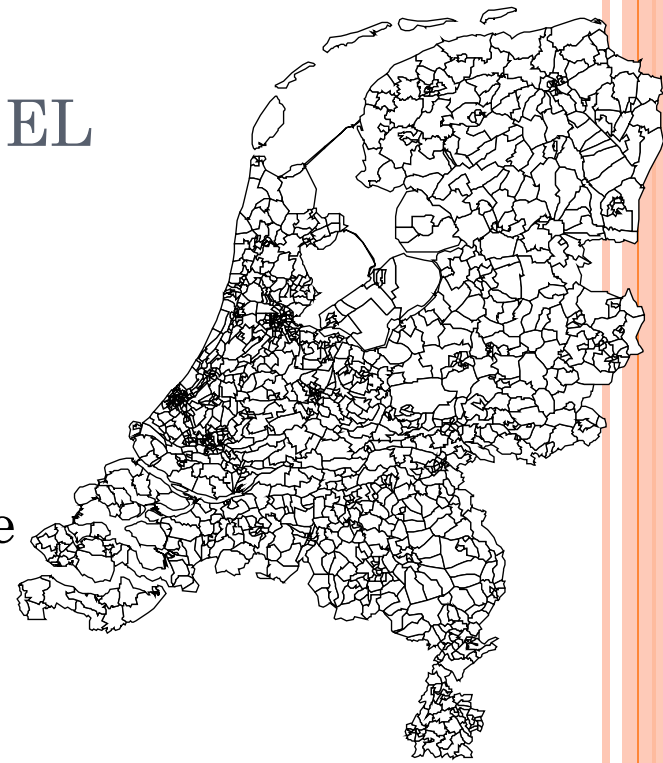
CHOICE MODELLING USED FROM 1970S

- random utility paradigm in UK and US
 - initially to explain behaviour
 - of a bureaucracy, or of travellers to estimate values of time
- use in forecasting from mid 70s
 - key study was McFadden's BART work
 - parallel UK studies of bus systems
- wider application from late 70s
 - MTC work in California
 - work leading to Netherlands National Model
- we now have 40 years of consistent experience using choice modelling for forecasting



NETHERLANDS NATIONAL MODEL DEFINED A TEMPLATE

- large-scale model:
 - 500-3000 zones
 - multiple modes including walk & cycle
 - 4 or 5 stages modelled together
 - based on tours and detours
 - many aspects of activity-based models
 - assignment to networks with congestion
- major modelling investment with pay-off over a long period
 - now operational for 27 years
 - flexibility to address many policy issues
 - transparent utility paradigm facilitates extensions



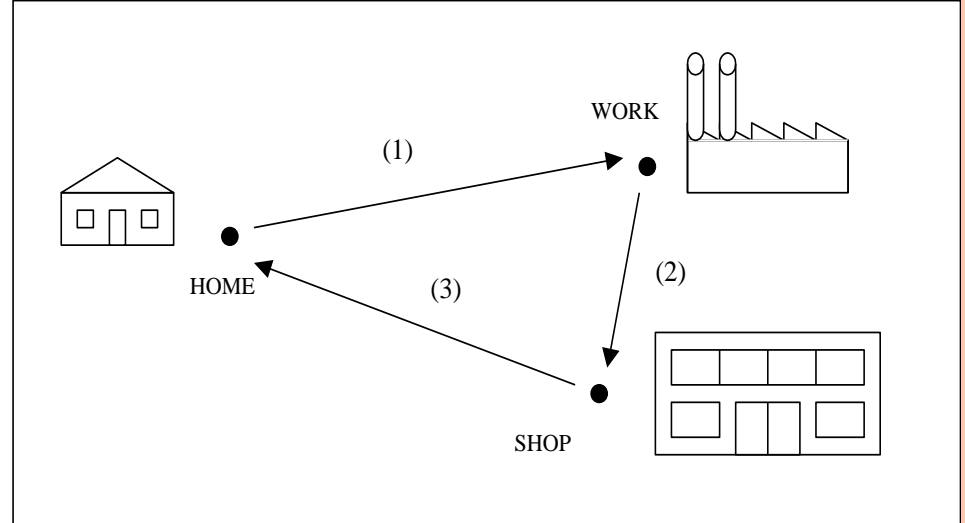
SIMILAR MODELS DEVELOPED IN SEVERAL COUNTRIES BETWEEN 1990 AND 2005

- Norway, Italy, Sweden developed national models
 - with implicit or explicit reference to NL
- France, Sweden, Denmark, Australia, Netherlands and UK developed regional or conurbation models of this type
- also the pan-European model TransTools
- the template is widely applicable

- but in the US, the most advanced development was of 'activity-based' models
 - becoming widespread only in last 10 years

THE TEMPLATE IS FLEXIBLE

- because of the clear behavioural basis



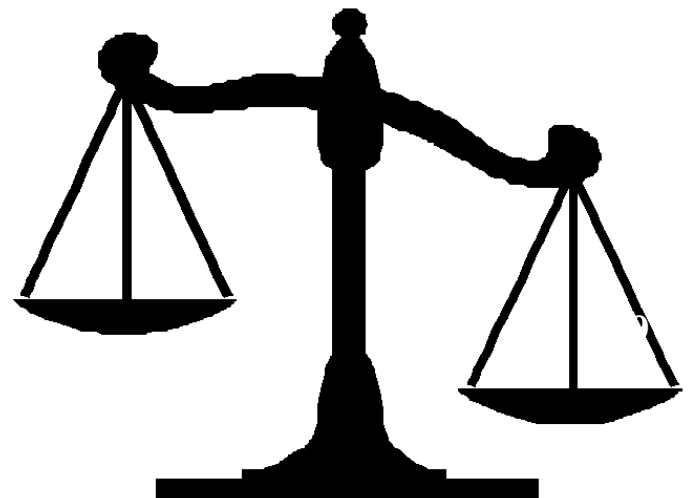
- but policy focus and data availability vary between areas
 - and perhaps over time
- so a model for a specific area needs to be designed for that area
 - and perhaps adjusted over time
- the objectives of model design are...
 - to give outputs that are required for flexibility
 - to accept variables describing policy actions

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WHAT DO WE NEED TO KNOW?

- forecasting is to help appraise policy options, which requires information on (e.g.)...
 - revenue**, for operators and governments
 - including indirect taxes
 - emissions**, local & global
 - includes (e.g.) noise, particulates and CO₂
 - user benefit**, for population groups
 - e.g. by income
- all of these depend on **demand**
 - in greater or lesser detail
 - e.g. **flows** on the networks



FIVE-STAGE MODEL COVERS THE BASICS

- travel frequency (“generation”)
- mode choice
- destination choice (“distribution”)
- time period choice
 - this is the key advance from the 4-stage model
 - predicts variation in peaking
- assignment

- the scope of these models does not look revolutionary, but...



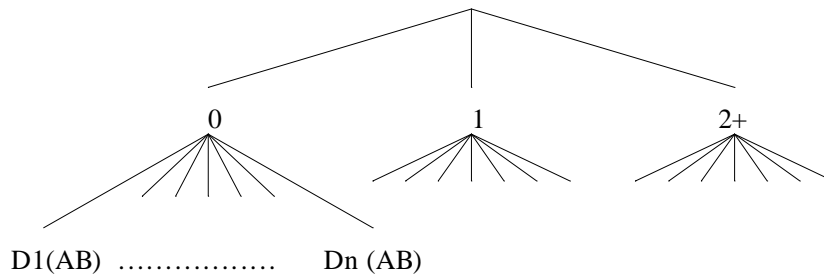
ONE KEY STEP IS MAKING EXPLICIT LINKAGES BETWEEN THE STAGES

- giving effectively a simultaneous choice over all behavioural aspects
 - achieved by using nested logit models
 - with simultaneous estimation over as many aspects as possible
 - currently tree-nested models, but should be extending to cross-nesting in near future
 - and to more general model forms after that
- means that impacts of policy changes are assessed over all aspects of behaviour
 - as far as is justified by the data
- the basis in utility theory ensures intuitive forecasts

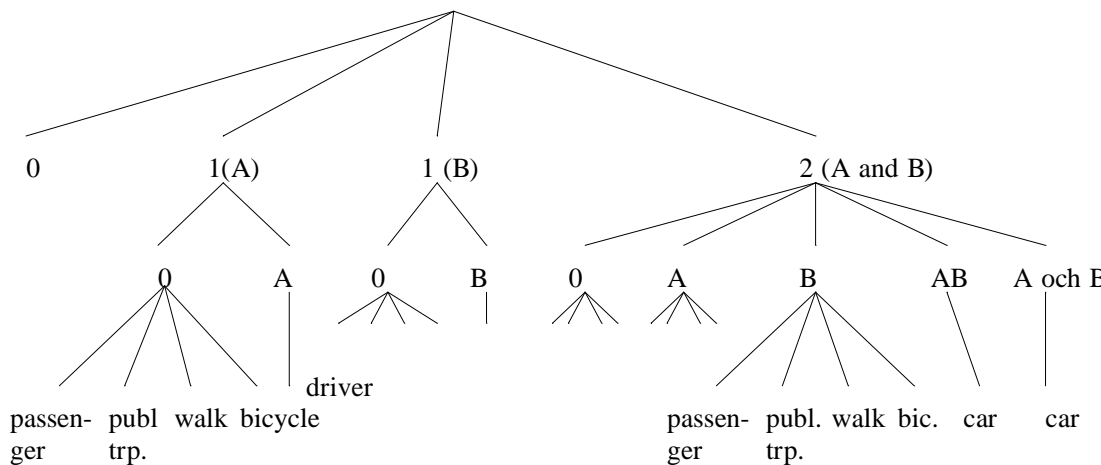
FURTHER STAGES CAN BE ADDED AS REQUIRED FOR LOCAL POLICY

- park-and-ride as a sub-mode
 - choice of toll roads
 - inclusion of car ownership (and licence holding)
 - car type if required
 - public transport pass ownership
 - train type or route choice
 - etc.
-
- this is all made possible by the explicit utility basis of the models

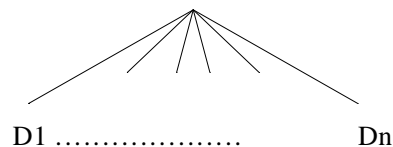
COMPLEX SYSTEMS OF CHOICES CAN BE MODELLED



CAR
OWNERSHIP
DESTINATION

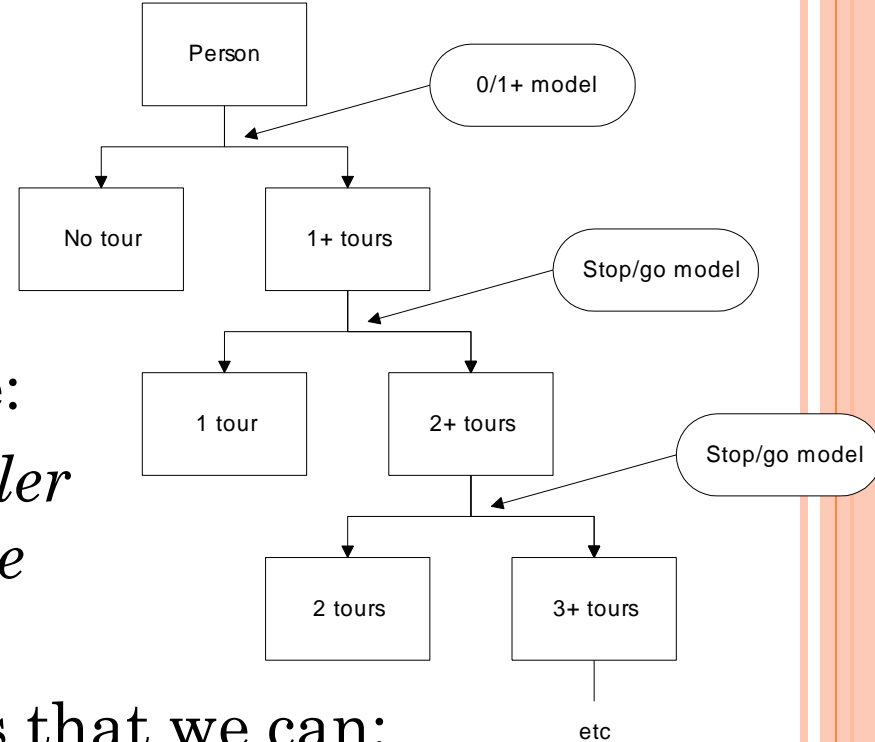


FREQUENCY
CAR
ALLOCATION
MODE
CHOICE



SECONDARY
DESTINATION

FREQUENCY MODEL



- can be formulated as a choice:
for a given purpose, a traveller makes 0, 1, 2 etc. tours in the period modelled
- the choice formulation means that we can:
 - link with the utility formulation for other choices, giving an accessibility impact on travel frequency
 - use rigorous estimation methods
- we can also predict the frequency of detours
- in future we need to link better across purposes
 - this may be where activity modelling has its greatest impact on this work

MODE CHOICE CAN BE EXTENDED AS NEEDED

- car driver and passenger as separate modes
 - gives a policy-dependent forecast of occupancy
- one or several public transport modes
 - integration in assignment gives better paths but
 - choice model gives better account of behaviour and linkage to other stages
 - this issue should be solved by assignment software
- walk and cycle are important for policy and as alternatives to motorised modes
- can introduce further nesting structure within mode choice
 - the main issue here is often sub-modes

DESTINATION CHOICE SHOULD BE MODELLED SIMULTANEOUSLY WITH MODE CHOICE

- simultaneous estimation maximises information
 - statistical efficiency is a technical concept, but here there are practical advantages as well
 - experience confirms these findings
 - and we need to determine the structure
- destination choice is formulated as choice over zones
 - ‘size’ of zones measures quantity of attraction
 - sampling can be used for estimation and/or application
 - but as yet there is no theory for application
- issue of ‘balancing’ to match attractions
 - if data is correct, this would improve the model
 - but this is not often plausible

TIME PERIOD CHOICE IS USEFUL BUT ADDS COMPLEXITY

- best also modelled with mode and destination choice
- need to model choice of out and return periods simultaneously
 - activity time depends on purpose
- complexity comes from increase in number of alternatives
 - $n \cdot (n+1) / 2$ out-back combinations of n time periods
- also issues with data for estimation
 - RP is not always successful



BEHAVIOUR AND MODEL CONTEXT VARY FROM PLACE TO PLACE

- so we need local estimation and therefore local data:
 - home interview trip diaries are the ‘classical’ data form
 - in particular they *should* be unbiased with respect to trip rates
 - can add data for specific modelling issues, e.g. park & ride
 - roadside interviews have proved difficult to use in choice modelling
 - in principle, biases can be corrected, but in practice...
 - Stated Preference can be useful
 - but need to correct inconsistency with RP data
- transport networks and zonal data are also needed

MAXIMUM LIKELIHOOD IS AN EXCELLENT ESTIMATION CRITERION

- it has a very good basis in academic statistics
- rigorous tests can be made of significance and model quality
 - χ^2 , t tests, equality tests etc. can be made on coefficients and overall model
 - these tests can also be extended to functions of coefficients
- efficient software exists
- but this isn't the whole story

WE NEED TO DEMONSTRATE THAT OUR MODEL PERFORMS REASONABLY

- it needs to get the support of decision-makers

- three criteria can be applied
 1. does the model fit the data?
 - the likelihood criterion seems to be best
 2. are the parameter values reasonable?
 - of course their signs!
 - but also relative values, particularly time/cost (VOT)
 3. does the model forecast reasonably?
 - a standard test is to calculate the implied elasticities with respect to time, cost etc.

PARAMETER VALUES NEED TO BE REASONABLE

- in particular, value of time
 - because many policies trade time and cost
- also different time coefficients should relate properly to each other
 - e.g. walking time to 'in-vehicle' time
- sometimes the local data is not adequate to estimate all the coefficients we want
- ➔ need to import coefficients from (e.g.) national sources



ELASTICITY IS A USEFUL TEST OF PERFORMANCE

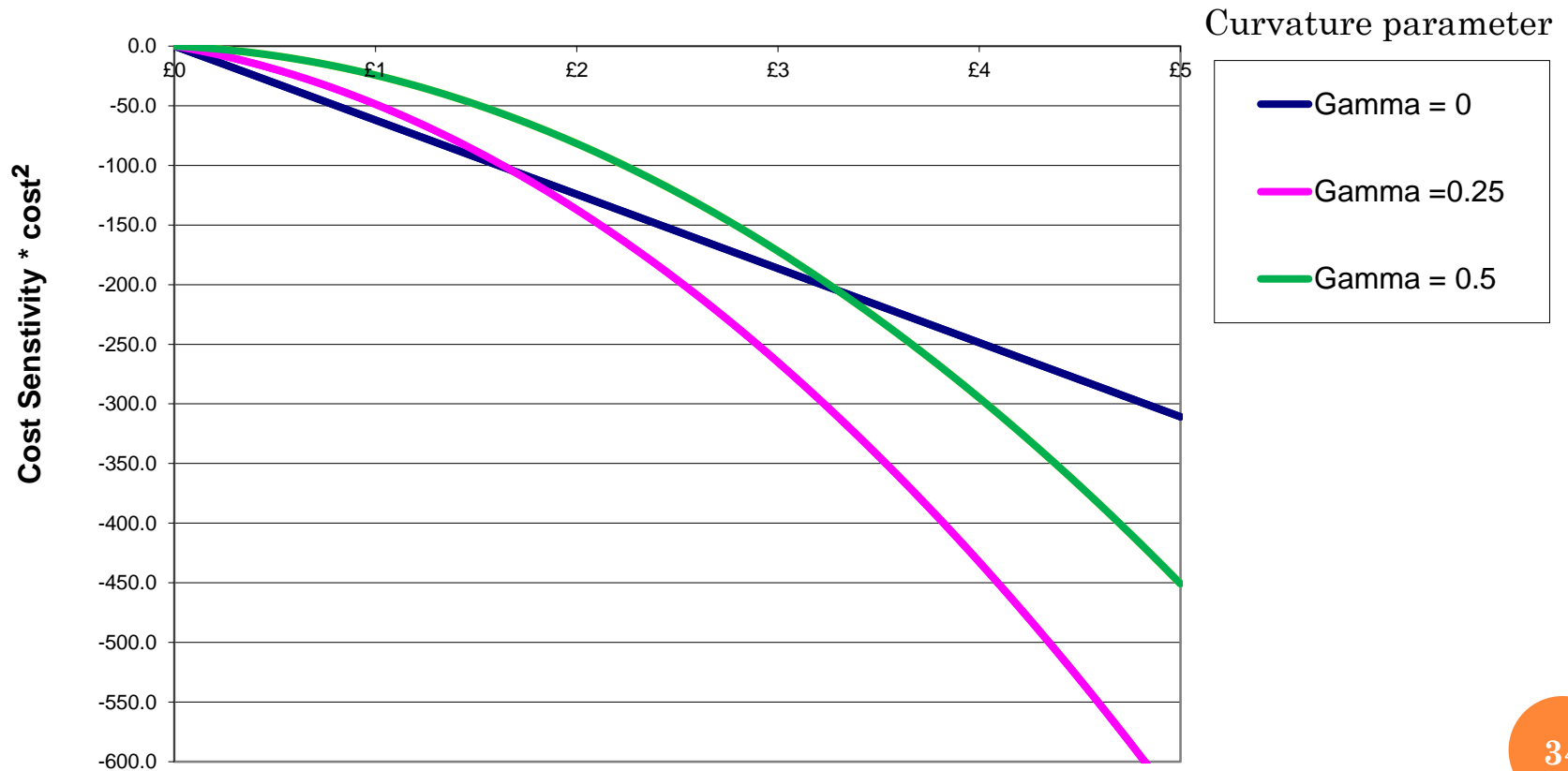
- not ideal, but values are widely published
 - allows models to be compared across areas and time
- add 10% to (e.g.) fuel cost and see what happens
 - with smaller percentages the impact may be too small to see reliably
- usually test fuel cost, public transport fares, car time, public transport time
- and, if suitable, income
- it could be argued that this is the most important test of a demand model

USUALLY, NON-LINEAR FUNCTIONS SEEM TO WORK BETTER

- this is ‘cost damping’
- gives freedom to obtain better fit and/or VOT and/or elasticity
- may mean abandoning strict criterion of maximum likelihood
 - but likelihood may not give strong discrimination between models when other criteria do
 - we may need to fix curvature coefficients on the basis of experience

MOST DATA IS FOR SHORT TRIPS, BUT LONG TRIPS ARE MORE IMPORTANT FOR ELASTICITY

Consumption elasticity change as cost increases



SO WE NEED TO TAKE A BALANCED VIEW OF MODEL SPECIFICATION

- to make the best forecasts we need to use as much information as we can
- this means experience and information that may not be strictly quantified
 - e.g. on VOT or elasticity
- the goal of forecasting is to derive the most objective view possible, not to advance the state of the art
 - at least not directly

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KEY FEATURES OF MODEL APPLICATION

- central equation $Q_j = \sum_k w_k \cdot p_j(x_k)$
- indicates the prominent role of population forecasting in determining the quality of forecasts
- with this model, we need to consider
 - how accurate the forecasts are
 - whether base data can be used to reduce error
 - how the population forecasting might work
 - how the stochastic aspect of the forecast should be handled
 - how we deal with endogeneity of congestion

CAN WE SAY HOW ACCURATE THE FORECASTS ARE?

- both population model and demand model contain error
- both model parameters and inputs contain error
- full error assessment needs to consider all of these
- can use analytical or simulation techniques
- simulation seems to work better because of scale of the models
- important for proper use of models



MANY VARIABLES ARE UNKNOWABLE

- tests and experience suggest that model errors are often moderate but inputs may be very wrong
- there is some progress in developing methods for robust decision making:
 - which policy works best over a range of possible futures?*
- we need to get decision makers to avoid reliance on a single forecast
 - best to consider a range of coherent scenarios
 - and decisions that work in all of them

PIVOTING CAN HELP TO IMPROVE FORECASTING ACCURACY

- if we have good information on the base situation, we can use the model to predict only changes

- the key formulae are

$$P = B \cdot \frac{S_f}{S_b} \quad \text{and} \quad P = B + (S_f - S_b)$$

- the former works better when error is proportional to demand, the latter when error is constant
 - generally expect proportionality, so use the first formula when possible
- a number of complications arise in practice, but methods are available to mitigate their effect

POPULATION FORECASTS

- one approach is to use IPF to match sample exactly to future-year targets
 - matches exactly but may be unreasonable
- an alternative is to balance error in matching targets to departure from base population
 - by minimising sum of squares ('QUAD')
- we have preferred latter approach
 - because targets may not be consistent
 - because population needs to be reasonable
- research in this area is needed
 - many very complicated papers on IPF

SIMULATION OR EXPECTED DEMAND?

- appraisal economists want expected values
- conventional models have always given these, rather simply:

$$E(Q_j) = \sum_k w_k \cdot p_j(x_k)$$

- the alternative is to sample randomly to get 0/1 variables with probability p_j : this is unbiased
- difficult to assess the benefits of each approach as analysts are committed to their favourite
 - convenience of outputs seems to depend on use being made of them
 - execution speed is a major consideration

CONGESTION POSES A SERIOUS MODELLING PROBLEM



- as well as a problem for society
- congestion and demand are interdependent
- modelling solutions involve iteration and this can be very time-consuming
- this has to be part of a model application

- but research on this issue is sorely needed

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MOVING ON

- to justify the investment, models need to adapt
 - behaviour changes over time
 - policy changes also
 - modelling methods improve
 - computers get faster
- there is now considerable experience in updating and extending models
 - using new data, often of reduced volume
 - maybe using SP data with appropriate adjustment
- allows the investment in model development to be fully exploited

CONCLUSIONS

- key aim is policy support, but we have duties to maintain professional standard
 - so model design is a function of policy and horizon
- basis for modelling is currently utility maximisation and tree logit
 - but this may change or be generalised
- plenty of experience with this form of modelling
 - following Netherlands National Model
- model structure can be extended to cover local policy issues

CONCLUSIONS (2)

- model search needs to incorporate forecasting capability
 - balance criteria using detailed local data and transferred information and experience
 - non-linearity is an important issue
- need to recognise error
- and argue for policy formulation to take account of uncertain future

- main message:
rigour is needed in both estimation and forecasting

FUTURE DEVELOPMENTS

- model structure improvements
 - cross-nesting or more advanced models
 - use latent concepts such as attitudes
 - alternative paradigms
- behavioural improvements
 - merge tour/activity schools of thought
- dealing better with error and uncertainty
 - policy formation needs to consider uncertainty
- merge benefits of expected values and simulation
- progress on equilibration

- thank you

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